VLÁKNA a TEXTIL

2

Ročník 8.
2001

ISSN 1335-0617

Indexed in:

Chemical Abstracts,

World Textile Abstracts

EMBASE

Elsevier Biobase

Elsevier GeoAbstracts

TECHNICKÁ UNIVERZITA LIBEREC · FAKULTA TEXTILNÍ ·

CHTF

VÚTCH
CHEMITEX

Výskumný ústav
Gumárenský
MATADOR

CONTENT

Ladies and Gentlemen,

Welcome to the Central European Conference organized on the occasion of the 50th anniversary of the beginning of the education in chemical technology of fibres and textile chemistry at the Faculty of Chemical Technology of the Slovak University of Technology in Bratislava and the 50th anniversary of the foundation of the Research Institute for Man-Made Fibres in Svit.

The eighty-years' history of chemical fibres and textile chemistry in Slovakia and particularly the advent of synthetic fibres in the world and in our country in the middle of the past century met with a response in the development of the higher technical education and research institutions. Polymer technology was introduced as a new subject at the Faculty of Chemistry at that time. In addition to the traditional subjects the specialisation of chemical fibres was founded at the Department of Wood and Cellulose in 1951.

The same year marked the founding of the Research Institute for Man-Made Fibres in Svit whose activities focused on the applied research.

The specialisation, later Department of Fibres and Textile Chemistry gained the leading position in the field of the education of experts for fibre and textile industry and together with the Research Institute in Svit it ranked among the significant scientific and research institutions.

During fifty years, four people were awarded the degree of Professor, 11 people achieved the degree of Associate Professor, and there were awarded 70 PhD degrees in chemical technology of fibres and textile. More than 800 students of the Faculty of Chemical Technology graduated in this specialization with the greatest number of graduates between 1970 and 1985. The basic and applied research conducted at the Department resulted in a number of original papers and patents, many of them having been applied in industry. The scientific and research achievements were presented at international conferences at home and abroad, as well. It is important to underline that the current level of graduate and post-graduate studies would not be achieved without very close cooperation of the Department, research institutes, industrial sphere, and its technical development. The maintenance and the development of this collaboration in the future should be our credo regardless of any change in social or ownership relations.

My sincere thanks go to all those working at our school, at research institutes, and in industry, who contributed to the success achieved in teaching, research and development in the field of fibres and textile in Slovakia.

This 2nd Central European Conference on Fibre Grade Polymers, Chemical Fibres, and Special Textiles is also an outcome of the Department's cooperation with home and foreign partners. Wishing you a pleasant and useful stay in Bratislava, I welcome you, on behalf of the Organizing and Scientific Committees, to our Conference.

Assoc. Prof. Anton Marcinčin

Vážené dámy a páni

Vítam Vás na 2. Stredoeurópskej konferencie, ktorá sa koná pri príležitosti 50 . výročia začiatku výučby v oblasti vlákien a textilu na CHTF STU v Bratislave ako aj 50 . výročia založenia Výskumného ústavu chemických vlákien vo Svite.

Už 80 ročná história chemických vlákien a textilnej chémie na Slovensku, a najmä nástup syntetických vlákien vo svete i u nás v polovici minulého storočia mali svoju odozvu i v rozvoji technického vysokého školstva a výskumných pracovísk. K tradičným odborom na Chemickej fakulte SVŠT pribudla technológia polymérov a v roku 1951 bola založená na Katedre dreva a celulózy tiež špecializácia chemických vlákien.

V tom istom roku bol založený aj Výskumný ústav Chemických vlákien vo Svite, ktorý sa orientoval na aplikovaný výskum.

Katedra vlákien a textilu získala vedúce postavenie v oblasti výchovy špecialistov pre vláknarský priemysel a textilnú chémiu a zaradili sa spolu s VÚCHV vo Svite medzi špeciálne vedecko-výskumné pracoviská.

Počas 50 ročnej činnosti v odbore chemickej technológie vlákien a textilu získali titul Profesor štyria pracovníci, 11 pracovníci získali titul Docent a 70 pracovníkov titul kandidát vied doktor (CSc. – PhD.). Štátne záverečné skúšky a obhajobu diplomovej práce úspešne absolvovalo vyše 800 poslucháčov CHTF, pričom najvyšší počet absolventov sa zaznamenal v r. 1970–1985. Vo vedeckej a výskumnej práci sa riešili úlohy základného i aplikovaného výskumu, ktoré vyústili do veľkého množstva pôvodných prác, patentov, realizačných výstupov v priemysle a do prezentácie na medzinárodných konferenciách doma i v zahraničí.

Čo je veľmi dôležité na doterajšom vývoji je skutočnosť, že príprava inžinierov a ich ďalšie vzdelanie, výskum i vývoj v oblasti vlákien a textilnej chémie by neboli nikdy dosiahli doterajšiu úroveň bez veľmi úzkej a ústretovej spolupráce katedry, výskumných ústavov, priemyselnej sféry a jej technického rozvoja. Zachovanie a rozvoj tejto spolupráce do budúcnosti by malo byť našim krédom bez ohľadu na zmenu spoločenských a vlastníckych vzťahov.

Dovoľte mi pri tejto príležitosti vysloviť úprimné poďakovanie všetkým pracovníkom školy, výskumných ústavov a priemyslu, ktorí sa pričinili o úspechy vo výučbe, výskume a rozvoji vlákien a textilu na Slovensku.

Výsledkom spolupráce katedry s domácimi i zahraničnými partnermi je aj táto Stredoeurópska konferencia o vláknotvorných polyméroch, chemických vláknach a špeciálnych textíliách, ktorá sa v poradí druhá koná v Bratislave a na ktorej Vás za prípravný a vedecký výbor konferencie srdečne vítam. Želám Vám príjemný a užitočný pobyt v Bratislave.

Assoc. Prof. Anton Marcinčin

PROGRAM

5. 9. 2001

3.00–6.00 p.m. Registration

6.00–6.10 p.m. Opening

6.10–7.30 p.m. Plenary Lectures

URBANOWSKI A.,
Institute of Chemical Fibres, Poland
The Man-made Fibres Industry in Central Europe

PEREPELKIN K., *Sankt-Petersburg State University of Technology and Design, Russia*
Development of Fibres for Special Textiles

ADLER H. J. P.*, JANSEN I., *Institute of Macromolecular Chemistry and Textile Chemistry, Dresden University of Technology, Germany*
HARDTKE G., FUCHS H., Saxon Textile Research Institute, Germany
Water-Dilutable Coatings Derived from Polyesters for Textile Use

ŠESTÁK J.*, PAPAJOVÁ V., *Research Institute of Textile Chemistry, Slovak Republic*
Development of Technical Textiles for the Slovak Textile Industry

8.00–9.30 p. m. Welcome party

6. 9. 2001

8.30–10.30 a.m. Plenary Lectures

OFFERMANN P., *Institute of Textile and Clothing Technology, TU Dresden, Germany*
Textile Materials in the Light of Innovative Developments for Lightweight Constructions

MILITKÝ J., *Technical University of Liberec, Czech Republic*
Ultimate Strength of Fibres and Fibrous Bundles

BUDZÁK D.*, VARGA J., BREJKA O., *Research Institute for Man-Made Fibres, Slovak Republic*
50 Years Activity of VÚCHV, a.s. Svit in the Domain of Chemical Fibres Development

MASAJTIS J., *Technical University of Lodz, Textile Faculty, Poland*
Perceiving of Textiles

10.30–11.00 a.m. Coffee Break

11.00–12.40 a.m. Lectures in Sections A and B

Section A

DUCHÁČEK V.*, ŠIMEK J., KUTA A., *Institute of Chemical Technology, Czech Republic*
ROSLANIEC Z.,
Technical University of Szczecin, Poland
Polyblends Based on Polyamide 6

RODA J., *Faculty of Chemical Technology, ICT Prague, Czech Republic*
Some Recent PA 6 and/or PA 66 Developments

VAN DE VELDE K.*, RAMBOUR S., KIEKENS P., *Ghent University, Belgium*
Influence of Pigments on the Properties of Polypropylene Fibres and Yarns

WLOCHOWICZ A.,
Technical University of Lodz, Poland
Conductivity of Fibres from PP and Polyaniline, its Forming, Fine Structure and Properties

Section B

PUŠIČ T.*, GRANCARIČ A.M., SOLJAČIČ I., *University of Zagreb, Croatia*
The Influence of Bleaching and Mercerization of Cotton on the Changes of Electrokinetic Potential

GOLOB V., *University of Maribor, Slovenia*
The Dyeing of Textiles in Supercritical CO_2

NOSEK S., *Technical University of Liberec, Czech Republic*
The Influence of Viscoelastic Behaviour of Textile Fibres on Dynamics of Mechanic Working Processes

SUPRUN N. P., *Kiev State University of Technology and Designe, Ukraine*
Modeling of Masstransfere Processes in Textile

12.40–2.00 p.m. Lunch

2.00–3.30 p.m. Plenary Lectures

STRUSZCZYK H.,
Institute of Chemical Fibres, Poland
Special Uses for Natural Polymers

HÖCKER H., THOMAS H.,
RWTH Aachen, Germany
Modification of Fibres by Means of Low Temperature Plasma Technology

MARCINČIN A., *Faculty of Chemical and Food Technology, STU, Slovak Republic*
Synthetic Fibres Based on Polymer Blends

3.30–4.00 p.m. Coffee break

4.00–5.30 p.m. Lectures in Sections A and B

Section A

LOMOV S. V.*, VERPOEST I.,
Katholieke Universiteit Leuven, Belgium
WiseTex – Virtual Textile Software

CZIGÁNY T.*, *Budapest University of Technologyand Economics, Hungary*
MOHD ISHAK Z.A.,
University of Sains Malaysia, Malaysia
Development of Ceramic Fiber Reinforced Polymer Composites

MAČALABA N., *Tverchimvolokno, Russia*
Technical Fibres – Production, Properties and Application

ROMHÁNY G.*, CZIGÁNY T.,
Budapest University of Technology and Economics, Hungary
Investigation of Glass Knitted Fiber Fabric Reinforced Poly(ethylene terephthalate) Composites by Acoustic Emission

Section B

KOVÁŘ R., *Technical University of Liberec, Czech Republic*
3-Dimensional Textile Materials

VLASENKO V.*, SUPRUN N., *Kiev State University of Technologies and Design, Ukraine*
Determination of Estimating Criteria for Clean Room Textile

SCHMIDT H.*, KAMINSKA I., LAO M.,
Institute of Textile Materials Engineering, Poland
Light Composites Reinforced with 3-Dimensional Distance Textiles

VUJASINOVIČ E.*, CUNKO R.,
University of Zagreb, Croatia
Modern Textile Sailclothes and Possibilities of Evaluating them

5.30–7.00 p.m. Posters

7.00–11.00 p.m. Dinner

7. 9. 2001

8.30–10.30 a.m. Round table discussion:
Education and Research Slovak Republic and Central Europe (in Slovak)

JAMBRICH M.,
Slovak Republic
Current Development of Chemical Fibers – World-wide and in Slovakia

BUDZÁK D.,
Research Institute for Man-Made Fibres, Slovak Republic
Perspective of Chemical Fibres Research

ŠESTÁK J.,
Research Institute of Textile Chemistry, Slovak Republic
Nowadays Applied Textile Research

MARCINČIN A.,
Faculty of Chemical and Food Technology, STU, Slovak Republic
Innovations Trends for Fibre and Textile Chemistry Education

SROKOVÁ I.,
Faculty of Industrial Technologies, TrU, Slovak Republic
Teaching and Research of Textile and Apparel Technology at the Faculty of Industrial Technologies

LIZÁK P.,
Faculty of Industrial Technologies, TrU, Slovak Republic
Textile Design in Slovakia

10.30–11.00 a.m. Coffee Break

11.00–12.30 a.m. Discussion

12.30 a.m. Farewell

50. Anniversary of Education and Research in Fibre and Textile Chemistry at Faculty of Chemical Technology, Slovak University of Technology in Bratislava.

Anton Marcinčin, Pavol Hodul

1. History

Department of Fibre and Textile Chemistry at the Faculty of Chemical Technology, Slovak University of Technology is the unique one in Slovak Republic which provides the education and research in fibre and textile chemistry and technology. Educational process in this field started at Faculty of Chemistry, Slovak Technical University (SVŠT) in the school year 1951–1952. Department in today's structure was established in 1991 by joining the divisions of Chemical Fibres and Textile Chemistry. Its formation was a result of gradual profile development during 60 years history of the Faculty of Chemical Technology. From its establishment until today the specialisation of Fibre and Textile chemistry has remained and important pedagogical and scientific centre in our country.

Division of Chemical Fibres was created at the Department of wood, cellulose and paper in 1951. Such outstanding personalities of the Slovak Science as Professor F. Kozmal (head of the Department) and Prof. V. Ríša (first head of the division) had the decisive merit in creation of the new division.

In the school year 1965/66 the independent Department of Chemical Fibres from the original division was created. Prof. Alexander Pikler was appointed head of the newly formed department. At the same time another division of Textile Materials was parallely estab-

1951
Creation of the division of **Chemical Fibres** within the **Department of wood, pulp and paper.**
Head of department: Prof. František Kozmal
Head of the Division: Prof. Viliam Ríša (1951–1954)
Prof. Ladislav Chodák (1954–1965)

1965–1970
Department of Fibres
Assoc. Prof. Alexander Pikler

1965–1970
Department of Leather and Textile Materials
Assoc. Prof. Anton Blažej

1970–1990
Department of Chemical Technology of Plastic Materials and Fibres
Head of Department: Prof. Jozef Beniska
Head of Fibres Division:
1970–1985 Assoc. Prof. Alexander Pikler
1985–1990 Prof. Martin Jambrich

1970–1990
Department of Textile, Cellulose and Paper
Head of Department:
1970–1978 Prof. Anton Blažej
1979–1990 Prof. Ľubomír Lapčík
Head of Textile Division:
1974–1981 Assoc. Prof. Jozef Očadlík
1982–1990 Assoc. Prof. Pavol Hodul
Head of detached working place in Trenčín:
1972–1992 Assoc. Prof. Václav Prchal

1991
Department of Fibres and Textile Chemistry
Head of Department: Assoc. Prof. Anton Marcinčin
Deputy Head of Department: Assoc. Prof. Pavol Hodul

Scheme 1 Education and research developments of the Fibre and Textile Science and Technology at Faculty of Chemical Technology STU.

lished within the Department textile, pulp and paper by Prof. Anton Blažej, head of department. After 1970 Department of chemical fibres was integrated as division into new Department of Chemical Technology of Plastic Materials and Fibres, with Prof. J. Beniska, head of Department and Prof. A. Pikler, later Prof. M. Jambrich as head of Fibre Division.

In the school year 1991/92 both division, the Chemical Fibres and Textile Materials started to function as a joined unit The Department of Fibre and Textile Chemistry whit orientation to fibre-forming polymers, natural and chemical fibres, science and technology as well as textile chemistry and technology. The scheme 1 indicates detailed development of education and research in the field of fibre and textile chemistry at Faculty of chemical technology. This development was strongly influenced not only by objective requirements of social and economical growth but also by negative political pressure mainly in ideology and personal policy at the Faculty during 50 years period of the totalitarian regime.

2. Education and Research Development

At the beginning education and research were oriented to the natural fibres and chemical fibres based on cellulose, processes of their preparation and textile application. In this stage the laboratory links and other laboratory equipment for fibre preparation (Blaschke aparatus) were gradually installed. The curriculum consisted of the following subjects: Technology of Chemical Fibres, Production of Synthetic Fibres, Textile Chemistry as well as synthetic shaping theoretical background e. g. Macromolecular chemistry were also included. Simultaneously the research programmes in the field of influence low molecular fractions of cellulose on fibre – forming process, Technical important cellulose derivatives and Targeted modification of synthetic fibres were formulated.

Further development (1960–1975) in education and research at the Department reflected the steadily growing importance of synthetic fibre – forming polymer and fibres as well as wider use of chemical process in textile dyeing and finishing respectively. As a results the new subjects as Physic of Polymers, Fibre Science and Technology, Textile Chemistry and Technology, Structure and Properties of Fibres became the basis of broader conception of education in the specialisation. Department progressively has won an appreciated position towards to research institutes and to industrial sphere. Number of diploma engineers leaving the divisions of Chemical Fibres and Textile Chemistry fluctuated from 30 to 40 yearly. Many of them became a leading persons in fibre and textile enterprises in Slovak as well as in Czech countries.

In 1965 the independent Department of Chemical Fibres was founded and co-operation with industry has been stressed. The condition for contract co-operation of department with fibre and textile industry has been extended mainly after 1975–1980.

In last twenty five years the education at the Department have been enriched by subjects connected with engineering aspect of technological process such as Fibre Technology-melt spinning and Fibre Technology-solution spinning in which the rheology of non – Newtonian liquids, rheology in deformation and orientation processes and changes in the structure of oriented polymer were emphasised. The postgraduate study has become a strong part of the highest qualification for Fibres and Textile Chemistry domain in this time. In co-operation with industry the many distance short and long term courses were organised in an attempt to enable a high qualification for researcher and industrial technical management. Broader activity of the Department towards to practice brought the detached workplace in Trenčín the centre of Slovak textile industry.

During 50 years of education and research in the field of Fibres and Textiles in Slovakia four titles of Professor, three DSc, 11 Associate Professor and more than 70 doctorands (CSc. – PhD.) were awarded. Diploma degree of master study at the both Chemical Fibres and Textile Chemistry divisions has obtained about 800 specialists.

The research in this period runs in framework of state plan. At the Fibre and Textile divisions the following partial tasks were investigated in key projects:

New methods for fibre preparation. Structure and properties relation, special fibres Physical modification of fibre-forming polymers, spun dyed fibres. Physiology parameters of garments , Textile materials modification, Textile auxiliaries, synthesis and properties. Dyeing and finishing-crease proofing. soil release and antistatic.

Close co-operation with domestic and foreign institutions was a characteristic feature of the Department activity. To the most important partners in research co-operation could be listed Research Institute for Man-Made Fibres in Svit and Research Institute of Textile Chemistry in Žilina. Further, the following co-operation with Chemlon Humenne, Chemosvit Svit, Istrochem (CHZJD) Bratislava, Slovak Silk Senica, Merina Trenčín, Maytex L. Mikuláš, Tatraľan Kežmarok, VŠCHT Pardubice, VÚOS Pardubice, VUGPT Zlín, UP SAV etc. Department participated in organising the international conferences such as Fibrichem a International Tatras Conference on Fibre-Forming Polymers their Processing and Application. Long time co-operations were developed with Department of Chemical Fibres at Polytechnic Lodž /Poland / and also with Departments of Textiles and Light Industry in Moscow and Peterburg Textile Institutes as well as with Magyar Viskosagyar in Nergesujfalu (Hungary).

3. Department of Fibre and Textile Chemistry on the threshold of a new century

After 1990 there was a decrease in production of fibres and textiles in Central and Eastern European countries. Disruption of the market of former Soviet block countries, insufficient capital resources together with fundamental economic and political changes in society have influenced not only industrial sphere but also the whole educational system. As a result a significant reduction in staff members of the Department followed. The number of workers gradually has been reduced from 40–45 in 1990 to 14 in 2001. The basic reform of curriculum was curried out taking in to account the study programmes of universities in democratic countries. The bachelor study and credit system were gradually implicated at the STU. Finally, the grand system has been accepted as a novelty in scientific and research activity.

The position and role of the Department of Fibre and Textile Chemistry in Slovakia is given by providing for following tasks:

- Education in fibres and textile chemistry and technology on the university level (BSc and MSc).
- Taking a part in educational process in special subjects at another Universities.
- Education in post graduate study (PhD) in the field of Macromolecular Chemistry and participation in PhD study in the area of Polymer Technology.
- Organisation regularly short and long term special courses and workshops for industry and research institutes.
- Participation in the development of a new technology of fibres and textile auxiliaries in close co-operation with research institutes and industrial partners. Department plays a significant role in transfer the basic research results into technological practise.
- Providing a consult and advisory service in field of chemical fibres and textile chemistry. Participation in testing and certification of polymers, fibres and textile material.
- Taking part in edition of " Vlákna a textil" (Fibres and Textiles) journal with original papers in English language.
- Maintenance the contacts and co-operation with foreign universities and institutes. Department represents STU in AUTEX (Association of Universities for Textiles) as associate member.
- Participation in the preparing the International Central European Conference on Fibre Grade Polymers, Chemical Fibres and Special Textiles.

4. Pedagogical process

Graduate of the Department of Fibre and Textile Chemistry of the FCHT, STU is specialist who has a profound knowledge in Fibre and Textile Science and Technology and ground practical training in this field of work. He is able to work in technical management of enterprises and institutions further as researcher in scientific and industrial institutions, municipal enterprises and services, at universities, colleges etc with the perspective of promotion.

The current curriculum reflect trends of development and restructuring fibre and textile areas after 1991. It should be pointed out that in modification of curriculum the introducing of bachelor study at our university and implication of credit system as well as transformation of some subjects from European Universities of similar branch were respected. The last but not least the requirements of the Slovak textile and fibre industry have been incorporate into study programme at the Department. New compulsory subjects such as Textile Engineering and Technology of Polymer Films were approved in the framework of master study. The last revision the study program was accomplished in 1999. The balance rate within the subjects shaping the graduate profile from the point of view: chemical and physical-chemical (Macromolecular Chemistry, Physics of Polymers, Colloid Chemistry and Dyes and Colorimetry), further subjects of technology-engineering (Fibre Science and Technology, Textile chemistry and Technology, Technology of Polymer Film, Modelling and Control of the Processes) and finally subjects of material-engineering (Principles of Textile Engineering, Technical Textiles, Physiology of Clothing) was stressed in last ten years of study. Smart textiles, informatics technologies and textile design are to be introduced in short period of time into educational process at the specialisation. Some of them in general level being a part of the bachelor study nowadays.

Department participates active also in bachelor study with subjects of Macromolecular Chemistry, Technology of Materials as well as Cosmetics and Indor Chemistry.

Review of the subjects in bachelor (general) and master study (Technology of Fibre and Textile Chemistry) are given abridged in the next list and in the table 1.

Bachelor programme (BSc.) at Faculty of Chemical Technology, Slovak University of Technology (semester 1-6): Mathematics I., II., III., Informatics, Physics I., II., Inorganic Chem. I., II., Organic Chem. I., II., Physic Chem. I., II., Analytic Chem. I., II., Material Balance, Chem. Engineering, Biology, Language I. begin. and II. adv., Economy, Environment. Philosophy, Law, Management, Environmental Techn., Cybernetic, Phys. Culture.

Subject of Technological Direction: Gen. Techn. Inorganic, Gen. Organic Technology, Technology of Materials, Thermical Technology, Appl. Mathematics, Optional Subjects.

Table 1 Subjects of specialisation Fibre and Textile Chemistry and Technology, C – compulsory subj., E – elective subj.

	Subject	C/E	Credits	Semester				
				5	6	7	8	9
B	Macromolecular Chemistry	C	2	2/0/0				
	Technology of Materials	C	2		2/0/0			
	Bachelor Project	C	4		0/0/4			
B	Physic of Polymers and Paper	C	6			2/2/0		
	Colloid Chemistry and Interfaces	C	5			2/1/0		
	a) Macromolecular Chemistry II	E	5			2/1/0		
	b) Natural Polymers and Fibres	E	5			2/1/0		
C	Fiber Sci and Technology	C	5			2/2/0		
	Laboratory of F. Sci. and Techn.	C	6			0/0/8		
	a) Special and Modified Fibres	E	2			0/2/0		
	b) Structure and Properties of Fibres	E	2			1/1/0		
	c) Modelling of Polymer Structure and Properties	E	2			1/1/0		
B	Financial Manage	C	3				2/0/0	
	Processing of Polymers	C	6				2/2/0	
C	Textile Engineering	C	4				2/0/0	
	Technical Textiles	C	3				2/0/0	
	Coloristics and Textile Auxiliaries	C	4				2/0/0	
	Laboratory of Textile Engineering	C	5				0/0/8	
	a) Chemical after Treatment of textiles	E	2				0/2/0	
	b) Physiology and Comfort of Clothing	E	2				0/2/0	
B	Utilisation of Wastes	E	2					2/0/0
C	Textile Chemistry and Technology	C	7					2/2/0
	Technology of Polymers Films	C	4					2/0/0
	Fiber and Textile Testing	C	4					2/0/0
	Laboratory of Textile Chemistry and technology	C	8					0/0/10

10th Semester (spring) Diploma work 0/0/27

Subjects of Food and Biochem. Direction: Microbiology I., Biochemistry I., Food Chemistry, Compulsory subject, Food Technology, Biochemical Technology, Elem. Nourishment, Analyt. Of Food, Optional Subjects.

5. Research activity

Two VEGA projects (National Grant Agency) cover basic research activity at Department:

1. VEGA No B9927/99 Fibre-forming blends of polypropylene with polar polymers.
2. VEGA 1/8106/01 Dispersion of organic pigments in synthetic polymer with particle size close to nano-scale.

These projects enable to continue in traditional research works at the Department which are oriented to following areas: Fibres on basic of polymer blend, Nanocomposite chemical fibres, New technology in pigmentation of fibres, Antibacterial chemical fibres, Enzymes and bioprocesses in finishing of textiles and Processing of fibre forming polymers in fibre preparation.

Department is well equipped with laboratory lines for melt spinning (extruders 16 mm and 32 mm diameter), Rheometer Göttfert, Plastometers and Rotation rheometers, Thermomechanical analylis TMA 50, Instron and Uster for mechanical properties, Alambeta for thermophysic properties, SALS (morfology), DSC-7 (Perkinelmer), Pretema, Ahiba (dyeing), Colorimeters, Polystat PS-1 (antistatic properties), etc.

Results of the research are published in international and domestic current journals, in technical journals, on International conferences (Dorbirn, Gent, Mainz, Eindhoven, Liberec, Lodž etc).

Part of the research capacity has been directed to co-operation with industrial partners (Research Institute for Man-Made Fibres in Svit, Research Institute of Textile Chemistry in Žilina, Nylstar a.s., Rhodia a.s. Humenné, Chemosvit, a.s. Svit, SH Senica, Istrochem Bratislava). In the last five years three projects the Antibacterial vis-

Table 2 The publication activity of the Department in years 1998–2000

Activities	1998	1999	2000
1. Publications abroad	7	7	7
2. Publications in home	6	6	5
3. Lectures and posters	21	21	23
4. Proceedings	19	19	22
5. Research reports (ZoD)	4	2	–
6. Courses	1	–	1
7. Projects GAV (grants)	1	1	1

cose fibres for Spolana Neratovice (CZ), Antibacterial PP fibres for Istrochem Co and New PET concentrates for Research Institute in Svit were finished successfully.

The publication activity of the Department is given in the table 2.

6. International co-operation

Department is an associated member of AUTEX (Association of Universities for Textiles) in EU. Activities of this organisation such as annual meetings provide fruitful possibilities for professional contact and offer overview the current development in European university education in textile. They bring also an opportunity for closer personal contacts and exchange of information concerning the study programmes, project preparation, new concepts of study and organisation of the conferences. Under the auspice of E–TEAM (AUTEX) project of the specialised study for experts has been organised.

Department has participated in international project CEEPUS, in framework of which already during four years our students of textile branch do stay in European Universities. Last year the mobility are organised also in the Socrates-Erasmus project.

Department in co-operation with Institute of Chemical Fibres from Poland started to organise the Polish – Slovak seminars which has transformed to international Central European Conference.

Staff of the department is active as committee members of several scientific journals as well as scientific boards of Universities. The professional contact are mainly with following institutions: Technical University of Liberec (CZ), Institute of Chemical Fibres, Lodz (PL), University of Gent (B), University of Maribor (SLO), Institute of Macromolecular Chemistry, Albert-Ludwigs University Freiburg (G), Institute of Polymers, VŠCHT Praga (CZ).

7. Concluding remarks

In a global market the only possibility for EU textile industry is the orientation to high-tech textile and industrial textile materials, to survive under the competition conditions. This development can not be accomplished without high qualified specialists. The similar situation is to be expected also in Associate states of EU. These changes will be inevitable reflected in education of textile specialists. There is an intensive discussion to these points in framework of AUTEX e.g. the First AUTEX Conference: Textile Education and Research, Strategies for the new millennium in June 2000 was devoted to the new aspects and new orientation of study at Textile Universities. It will be necessary all positive results in this development to implicate in study program at the Department, which has a good background and prospect to be a perspective educational and research unit in fibre and textile chemistry, science and technology in Slovakia.

---

50. Výročie výučby a výskumu vlákien a textilnej chémie na Chemickotechnologickej fakulte, Slovenskej technickej univerzity v Bratistislave

Anton Marcinčin, Pavol Hodul

Katedra vlákien a textilu, CHTF STU

1. História

Katedra vlákien a textilu na Chemickotechnologickej fakulte, Slovenskej technickej univerzity je jedinečné pracovisko v Slovenskej republike, ktoré vychováva vysokoškolsky kvalifikovaných absolventov v odbore vlákien a textilnej chémie a technológie a rieši úlohy základného i aplikovaného výskumu.

Výchovno-vzdelávací proces na špecializácii chemické vlákna začal na fakulte, Slovenskej vysokej školy technickej v šk. roku 1951/52.

Katedra v súčasnej štruktúre vznikla v roku 1991 spojením oddelení chemických vlákien a textilnej chémie.

Založenie Katedry vlákien a textilu bolo výsledkom postupnej profilácie Chemickotechnologickej fakulty STU počas 60-ročnej histórie.

Schéma 1 Vývoj výučby a výskumu v chémii a technológii vlákien a textilu na Chemickotechnologickej fakulte, STU

1951
Vznik oddelenia Chemických vlákien na Katedre dreva, celulózy a papiera
Vedúci katedry: Prof. František Kozmal
Vedúci oddelenia: Prof. Viliam Ríša (1951–1954)
Prof. Ladislav Chodák (1954–1965)

1965–1970
Katedra vlákien a textilných materiálov
Doc. Alexander Pikler

1970–1990
Katedra plastických látok a vlákien
Vedúci katedry: Prof. Jozef Beniska

Vedúci oddelenia:
1970–1985 Doc. Alexander Pikler
1985–1990 Prof. Martin Jambrich

1965–1970
Katedra koží
Doc. Anton Blažej

1970–1990
Katedra textilu, celulózy a papiera
Vedúci katedry:
1970–1978 Prof. Anton Blažej
1979–1990 Prof. Ľubomír Lapčík
Vedúci oddelenia:
1974–1981 Doc. Jozef Očadlík
1982–1990 Doc. Pavol Hodul
Vedúci detašovaného pracoviska katedry v Trenčíne
1972–1992 Doc. Václav Prchal

1991
Katedra vlákien a textilu
Vedúci katedry: Doc. Anton Marcinčin
Zástupca vedúceho katedry: Doc. Pavol Hodul

Od vzniku po dnešok špecializácia chemickej technológie vlákien a textilu plnila dôležité pedagogické a výskumné úlohy a stala sa významným pedagogickým i vedeckovýskumným pracoviskom na Slovensku.

Špecializácia Chemických vlákien vznikla na Katedre dreva, celulózy a papiera v r. 1951.

Rozhodujúci podiel na jej vzniku mali takí významní vedci a pedagógovia Slovenskej vedy ako Prof. F. Kozmal (vedúci katedry) a Prof. V. Ríša (prvý vedúci oddelenia). V šk. roku 1965–1966 vznikla z pôvodnej špecializácie samostatná Katedra chemických vlákien. Jej vedúcim sa stal Prof. A. Pikler. V tom istom čase paralelne vzniká oddelenie Textilných materiálov na Katedre textilu, celulózy a papiera pod vedením Prof. A. Blažeja. Po r. 1970 Katedra vlákien bola integrovaná ako oddelenie do novej Katedry plastických látok a vlákien, s vedúcim katedry Prof. J. Beniskom a vedúcim oddelenia Prof. A. Piklerom, po r. 1985 Prof. M. Jambrichom.

V šk. roku 1991–1992 boli oddelenia Chemických vlákien a textilných materiálov spojené do jedného pracoviska Katedry vlákien a textilu s orientáciou na vláknotvorné polyméry, na chémiu a technológiu prírodných a chemických vlákien ako aj na textilnú chémiu a technológiu. Počas 50. Rokov bol vývoj katedry a špecializácie silne ovplyvňovaný nielen objektívnymi potrebami spoločnosti, priemyslu a ekonomickými faktormi, ale tiež negatívne politickým a ideologickým zasahovaním najmä do personálnej politiky fakulty a katedry v priebehu 40-ročného obdobia totalitného režimu.

Nasledujúca schéma znázorňuje detailne vývoj výučby a výskumu v oblasti vlákien a textilnej chémie na Chemickotechnologickej fakulte od r. 1951.

2. Vývoj výučby a výskumu

Obsahové zameranie výučby a výskumu bolo po vzniku špecializácie orientované na prírodné vlákna a na chemické vlákna na báze celulózy, na procesy ich prípravy a textilné aplikácie. Postupne sa vybudovali laboratóriá základnými prístrojmi a inštalovala sa laboratórna linka na prípravu roztokov polymérov a vlákien mokrým postupom (viskózové vlákna). Učebný program pozostával zo základných technologických predmetov, ako Technológia chemických vlákien, Výroba syntetických vlákien a Textilná technológia, ale užv začiatkoch sa začali formovať predmety teoretického základu ako napr. Makromolekulová chémia. Simultánne sa začala na katedre aj výskumná činnosť, ktorá bola orientovaná na technicky dôležité deriváty celulózy, vplyv nízkomolekulových frakcií na zvlákňovanie viskózových vlákien a na zámerné premeny syntetických vlákien.

Ďalší vývoj po roku 1960 odrážal vo vtedajšej dobe výrazný nárast syntetických vlákien vrátane syntézy polymérov, ako aj širšie využitie chemických procesov v textile v procese farbenia a finálnych úprav. Výsledkom tohto vývoja boli nové predmety vo vzdelávacom procese, ako Fyzika polymérov, Procesy prípravy syntetických vlákien, Základy textilnej technológie a Štruktúra a vlastnosti vlákien. Tieto predmety sa stali základom inovovanej koncepcie výučby so širším zameraním a inžiniersky orientovanou technológiou. V oblasti vedecko-výskumnej činnosti sa rozvíjala spolupráca s výskumnými ústavmi a priemyselnou sférou. V tom čase špecializáciu Chemických vlákien a Textilnej chémie končilo ročne 30 až 40 absolventov. Mnohí z nich sa stali vedúcimi pracovných a výskumných tímov a do dnešných dní pracujú v manažmentoch podnikov a inštitútov na Slovensku i v Českej republike.

V roku 1965 bola založená samostatná Katedra vlákien a textilu a spolupráca s priemyslom sa stala ešte významnejšia. Začalo sa obdobie zmluvnej spolupráce, ktorú umožnila nová legislatíva najmä po r. 1975. Posledných 25 rokov sa výchovno-vzdelávací proces ďalej orientoval na inžinierske aspekty technologických procesov v predmetoch Procesy prípravy syntetických vlákien zvlákňovanie z taveniny a Chemické vlákna na báze prírodných polymérov zvlákňovanie z roztoku. V týchto disciplínách sa dôraz kládol najmä na reológiu nenewtonovských kvapalín, deformačné a orientačné procesy a na zmeny štruktúry vlákien v orientovaných polyméroch.

Okrem výchovy absolventov riadneho štúdia, ďalšou dôležitou formou štúdia bolo postgraduálne štúdium (ašpirantské doktorandské). Toto štúdium patrilo k najvyššej forme vzdelania pre odbor vlákna a textil.

Katedra v tomto období bola veľmi aktívna aj pri organizovaní doplnkového štúdia, krátkodobých a niekoľko semestrálnych odborných kurzov pre pracovníkov technického manažmentu vláknarenského a textilného priemyslu. K rozšíreniu spolupráce s praxou prispelo tiež detašované pracovisko katedry v Trenčíne.

Počas 50. rokov výučby a výskumu v odbore chemických vlákien a textilnej chémie na Slovensku boli udelené hodnosti riadnych profesorov (3), DrSc (3), docentov (11), kandidátov vied CSc. – PhD. (70). Špecializáciu Chemických vlákien a Textilnej chémie absolvovalo vyše 800 špecialistov.

Vedecko-výskumná práca v období 1975–1990 sa organizovala v rámci Štátneho plánu základného výskumu, ktorého jednu z hlavných úloh koordinovala katedra. Na oddeleniach Vlákien a Textilu sa riešili nasledovné čiastkové úlohy:

- Nové postupy prípravy vlákien
- Vzťah štruktúry a vlastnosti špeciálne vlákna
- Fyzikálna modifikácia farbenie vlákien v hmote
- Fyziologické vlastnosti textílií
- Modifikácia textilných materiálov
- Textilné pomocné prostriedky syntéza a vlastnosti
- Farbenie a finálne úpravy

Pre uvedené obdobie bola charakteristická intenzívna spolupráca oddelení Chemických vlákien a Textilnej chémie s domácimi i zahraničnými inštitútmi a priemyslom. K najdôležitejším partnerom patrili Výskumný ústav chemických vlákien vo Svite a Výskumný ústav textilnej chémie v Žiline. Ďalej to bola spolupráca s podnikmi ako Chemlon Humenné, Chemosvit Svit, Tatrasvit Svit, Istrochem (CHZJD) Bratislava, Slovenský hodváb Senica, Merina Trenčín, Maytex Liptovský Mikuláš, Tatraľan Kežmarok, Levitex Levice, VŠCHT Pardubice, VÚOS Pardubice, VUGPT Zlín a ÚP SAV Bratislava. Zo zahraničných kontaktov je potrebné spomenúť dlhoročnú spoluprácu s Katedrou vlákien Polytechniky Lodz (Poľsko), s Katedrou textilu a ľahkého priemyslu na Moskovskom a Peterburskom Textilnom inštitúte ako aj s vláknarským podnikom Magyar Viskosagyar v Nergasujfalu (Maďarsko).

Katedra sa podieľala na organizovaní medzinárodných konferencií Fibrichem a Tatranskej konferencie Vláknotvorné polyméry a ich spracovanie.

3. Katedra vlákien a textilu na začiatku 21. storočia

Po roku 1990 došlo k poklesu vláknarskej ale najmä textilnej výroby v krajinách strednej a východnej Európy. Rozpad bývalého Sovietskeho bloku krajín združených v RVHP, všeobecný nedostatok investícií spolu so základnými ekonomickými a politickými zmenami silne ovplyvnil nielen priemyselnú sféru, ale aj celý vysokoškolsky vzdelávací systém. Na fakulte sa zaviedlo bakalárske a másterské štúdium a kreditný systém podľa vývoja v európskych demokratických krajinách. Vo vedeckovýskumnej činnosti sa akceptoval grantový systém. Na Katedre došlo postupne k redukcii pracovníkov zo 40–45 v r. 1990 na 14 v r. 2001.

Katedra vlákien a textilu je jedinečným vysokoškolským pracoviskom na Slovensku. Plní nasledovné úlohy:

- Výchova absolventov pre vláknarský a textilný priemysel, výskumné a školské pracoviská, komunálne služby, vo všeobecnosti pre oblasť polymérov, vlákien a textilu.
- Podieľa sa na pedagogickom procese iných vysokých škôl a fakúlt.
- Zabezpečuje (garantuje) doktorandské štúdium v odbore „ Makromolekulová chémia“ a školí doktorandov aj v odbore „Technológia makromolekulových látok“.

- Pravidelne organizuje odborné kurzy pre pracovníkov vláknarských a textilných spoločností a podnikov (krátkodobé (1 semester) a dlhodobé (2–4 semestre)).
- Podieľa sa efektívne na výskume a vývoji nových vlákien a textilných pomocných prostriedkov v spolupráci s aplikačnými výskumnými ústavami a priemyselnými podnikmi. Má významnú úlohu pri prenose výsledkov základného výskumu do technologickej praxe.
- Poskytuje konzultačnú a poradenskú službu, expertízne a oponentské posudky a technický servis v odbore chemické vlákna a textilná chémia. Zúčastňuje sa na certifikačnom procese v rámci SNAS pre vlákna a textil.
- Podieľa sa na vydávaní časopisu „Vlákna a textil" (Fibres and Textiles) s pôvodnými článkami v anglickom jazyku.
- Rozvíja kontakty a spoluprácu na univerzitnej úrovni s vysokoškolskými pracoviskami v zahraničí. Reprezentuje STU v organizácii AUTEX (Association of Universities for Textiles in Europe) ako asociovaný člen.
- Členovia katedry pôsobia vo Vedeckých radách iných fakúlt, v redakčných radách vedeckých a odborných časopisov.
- Podieľa sa na organizácii vláknarských a textilných konferencií, napr.: Central European Conference on Fibre Grade Polymers, Chemical Fibres and Special Textiles.

Pedagogický proces na katedre

Absolvent chemicko-technologickej fakulty STU, špecializácie technológie vlákien a textilnej chémie je odborník -špecialista ovládajúci teoreticky i prakticky problematiku chémie a technológie polymérov s orientáciou na vláknotvorné polyméry, chemickú technológiu vlákien a fóliových materiálov a tiež na finálne procesy textilnej chémie a technológie. Je spôsobilý pracovať v technickom manažmente podnikov a inštitúcií, ďalej ako výskumný pracovník vo vedeckých ústavoch a priemyselných inštitúciách, v komunálnych službách, na univerzitách a na fakultách..

Súčasný študijný program zamerania je výsledkom vývoja v uplynulých desaťročiach, ale najmä reštrukturalizačných zmien na CHTF po roku 1991 a študijného programu pre novú katedru vlákien a textilu, ktorý vznikol spojením študijných programov pre chemickú technológiu vlákien a textilnú chémiu a technológiu. Pri tvorbe tohto programu sa zohľadňovali všetky kvalitatívne zmeny v študijnom programe v 1–3 ročníku, t. j. v súčasnom bakalárskom štúdiu, ďalej sa v programe aplikovali poznatky zo študijných programov európskych a amerických univerzít katedier podobného zamerania. V neposlednom rade sa zohľadnili požiadavky praxe a to takým spôsobom, že po predchádzajúcom anketovom „liste pre vedúcich pracovníkov podnikov na Slovensku" sa diskutovalo o študijnom programe katedry s týmito pracovníkmi osobne. Na základe toho boli zaradené do študijného programu dve nové disciplíny a to „Textilné inžinierstvo" a „Technológia polymérnych fólií". Takto pripravený študijný program bol upravený v r. 1999 po formálnej i obsahovej stránke, vzhľadom na zmeny v priemyselnej sfére na Slovensku i v Európe ako aj s ohľadom na vývoj študijných odborov na Chemickotechnologickej fakulte.

V študijnom programe pre inžinierske štúdium na katedre sa kladie dôraz na rovnováhu disciplín chemických a fyzikálnochemických (Makromolekulová chémia, Fyzika polymérov, Koloidné sústavy a fázové rozhrania, Farbenie a koloristika), ďalej procesovo – inžinierskych (Chémia a technológia vlákien, Textilná chémia a technológia, Technológia polymérnych fólií, Modelovanie a riadenie procesov v polyméroch) a nakoniec materiálovo inžinierskych (Základy textilného inžinierstva, Technické textílie, Modelovanie a simulácia procesov v polyméroch).

Samostatnú skupinu tvoria predmety spojené s metódami hodnotenia štruktúry vlákien a vláknitých materiálov, Skúšobníctvo a certifikácia, ako aj Fyziológia a komfort odievania. Absolvent špecializácie takto dostáva kombináciu disciplín od polymérov cez vlákna po textilné materiály a ich funkcie v odevných a technických aplikáciách.

Technické textílie a inteligentné textílie (smart textiles) a informačné technológie sa považujú za dominujúce oblasti vo výskume a vývoji textilu pre najbližšie obdobie vo vyspelých krajinách sveta i Európy, zatiaľ čo masová vláknarska i textilná výroba začína dominovať v krajinách tretieho sveta. V tomto zmysle je potrebné upraviť v budúcnosti obsahovú stránku niektorých predmetov.

Katedra sa aktívne podieľa tiež na bakalárskom štúdiu a to prednáškami z Makromolekulovej chémie I (garant prednášok Katedra plastov a kaučuku) a spolupednáša a garantuje predmety Technológia materiálov a Kozmetika a bytová chémia. Podieľa sa na vedení semestrálnych projektov bakalárskeho štúdia, diplomových prác v inžinierskom štúdiu a na štátnych skúškach bakalárskeho i inžinierskeho štúdia.

Skrátený prehľad predmetov bakalárskeho štúdia:

Spoločný základ pre chemickotechnologický a potravinársko-biochemický odbor, 1–3 ročník:

Matematika I., II., III.
Základy informatiky
Fyzika I., II.
Anorganická chémia I., II.
Organická chémia I., II.
Fyzikálna chémia I., II.
Analytická chémia I., II.
Materiálové bilancie
Chemické inžinierstvo I., II.

Ekonómia
Základy environmentálnej filozofie
Základy práva
Základy manažmentu chem. a potr. podnikov
Technológia životného prostredia
Základy automatizácie
Technická angličtina
Biológia
Telesná výchova

Tab. 1 Predmety špecializácie chemickej technológie vlákien a textilu

	Predmet	P/V	Kredity	Semester				
				5	6	7	8	9
B	Makromolekulová Chémia	P	2	2/0/0				
	Technológia materiálov	P	2		2/0/0			
	Bakalársky projekt	P	4		0/0/4			
B	Fyzika polymérov a papiera	P	6			2/2/0		
	Koloidné sústavy a fázové rozhrania	P	5			2/1/0		
	a) Makromolekulová chémia II	V	5			2/1/0		
	b) Prírodné polyméry	V	5			2/1/0		
C	Chémia technológia vlákien	P	5			2/2/0		
	Lab. cvič. z chémie a techn. vlákien	P	6			0/0/8		
	a) Špeciálne a modifikované vlákna	V	2			0/2/0		
	b) Štruktúra a vlastnosti vlákien	V	2			1/1/0		
	c) Modelovanie a simulácie technologických procesov	V	2			1/1/0		
B	Kapitálový trh a podn. financie	P	3				2/0/0	
	Modelovanie a riadenie procesov sprac. polymérov	P	6				2/2/0	
C	Základy textilného inžinierstva	P	4				2/0/0	
	Technické textílie	P	3				2/0/0	
	Farbivá a textilné pomocné prostriedky	P	4				2/0/0	
	Lab. cvič. z text. inžinierstva	P	5				0/0/8	
	a) Špec. chem. úpravy textílií	V	2				0/2/0	
	b) Fyziológia a komfort odievania	V	2				0/2/0	
B	Zneškodňovanie a zužitkovanie odpadov	V	2					2/0/0
C	Textilná chémia a technológia	P	7					2/2/0
	Technológia polymérnych fólií	P	4					2/0/0
	Textilné skúšobníctvo a certifikácia	P	4					2/0/0
	Lab. cvič. z text. chémie a technológie	P	8					0/0/10

10. semester (letný)
Diplomová práca 0/0/27

P – povinný predmet
V – voliteľný predmet

Predmety pre chemickotechnologický odbor: Všeobecná a anorganická technológia, Organická technológia a petrochémia, Makromolekulová chémia, Technológia materiálov, Energetika, Metódy počítačového spracovania dát, Voliteľné predmety.

Predmety pre potravinársko-biochemický odbor: Mikrobiológia I., Biochémia I., Chémia potravín, Základy potravinárskej technológie, Základy biochemickej technológie, Základy výživy, Analýza potravín, Voliteľné predmety.

Na tieto nadväzujú predmety špecializácií. Študijný program špecializácie chemickej technológie vlákien a textilu je v tab. 1.

5. Vedeckovýskumná činnosť katedry

Vedeckovýskumná činnosť katedry v súčasnom období sa realizuje v rámci dvoch projektov VEGA (Národnej Grantovej Agentúry)

1) VEGA B 99 27/99 Vláknotvorné zmesi polypropylénu s polárnymi polymérmi
2) VEGA 1/81 06/01 Disperzie organických pigmentov v syntetických polyméroch s časticami blízkymi nano-časticiam.

Tieto projekty umožňujú pokračovať v tradičnej výskumnej práci na katedre, ktorá je orientovaná v súčasnom období do nasledovných úloh:

- Vlákna na báze polymérových zmesí
- Nanokompozitné chemické vlákna
- Nové technológie pri pigmentácii vlákien
- Antibakteriálne chemické vlákna
- Enzými a bioprocesy vo finálnych úpravách
- Spracovanie polymérov pri príprave vlákien

Katedra je relatívne dobre vybavená laboratórnymi zariadeniami – linkami pre zvlákňovanie z taveniny (extrúdery ϕ 16 a 32 mm), Rheometer Göttfert, Plastometre, Rotačné viskozimetre, Termomechanická analýza TMA 50, INSTRON 1112, WOLPERT, Uster pre mechanicko-fyzikálne vlastnosti, Alambeta pre termofyzikálne vlastnosti textílií, SALS (morfológia), DSC 7 (Perkin Elmer), PRETEMA, AHIBA (farbenie), Kolorimeter, Polystat PS-1 (antistatické vlastnosti) atď.

Výsledky výskumu sú publikované v medzinárodných a domácich vedeckých časopisoch, v odborných časopisoch, na medzinárodných konferenciách doma i v zahraničí (Dornbirn, Gent, Mainz, Eindhoven, Liberec, Lodz, atď.). Časť výskumnej kapacity je venovaná spolupráci s partnermi z priemyslu (VÚCHV Svit, VÚTCH CHEMITEX Žilina, NYLSTAR a. s., RHODIA a. s. Humenné, CHEMOSVIT Svit). V posledných štyroch rokoch boli na katedre úspešne vyriešené Antibakteriálne viskózové vlákna pre Spolanu Neratovice (CZ), Nové PET koncentráty pre VÚCHV Svit a Antibakteriálne PP vlákna pre ISTROCHEM a. s. Bratislava. Publikačná aktivita katedry je uvedená v tab. 2.

Tab. 2 Publikačná aktivita katedry za roky 1998–2000

Aktivity	1998	1999	2000
1. Publikácie v zahraničí	7	7	7
2. Publikácie doma	6	6	5
3. Prednášky a postery	21	21	23
4. Zborníky	19	19	22
5. Správy (ZoD)	4	2	–
6. Kurzy	1	–	1
7. Projekty GAV (granty)	1	1	1

6. Medzinárodná spolupráca

Katedra je asociovaným členom AUTEX-u (Association of Universities for Textiles), organizácie Univerzít s výučbou textilu ae1kien. Aktivity tejto organizácie, ako sú pravidelne ročné stretnutia vedúcich pracovníkov, poskytujú dobré možnosti profesionálnych kontaktov a dávajú prehľad o vývoji Európskeho Univerzitného vzdelávania v odbore textil vlákna. Sú príležitosťou na osobné kontakty a výmenu informácií týkajúcich sa študijných programov, prípravy projektov, nových koncepcií štúdia a prezentovanie výsledkov.

V rámci projektu E-TEAM (AUTEX) sa organizuje špičkové vzdelávanie expertov pre Textilné odbory.

Katedra sa podieľa na projekte CEEPUS, v rámci ktorého sa už štyri roky uskutočňuje mobility poslucháčov špecialistov medzi účastníkmi projektu. V poslednom období sa pre zahraničné krátkodobé stáže doktorandov využíva tiež projekt SOCRATES/ERASMUS.

V spolupráci s Institute of Chemical Fibres v Lodži (Poľsko) katedra organizovala cykly Poľsko Slovenských seminárov, ktoré sa v poslednom období transformovali do medzinárodnej „Stredoeurópskej konferencie o vláknotvorných polyméroch, chemických vláknach a špeciálnych textíliách“.

Pracovníci katedry sú aktívnymi členmi redakčných rád niekoľkých renomovaných časopisov ako aj vedeckej rady Univerzity. Odborné kontakty sa realizujú najmä s Technickou Univerzitou Liberec (CZ), Inštitútom chemických vlákien Lodž (Poľsko), Univerzitou Gent (B), Univerzitou Maribor (SLO), Inštitútom Makromolekulovej Chémie, Albert-Ludwigs University Freiburg (G) a Ústavom polymérov, VŠCHT Praha (CZ).

7. Na záver

Perspektívne možnosti textilného i vláknarského priemyslu v krajinách EU sa ukazujú v orientácii na vysokoúžitkové výrobky pre odevníctvo a na priemyselné vlákna a textilné materiály. Len tak sa vytvárajú podmienky pre konkurenčnú schopnosť produkcie i v tejto oblasti. Tento rozvoj sa samozrejme nemôže uskutočniť bez vysokokvalifikovaných špecialistov. Podobná situácia sa očakáva aj v asociovaných štátoch EÚ.

Tieto zmeny sa nevyhnutne odrážajú aj vo výchove a vzdelávaní. V súčasnej dobe prebieha na túto tému intenzívna diskusia v rámci AUTEX-u, napr. aj 1. Autex konferencia o vzdelávaní a o výskum v odbore Textil s podnázvom „Stratégie pre nové milénium“, ktorá sa koná v júni 2001 v Portugalsku bude venovaná novým aspektom a orientácii univerzitného vzdelávania v odbore. Bude nevyhnutné všetky pozitívne výsledky tohto vývoja implikovať do študijného programu katedry. Katedra vlákien a textilu má v tomto smere dobré odborné zázemie a tiež predpoklady byť perspektívnym výchovno-vzdelávacím i výskumným pracoviskom pre chemickú technológiu vlákien a textilnú chémiu na Slovensku i v nasledujúcich desaťročiach.

HISTÓRIA ROZVOJA CHEMICKÝCH VLÁKIEN VO SVETE A NA SLOVENSKU

Jambrich, M.*, Budzák, D.**, Marcinčín, A.***, Revús, M.*,

** Slovenská spoločnosť priemyselnej chémie Bratislava*

*** Výskumný ústav chemických vlákien, a.s. Svit*

** Chemickotechnologická fakulta STU Bratislava*

Príspevok je zameraný na rozvoj vlákien vo svete a na Slovensku a vplyv 50 ročnej činnosti Výskumného ústavu chemických vlákien vo Svite a katedry vlákien CHTF STU na rozvoj chemických vlákien.

The contribution is aimed at the development of fibres in the world and Slovakia, and at influence of 50-years-long activity both of the Research Institute for Chemical Fibres and Fibres Department of CHTF STU which they have had in the development of chemical fibres.

1. ÚVOD

Medzi základné spoločenské a osobné potreby ľudí patria potraviny, ošatenie a bývanie. Požiadavky na ošatenie a bývanie sú bezprostredne spojené s potrebou ochrany ľudí od rozmarov prírody – počasia (chladu), ale aj osobnostných prejavov a druhu odevu a módnych prvkov. Širšie ponímanie spoločenskej a pracovnej činnosti zvyšuje nároky i na vlastnosti výrobkov tohoto odboru. Túto funkciu v najširšom slova zmysle plnia vlákna a vláknité materiály – textilne a technické textílie.

Význam hodnotenia histórie rozvoja chemických vlákien na Slovensku treba vidieť v tom, že nám môže ukázať niečo živé, čo nás obohacuje a posilňuje v prítomnom čase a umožňuje nám pohľad do budúcnosti. Musí nám ísť o to, aby sme udržali, obohatili a rozvinuli to živé, tie dobré výsledky a skúsenosti, ktoré sme doteraz získali.

2.0 HISTÓRIA ROZVOJA VLÁKIEN

2.1 Prírodné vlákna

Dejiny vývoja vlákien sú rovnako staré ako dejiny civilizácie ľudstva. Za obdobie asi 7000 rokov používania textilných vlákien boli až do konca 19. storočia používané iba ľan, vlna, bavlna, juta, konope a prírodný hodváb [1].

Archeologické nálezy poukazujú, že už v mladšej dobe kamennej boli používané traviny na prípravu tkanín.

Vlna patrí medzi najstaršie typy vlákien. Začiatky používania vlny na látky majú najmenej 7000 ročnú tradíciu. Vlnené výrobky boli v Babylone už viac ako 1000 rokov pr. Kr. predmetom výroby z obchodu. V Malej Ázii bol chov oviec veľmi rozšírený, nakmä v období okolo 8.–7. storočia pr. Kr. Vlna bola v Egypte, Grécku a v Ríme veľmi obľúbená a vlnené oblečenie v tomto období znamenalo vysoké spoločenské postavenie. Chov oviec sa rozširoval z Grécka cez Rím do Španielska a to najmä Merina. V r. 1788 bolo prevezené do Austrálie 29 kusov oviec Merina, ktoré sa rozmnožili na dnešný stav okolo 175 mil. kusov a zásobujú vlnou pol sveta.

Z ľanu už pred 5000 rokmi boli v Mezopotámii pripravované jemné tkaniny a tiež v Egypte (nálezy v hrobkách faraónov). V strednej Európe bol ľan viac tisícročí jediná kultúrna rastlina, ktorá až koncom 18.storočia bola postupne nahradzovaná lacnejšou bavlnou. V mladšej dobe kamennej (3000–1800 r. pr.Kr.) sa ľanové vlákno a výrobky z neho používali aj na kolových stavbách.

Bavlna sa pestovala v Indii už pred 5000 rokmi a používala sa na prípravu mušelínových a kartúnových textílií. V Amerike bola bavlna známa a používaná skôr ako v Európe. V 19. storočí bola Amerika hlavným dodávateľom bavlny do celého sveta, najmä po zavedení zariadenia na odsemeňovanie. Až v 13. storočí doniesli bavlnu do Nórska cez Arábiu, Španielsko a Sicíliu.

Juta má svoju históriu pestovania a používania už v období pestovania bavlny v Indii. Do Európy sa dostala až v polovici 19. storočia.

Konope sa dostalo do Európy už v 5. storočí pr.Kr. z Centrálnej Ázie, avšak sa nepoužívalo na textílie tak, ako vo východnej Ázii v domovine Rámie. Rámia sa spracováva v zmesi s bavlnou, ale aj s chemickými vláknami na jemné tkaniny.

Hodváb pravý patrí k najstarším typom vlákien na látky. Je produktom húsenice Moruše hodvábnej a jej pestovanie v Číne datuje sa min. 3000 r. pr.Kr.. Dlhú dobu sa príprava hodvábu utajovala (dar Bohov), pretože výrobky z pravého hodvábu slúžili Číne ako platidlo. Výrobky z hodvábu sa našli vo vykopávkach zo Sang – Dynastie (1800–1000 r. pr. Kr.). Z Číny sa príprava hodvábu preniesla do Buchary a Indie. Z Číny doniesli vajíčko húsenice Moruše hodvábnej v bambusovej palici Byzantskí mnísi r. 552. Príprava pravého hodvábu v Europe sa začala v Taliansku až v 14. storočí. Jeho výroba bola v 19. storočí i na Západnom Slovensku.

2.2 Predhistória chemických vlákien

Hoci úsilie získavať vlákna z iných zdrojov ako prírodných je relatívne veľmi staré, jeho prvá písomná formulácia sa datuje už z r. 1665. Hooke Robert v tom čase vyjadril myšlienku vyrábať vlákno zo želatínovej suroviny.

Francúz R.A.F. Réaumur v r. 1713 oznámil možnosť prípravy jemného vlákna z taveniny skla. Príprave vlákna zo skla venovali pozornosť i ďalší pracovníci a to J.Dubet (1770).

L.Schwabe v Manchestri (1842) prvý použil pri zvlákňovaní hubicu a pripravil jemné vlákna a z nich tkaninu.

Edison v r.1883 karbonizoval bambusové vlákno na uhlíkové vlákno. Francúz A.Payen izoloval celulózu z dreva r.1839 a dal jej dnešné meno. V roku 1840 J. Mercier napučiaval celulózu v roztoku lúhu sodného. Hanock W. skúšal už v r. 1820 surový kaučuk a Goodyear v r.1839 ju vulkanizoval do tenkých foriem, neskoršie to bol základ pre elastomerné vlákna.

Chr. F. Schönbein (1845 Basel) pripravil nitrát celulózy ako strelnú bavlnu a pozdejšie i jej roztok v alkoholéterovej zmesi, z ktorej pozdejšie gróf Chardonnet pripravil nitrátový hodváb.

George Ph. Audemars v r.1855 pripravil z lyka moruše nitrát celulózy a z jej roztoku v zmesi alkohol-éter vlákno. Postup sa neujal.

Schweizer Ed. v Zurichu r.1857 rozpustil celulózu v amoniakovom oxide medi (Schweizerovo činidlo), čím vytvoril základ neskoršieho postupu Fremeryho a Urbana na prípravu vlákien.

Schützenberger a Naudin pripravili vo Francúzsku v r. 1865 acetát celulózy, surovinu pre pozdejšiu výrobu vlákien. Postup prípravy acetátu celulózy zdokonalil G.W.Miles (1894–1911) a Dreyfus po 35 rokoch začal vyrábať z daného derivátu celulózy laky a filmy. V r. 1921 v USA bola začatá výroba vlákna.

Angličan B.C.Tilghman ohlásil v r.1866 patent na získanie celulózy z dreva pomocou kyseliny siričitej. Ekman C.D. založil vo Švédsku v r. 1874 továreň na výrobu celulózy sulfitovým spôsobom. Pracoval s bisulfitom horčíka.

Tilghmanov postup prípravy celulózy rozpracovali do priemyselného postupu roku 1875 nemeckí chemici A. Mitscherlich, Kellner K. a Ritter E. a založili v Podgore v78 pri Görzu fabriku na výrobu sulfitovej celulózy.

Gróf H. Chardonnet začína v Besancone v r.1878–79 s pokusmi prípravy nitrátového hodvábu.

Anglický chemik a fyzik Sir W. Cross v r.1881 pripravil vlákno pre žiarovky z Cu-oxamového roztoku celulózy.

Sir J. W. Schwan v r. 1883 získal patent na prípravu vlákna pre žiarovky z nitrocelulózového roztoku v kyseline octovej.

Gróg Hilaire Chardonnet popísal a predviedol v r.1884 na Akadémii v Paríži prípravu umelého hodvábu z nitrocelulózového roztoku, ktorú si nechal patentovať vo Francúzsku (Fr. p. 165 349) a v Nemecku (D. p. 38368).

V r.1889 postavil výrobu v Paríži na umelý hodváb a založil súkromnú spoločnosť Schardonnet.

Lehner F. z Augsburgu pripravil v r.1890 nitrocelulózové vlákno mokrým zvlákňovaním a dĺžením.

Francúzsky chemik C. Moure v r. 1893 polymerizoval akrylonitril.

2.3. Chemické vlákna v období ich priemyselného rozvoja

Koncom 19. a počiatkom 20. storočia sa začína priemyselná výroba chemických vlákien z regenerovaných prírodných polymérov a tesne pred druhou svetovou vojnou sa objavujú prvé, priemyselne vyrábané syntetické vlákna v prírode sa nenachádzajúce, chemické vlákna sú teda legitimným dieťaťom 20. storočia. [1,2]

V roku 1891 bola prvá priemyselná výroba umelého hodvábu realizovaná nitrátovým spôsobom grófom Chardonnetom v Besacone s výrobou cca 110 kg/deň.

Charles Frederick Croos, Edward John Bevan a Clayton Beadl pripravili v r.1892 roztok xantogenátu celulózy – viskózu. Cross a Bevan založili v Londýne r. 1894 firmu Viscose Syndicate Ltd.. Na tento nový postup prípravy roztoku celulózy–viskózy získal licenciu pre centrálnu Európu, najmä pre Sliezsky veľkopriemysel Henkel z Donnersmarcku a v r. 1901 vybudoval viskózovú fabriku v Sydoxane pri Štetíne, ktorú v r. 1911 odkúpila fa Glanzstoff a uviedla ju do prevádzky po úpravách v r. 1916.

Fremery M. a Urban J. v r.1982 začínajú v Oberbruchu výrobu hodvábu z meďnato-amoniakálneho roztoku celulózy na prípravu C-vlákna pre žiarovky.

V r. 1984 F. Lehner zakladá výrobu na nitrátový hodváb v Glattburgu vo Švajčiarsku.

Stern Ch. H. získal v r. 1898 patent na zvlákňovanie viskózy do roztoku amoniakálnych solí, najmä v chloride amónnom.

Chardonnet a Lehner v r. 1900 založili akciovú spoločnosť na umelé vlákno nitrátovým postupom so sídlom vo Frankfurte n/Mohanom a fabriku v Kelsterbachu, Bobingen Glattburg a Spreitenbachu.

Bemberg J.P. AG Barmen začína v r. 1900 prípravu umelého hodvábu z meďnatoamoniakálneho roztoku celulózy. Do spločnosti vstupuje aj E. Thiele, kde dopracoval svoj spôsob zvlákňovania a dĺženia v lieviku meďnatoamoniakálneho hodvábu, ktorý si v r. 1901 patentoval. Táto firma zaviedla tento spôsob výroby hodvábu v r. 1904.

Stern a Tophan vybudovali v r. 1901 poloprevádzku v Kentel (Anglicko) na výrobu nitrátového hodvábu a zároveň si Tophan nechal patentovať zvlákňovacie čerpadlo.

Henkel Fürst z Donnersmarcku zakladá v r.1903 výrobu umelého hodvábu a acetátový závod v Sydowsane pri Štetíne.

Vo Francúzsku fa Societe Francaise v r.1903 zakladá výrobu viskózového hodvábu.

V r.1904 zakladá fa Samuel Courtaulds Co. Ltd. v Anglicku výrobu viskózových vlákien.

Lekárnik Todtenhaupt F. začal v r.1904 výrobu vlákna z mliečneho kaseinu. Túto výrobu zaviedla v 30-tych rokoch v Taliansku fa SNIA pomocou Antónia Ferettiho pod menom „Merinova“. V Holandsku bola zavedená výroba kaseinového vlákna „Enkasa“. V USA zaviedli výrobu proteinového vlákna zo zeinu a vo V. Británii z proteinu burského orieška (Erdnuss).

Firma Farbenfabriken F. Bayer Co. v Eberfelde, dnešná fa Bayer AG ohlásila vynález Arthura E. Eichengrüna na prípravu acetátového hodvábu postupom priamej acetylácie celulózy a suchého zvlákňovania. Trvalo však veľmi dlho pokiaľ túto výrobu zaviedli firmy IG Farbenindustrie a Glanzstoff v r. 1926 v Berlíne.

Max Müller v Sydowsane v r.1905 dopracoval proces zvlákňovania viskózy do kúpeľa Na_2SO_4. Boos E. fa. Glanzstoff ohlásil vynález v r.1906 na kontinuálnu prípravu umelého hodvábu a v r.1909 založili spoločnosť Glanzfäden AG a založenie fabriky v Petersdorfe.

V r. 1910 Hottenroth zaviedol metódu hodnotenia zrelosti viskozy, dôležitej veličiny pred zvlákňovaním.

Francúzski výrobcovia hodvábu meďnato-amoniakálnym a viskózovým spôsobom uzavreli v r. 1910 dohodu o trvalej dodávke vlákien textilného priemyslu.

V r. 1911 bola založená fabrika Enka v Arnheime (Holandsko) na výrobu umelého hodvábu.

Na prvé syntetické vlákno z PVC získal patent Fritz Klatte v r. 1913 z chemickej fabriky Griesheim-Elektron.

V r. 1918 bola založená fabrika Spinnfasern AG v Elsterbergu.

V r. 1919 sa uskutočnilo založenie výroby viskózového hodvábu v SH Senica.

V r.1920 bola zavedená výroba jemných vlákien Bembergovým spôsobom na dámske pančuchy a módne oblečenie.

Köln-Rottweil AG zaviedla v r. 1921 v Permnitz (Nemecko) výrobu viskózovej strože s označením „Vistra“.

Firma Agfa vo Wolfen v r. 1921 zaviedla výrobu viskózového hodvábu. Glanzstoff AG s rakúskou AG Glanzstoff zakladá v r. 1921 s českým priemyslom českú Glanzstoff fabriku systému Eberfeld a krajovú banku so sídlom v Prahe a fabriku v Lovosiciach.

Firma Glanzstoff AG zriaďuje v r. 1921 Výskumný ústav v Teltow-Seehof pri Berlíne. Prvým vedúcim tohoto ústavu bol Prof. Dr. Bronerton.

V r. 1922 fa Bemberg postavila závod na výrobu hodvábu v Barmen-Oehde.

V r. 1923 zakladá firma AG Spinnstoffwerk Glachau „Borvisk“ firmu Kunstseiden AG Herzberg.

Georg V. Gieschés Erben založil v r. 1923 fabriku Cavallen pri Breslave na výrobu umelého vlákna.

V r. 1924 bola založená spoločnosť a fabrika na výrobu zariadenia pre vlákna Maschinenfabrik AG a v r. 1925 bola uvedená do prevádzky v Reimscheide-Lennep.

V r. 1925 Prof. Dr. H. Staudinger svojimi prácami o makromolekulách dáva základ teórie v tejto oblasti. Pripravil polyoximetylén polykondenzáciou formaldehydu. Hlbším štúdiom prišiel k záveru, že pre tvorbu vláknitého útvaru je potrebný lineárny polymérny reťazec.

V r. 1925 vznikla spoločná firma Glanzstoff-Courtauld GmbH v Kolíne na výrobu viskózového hodvábu. V tom istom roku firmy Glanzstoff a Bemberg zakladajú americkú firmu Bemberg Corporation New York so závodom v Johnson City/ Tenn.

IG Farbenindustrie AG zakladá výrobu v r. 1925 Kunstseidenfabriken vo Wolfen, Premnitz, Bobingene, Rotweile a Worringene.

V r. 1926 Lilienfeld Leon z Viedne ohlásil vynález na postup prípravy vysokopevného viskózového vlákna zvlákňovaním nezrelej viskózy a vysokým stupňom dĺženia v koncentrovanej kyseline sírovej.

V r. 1926 fa Celta AG zaviedla výrobu dutého vlákna.

V r. 1927 americká firma Glanzstoff Corp. zakladá spoločnosť North American Rayon Corp. na výrobu vlákien.

V r. 1928 uvádza práce Wallace H. Carothers (Du Pont de Nemours) v USA o polykondenzácii a tvorbe organických substancií s kruhovou štruktúrou.

V r. 1934 zavedením dodatočnej chlorácie PVC sa vytvorili podmienky na výrobu PVC vlákien v IG Farben Wolfen.

V r. 1935 W.H.Carothers pripravil polyamid 66 polykondenzáciou hexametyléndiamínu a kyseliny adipovej, z ktorého po vyzvláknení a dĺžení sa získalo vlákno o dobrých pevnostiach a iných textilných vlastnostiach.

V r. 1936 bola zavedená výroba viskózového hodvábu v Lovosiciach.

V r. 1937 O. Bayer so spolupracovníkmi pripravili v Leverkusene polyuretán a polyamid, z ktorého pozdejšie vyrábali monofily-vlasce.

V r. 1938 Paul Schlack u firmy IG Farbenindustrie AG pokračoval v prácach Carothersa, ale v protiklade k jeho výsledkom sa mu podarilo spolymerizovať kaprolaktam na polyamid 6 a pripraviť vlákno o dobrých vlastnostiach, ktoré nazvali „Perlon“.

V r. 1939 firma Du Pont postavila v Seaforde (USA) overovaciu linku na polyamid 66 a nazvala ho „Nylon“, ktoré bolo vystavované v San Francisku a už v r. 1940 dodávala Nylon na trh.

V r. 1939 fa IG Farbenindustrie AG zaviedla výrobu Perlonu (PA6) v Berline–Lichtenbergu. V dôsledku vojny veľkovýrobu Perlonu zaviedli až v 50 rokoch. V tom istom roku si vymenili patenty fy IG Farbenindustrie a Du Pont na výrobu Perlonu a Nylonu.

O. Bayer a Kurz v Leverkusene vypracovali v r. 1939 postup na prípravu akrylonitrilu z acetylénu, surovinu pre PAN vlákna.

V r. 1936 bola zavedená výroba viskózového hodvábu vo Svite.

V r. 1941 Whinfield J.R. a Dickson T. z Calico Printer Ass Ltd. v Manchestri ohlásili vynález na prípravu polyesteru polykondenzáciou kyseliny tereftalovej a etylénglykolu. Výrobu polyméru a vlákien zaviedla fa ICI až po vojne pod názvom „Terylen“.

V r. 1942 bola zavedená výroba viskózovej strižе v Bratislave firmou Dynamit Nobel pod označením „Vistra“.

V r. 1947 sa začala výroba viskózovej striže v Neratoviciach.

Po roku 1941 bola venovaná pozornosť príprave PA6 z kaprolaktamu i v laboratóriach formy Baťa v Zlíne a to v nadväznosti na práce P. Schlacka, v rámci dobrých kontaktov s jeho laboratóriami. Tieto práce dali základ pre pozdejšiu výrobu PA6 odvábu Silon a tiež PA6 striže.

V 30-tych rokoch pripravil H. Rein v IG – závod Wolfen polyakrylonitril s lineárnym reťazcom, ale až v r. 1942 sa podarilo nájsť vhodné rozpúšťadlo polyméru a to DMF. Výroba vlákna bola zavedená v r.1952 firmou Cassella Farwerke Mainkur vo Frankfurte n/M.

V r. 1953 fa Bayer v Dormagene a Bobingene zaviedla výrobu PAN hodvábu „Perlon“ a tiež striž „Dralon“ v r. 1954.

V r. 1944 firma Du Pont podala patent na prípravu PAN vlákien, ktoré dala na trh v r.1946 pod označením „Orlon“.

V r. 1946 fa Du Pont zavádza výrobu polyesterov s označením „Dacron“.

V r. 1950 viskózový hodváb sa začal označovať ako „Rayon“ podľa anglicko-francúzskeho pomenovania.

V r. 1951 sa začína výroba viskózového hodvábu v Bratislave u firmy Dynamit Nobel (Závod Mieru).

V r. 1952 bola zavedená výroba PA6 hodvábu v Silone Planá nad Lužnicí pod označením „Silon“ na podkladoch výskumu zo Zlína.

V r. 1954 ohlásil Giulio Natta svoj vynález na prípravu stereoregulárneho polypropylénu na základe stereošpecifickej polymerizácie pomocou Ziegler-Nattových katalyzátorov. V rovnakom období sa ukončovali práce i u amerických firiem. Prvé výroby PP vlákien boli ohlásené už v r. 1958.

V r. 1955 začala výrobu PET vlákien fa Hoechst v Bobingene pod označením „Trevira“.

V r. 1959 bola zavedená výroba PA6 vlákna v Chemlone Humenné pod označením „Kapron“ a v Rudníku výroba vysokopevných viskózových kordov na podkladoch výskumu VÚCHV Svit.

V r. 1958 zaviedli pokusnú výrobu vysokotepelne odolných a vysokopevných vlákien v bývalom ZSSR na podkladoch Kudrjavceva a jeho kolektívu pod označením Fenilon, Sulfon T, SVM z aromatických polymérov (aramidy).

V r. 1959 fa Du Pont zaviedla výrobu elastických vlákien „Fiber k“ a v r. 1962 pod označením „Lycra“.

V r. 1960 bol pripravený vysokomolekulový polyetylén na podkladoch patentu Jurgeleitovho z r. 1956, rozpustný v parafinovom oleji, ktorý tvoril základ pre výrobu vysokopevných vlákien Dyneema a Spektra.

V r. 1960 u firmy Du Pont pripravili aramidové vlákno. V r. 1962 ho vyrábali pod označením „Nomex“.

Vývoj vlákien na báze aromatických polymérov sa rýchle rozvíjal najmä po r. 1970 po objavení kvapalno–kryštalického stavu u niektorých polymérnych systémov. Dnes poznáme tieto vlákna pod označením Kevlar, Twaron, Technora, SVM a iné.

Veľká pozornosť sa venovala i rozvoju výroby uhlíkových vlákien. V r. 1883 Edison pripravil C-vlákno karbonizáciou vlákna z bambusu a pozdejšie z nitrátového vlákna. V r. 1950 Wright Patterson u firmy Union Carbide pripravil vysokopevné a tepelne odolné C-vlákno. V r. 1963 L. N. Philips oznámil výrobu C-vlákna z PAN vlákien a označil ho ako „čierny Orlon“. Tento spôsob výroby je rozvinutý v USA, Japonsku, Rusku a v Ďalších štátoch Európy. Uhlíkové vlákna sa dnes vyrábajú z celulózových a PAN vlákien a tiež z pyrolýznych olejov.

V tomto období sa venuje veľká pozornosť vo výskume a vývoji nových technológií prípravy vlákien pre náročné oblasti aplikácie ako sú napr vlákna:

- vysokopevné a vysokomodulové
- odolné voči vysokým teplotám a termicky stabilné
- chemicky odolné voči rozpúšťadlám
- nízkej váhy
- svetlovodivé
- elektricky vodivé
- bakteriocidné
- svetlostabilné
- vhodné pre EKO systémy
- vlákna pre nové generácie pórométrov
- bio vlákna z mikrobiálnych polymérov
- vlákna pre kompozitné konštrukčné a stavebné materiály
- vlákna pre medicínu
- vlákna pre ochranu voči radiácii
- vlákna pre zvukovú a tepelnú izoláciu
- iné.

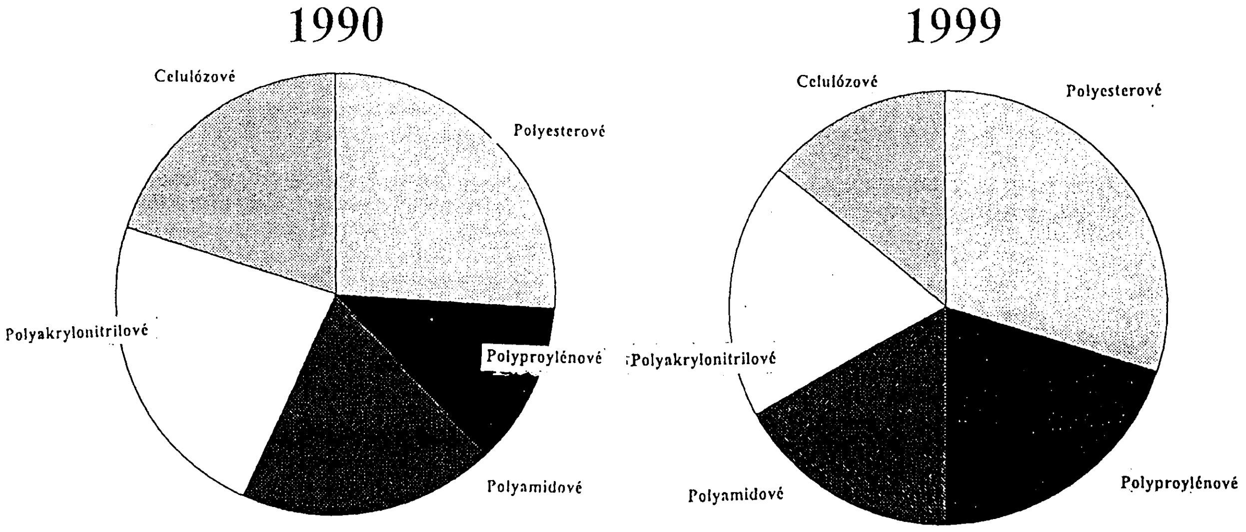
Už v 70-tych rokoch bola upriamená pozornosť v technickom rozvoji na prípravu jemných vlákien a mikrovlákien a to jednak pre zlepšenie parametrov fyziológie odievania textílií a tiež pre ich módnosť a luxusnosť. Rovnako mikrovlákna sú vhodné i pre technické aplikácie ako sú filtračné materiály, textílie pre klimatizáciu, syntetické papiere, semiš, syntetickú kožu a iné.

Rozvoj chemických vlákien v 20. storočí, najmä po r. 1950 bol tak veľký, že dnes ich spotreba vo všetkých oblastiach aplikácie, t.j. v textilných, bytových a technických vlaknitých výrobkoch predstavuje 61 % spotreby všetkých druhov vlákien [1,2] (tab. 1.). Za posledných 10 rokov veľký nárast výroby bol PES a PP vlákien (obr. 1) [3,4]. Najväčší rozvoj základných typov chemických vlákien za posledných 20. r. je uskutočňovaný

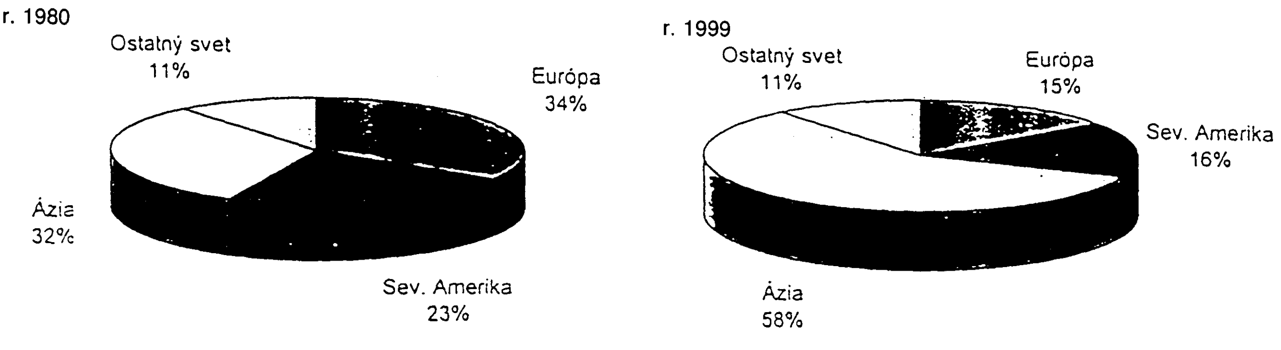
Tab. 1 Vývoj výroby a spotreby vlákien vo svete

Rok	Populácia vo svete (mld)	Spotreba vlákien (mil.ton)					
		Prírodné vlákna		Chemické vlákna		Celkom	kg/osobu
		bavlna	vlna	celulózové	syntetické		
1900	1,6	3,2	0,7	0	0	3,9	2,44
1950	2,5	6,6	1,1	1,6	0,1	9,4	3,76
1960	3,0	10,1	1,5	2,6	0,7	14,9	4,97
1970	3,7	12,0	1,6	3,6	4,8	22,0	5,95
1980	4,5	14,3	1,6	3,5	10,8	30,2	6,7
1985	4,8	16,3	1,6	3,2	13,1	34,2	7,10
1990	5,3	18,7	1,5	3,2	15,9	39,3	7,41
1995	5,6	18,5	1,5	2,986	22,781	45,767	8,17
1996	5,7	19,04	1,5	2,979	25,062	48,581	8,52
1997	5,8	19,31	1,44	2,897	27,358	51,005	8,79
1998	5,9	19,02	1,4	2,726	28,561	51,707	8,76
1999	6,0	19,04	1,33	2,647	29,974	52,991	8,83

Nie sú započítané ostatné typy prírodných vlákien, juta, ľan, ramia, konope, prírodný hodváb (cca 4,5 mil. ton)



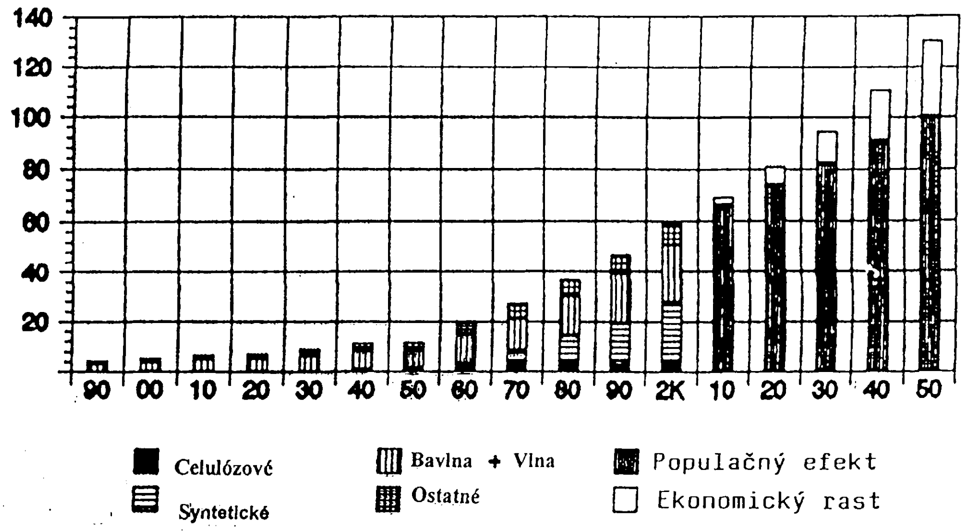
Obr. 1 Zloženie spotreby chemických vlákien



Obr. 2 Lokalizácia výroby chemických vlákien vo svete

v štátoch Ázie a rozvojových krajinách Afriky a Južnej Ameriky (obr. 2) [5,6,7].

Podiel výroby chemických vlákien v štátoch Ázie za posledných 20 r. stúpol (r. 1980–1999) z 32 % na 58 % pričom podiel Európy a Sev. Ameriky klesol z 57 % na 31 % [4,7,8]. V Európe a štátoch Sev. Ameriky dochádza k zvyšovaniu výroby špeciálnych a technických typov vlákien s vysokými úžitkovými vlastnosťami. Za posledných 10–15 rokov sa zvýšil podiel aplikácie chemických vlákien v technických textíliách (TT) celkovo vo svete z pôvodných 22 % na 34 % na úkor odievania (O) a bytového textilu (BT), (v r. 1999 O ≈ 38 % a BT cca 28 %). V priemyselne vyspelých krajinách výroba a aplikácia technických vlákien je viac ako



OBR.3. Spotreba vlákien (mil. ton) 1890-2050

40 % (Japonsko 45 %) a tento podiel v týchto krajinách bude stúpať. Predpokladá sa, že v priebehu 10–15 rokov budú špeciálne a technické vlákna predstavovať viac ako 50 %. Tieto tendencie by sa mali zohľadňovať v rozvoji vlákien i u nás na Slovensku.

3. ROZVOJ VLÁKIEN V ĎALŠOM OBDOBÍ

Rozvoj spotreby a výroby vlákien v ďalšom období sa predpokladá, že bude podmienený prírastkom obyvateľstva, zmenou ekonomického potenciálu a zvýšenými nárokmi ľudí na ich vlastnosti (obr. 3) [6,7,8,9,10]. Demografický vývoj bude podstatne ovplyvňovať lokalizáciu výroby základných typov masovej spotreby vlákien. Krivka rastu obyvateľstva a spotreby vlákien od r.1950–2000 má exponenciálny charakter. (obr.3) V r. 1900 žilo na našej zemeguli 1,6 mld. obyvateľov a spotreba vlákien (prírodných) bola 3,9 mil. ton. V r. 1950 bolo 2,5 mld. obyvateľov a spotreba vlákien 9,4 mil. ton. V r. 1990 bolo 5,3 mld. obyvateľov a spotreba 39,3 mil. ton vlákien a v r. 1999 6 mld. obyvateľov a celková spotreba všetkých druhov vlákien bola viac ako 60 mil. ton [1,2]. Do r. 2050 sa predpokladá nárast obyvateľstva na 11 mld. a spotreba vlákien 130 mil. ton [3,4,7,8,9,10].

Ďalším dôležitým faktorom, ktorý už v tomto období podmieňuje rozvoj výroby vlákien je celosvetová globalizácia (vplyv kladný i záporný), čo sa prejavuje predovšetkým koncentráciou výrobcov vlákien a integráciou výrobných odborov (vertikálne prepojenie). Za posledných 10 r. došlo keniu výrobcov vlákien (spojenie ekonomického, technického a kapitálového potenciálu). Táto skutočnosť sa prejavila v poklese počtu výrobcov vlákien na cca 50 % z počtu v r.1989. Integračný efekt viedol k vertikálnemu prepojeniu výrobných odborov ako napr. u PES vlákien od výroby KT, polykondenzátu PET, výroby technických vlákien a ich aplikáciám vo výrobe gumárskych výrobkov (pneumatík, dopravných pásov) [6,8].

Prírastok spotreby vlákien v ďalšom období sa bude zabezpečovať predovšetkým chemickými vláknami (obr. 4). Prírastok spotreby prírodných vlákien nebude veľký, nakoľko rozhodujúci podiel majú vlákna rastlinného pôvodu (bavlna, ľan, konope, juta), ktorých rozvoj výroby je podmienený predovšetkým osevnými plochami.

V podmienkach Európy dôjde pravdepodobne k zvyšovaniu spotreby ľanu a konope, ktoré sa postupne uplatňujú vo forme technických textílií v kompozitných – konštrukčných materiáloch.

Celulózové vlákna sú nevyhnutnou zložkou v textilných a technických textíliách. Nakoľko nárast výroby prírodných vlákien s celulózovým základom nepokryje potrebu v množstve, ale i z hľadiska vlastností, vývoj smeruje k rozvoju a zvýšeniu výroby chemických celulózových vlákien [6,7,8,9,10]. Tieto predpoklady sa opierajú o nasledovné skutočnosti.

Základným zdrojom surovín pre prípravu vlákien je celulóza z drevnej hmoty, ktorá sa pravidelne v prírode obnovuje na základe fotosyntézy. V tomto období sa ťaží cca 1,7 mld. ton dreva. Z tohoto množstva je 10 % spracované na buničinu. Na výrobu vlákien sa spracuje 2,5 % z celkového množstva buničiny. Základný zdroj suroviny nie je teda obmedzujúcim faktorom rozvoja týchto vlákien [13].

Druhým vážnym dôvodom ďalšieho rozvoja celulózových vlákien sú ich vlastnosti vyplývajúce z chemickej a fyzikálnej štruktúry celulózového reťazca. Tento polotuhý polymérny reťazec predstavuje vysoko funkčný polysacharid (hydroxylové skupiny) so sindiotaktickou konfiguráciou. Tento polymér umožňuje prípravu hydrofilných vlákien so širokou škálou požadovaných vlastností. Celulózové vlákna sú biodegradovateľné. Táto vlastnosť ich bude predurčovať i v aplikáciách nielen do textilných, ale i do technických textílií. Nový postup prípravy celulózových vlákien s využívaním rozpúšťadla NMMNO (lyocellový) bude v budúcnosti podstatne ovplyvňovať rozvoj výroby celulózových vlákien. Klasický viskózový proces prípravy celulózových vlákien sa bude i v ďalšom období podieľať na ich rozvoji pretože umožňuje výrobu širokého zaužívaného sortimentu vlákien a tiež z dôvodov riešenia ekonomizácie, regenerácie CS_2 a likvidácie odpadov z tohoto systému výroby.

Rozvoj syntetických vlákien masových typov sa bude v najbližších 10 rokoch opierať predovšetkým o širokú škálu PES a PP polymérov a ich modifikovaných typov, ďalej PA, PAN [1,3,4,5,7,8,10,11,12,14,15,19]. Špeciálne typy vlákien s vysokými úžitkovými vlastnosťami sa budú rozvíjať na báze aromatických polymérov (aramidy, aromatické kopolyestery), vinylových typov (PVA), C – vlákien, hutníckých vlákien, (kovové, sklenené, oxidy Al, Zr, BSi, BC) a mikrobiálnych typov (biodegradovateľných, PMK, polylaktóny) [4,19,20].

V tomto období výroba nekonečných technických vlákien je zabezpečovaná výrobou PA6 a PA66 (cca 950.000 t/r), PET (cca 750.000 t/r), celulózovými vláknami (viskózové a lyocellové, cca 80.000 t/r, aramidovými a aromatickými kopolyesterovými (cca 50.000 t/r), C – vláknami (cca 30.000 t), vysokopevnými PE (cca 3.000 t/r), oceľovými a sklenenými vláknami. Vzhľadom k tomu, že PES vlákna a ich surovinová báza sa relatívne dobre rozvíjajú, predpokladá sa, že v priebehu niekoľkých rokov získajú dominantné postavenie i v oblasti technických textílií [11,19].

Procesy prípravy nekonečných PES vlákien sú prezentované kontinuálnym systémom POY a HOY pri vysokých rýchlostiach navíjania vlákna a diskontinuálnym systémom so stolicovým postupom dĺženia a s finálnou úpravou vlákien. V ďalšom období sa predpokladá ich ďalší vývoj so zámerom zvyšovania kvality vlákien a ekonomiky procesov výroby [15].

4. ROZVOJ CHEMICKÝCH VLÁKIEN U NÁS

Výroba chemických vlákien v predchádzajúcim období na Slovensku a v Čechách zohrávala dôležitú úlohu v rozvoji spotrebných tovarov a v rozvoji národného hospodárstva [1].

Chemické vlákna ovplyvňovali štruktúru textilných a technických textílií aplikovaných v rôznych oblastiach najmä textilného priemyslu, dopravy, gumárenských výrobkov, stavebníctva, pôdohospodárstva, strojárstva, potravinárskeho priemyslu a iných. Chemické vlákna nenahradzovali prírodné vlákna, ktorých máme nedostatok, ale pokrývali zvýšenú spotrebu textílií a zvýšené nároky na vlastnosti, najmä v oblasti technických textílií.

V oblasti odievania chemické vlákna v kombinácii s prírodnými vláknami umožňujú pripravi'9d výrobky s lepšími vlastnosťami z hľadiska komfortu a fyziológie odievania a zníženia spotreby energie na ich ošetrovanie. Ich podiel v týchto výrobkoch je cca 40–45 % avšak v športovom oblečení je až cca 70 %.

Chemické vlákna podstatne podmienili tiež rozvoj bytového textilu, v ktorom majú cca 75 % zastúpenie. V technických textíliách chemické vlákna majú asi 85% podiel.

Prvá výroba chemických vlákien bola u nás (v bývalej ČSR) zavedená v r. 1919 v SH Senica a v Moravskej Chrastave. V r. 1950 produkcia chemických vlákien predstavovala na báze celulózy 26.587 ton a na báze syntetických polymérov 52 ton.

Významný rozvoj výroby chemických vlákien u nás (v bývalej ČSSR) nastal po druhej svetovej vojne, najmä po r. 1950, ktorý vyplynul z dlhodobej koncepcie rozvoja národného hospodárstva vypracovanej v r. 1950. Na podporu rozvoja vlákien, pre ktoré sa vytvárali materiálne a technické predpoklady na Slovensku boli založené v r. 1951 VÚCHV vo Svite, špecializácia chemických vlákien na CHTF SVŠT v Bratislave a projekčná organizácia Chempik v Bratislave.Vznikli tiež výskumno-vývojové základne v Chemlone, Chemosvite, Slovenskom hodvábe a Istrocheme. V Čechách na VŠCHT v Pardubiciach v r. 1952 vzniklo zameranie na vlákna a textil, ÚZCHV v Českej Třebovej v r. 1967 so zameraním na spracovanie a aplikáciu chemických vlákien. Vytvárala sa dobrá spolupráca výrobcov vlákien aškoly a VÚCHVs VÚPC v Bratislave, VÚGPT v Zlíne, VÚP Novákoch, VÚTCH Žiline, VÚCHT Bratislave, s VÚMCH, VÚP a VÚV v Brne, ďalej s VŠST v Liberci, VÚTS v Brne, Liberci a Bratislave s VÚB v Ústí n/Orlicí, VÚVL v Dvúr Králové, VÚOS a OSDP v Pardubiciach. Dobrá spolupráca bola s ÚP a CHÚ SAV v Bratislave a ÚMCH Praha a VŠCHT v Prahe. Dobré zázemie pre rozvoj výroby chemických vlákien bolo vytvorené spoluprácou s Chemosvitom v oblasti výroby zariadení na výrobu chemických vlákien, ďalej s Považskou Bystricou PZVL, Dubnicou, VSS v Košiciach, Adamovskými strojárňami, ZVS v Brne, Elitexom v Liberci a ďalšími podnikmi a inštitúciami [1].

V tab. 2 uvádzame výrobu chemických vlákien na Slovensku a v Čechách od r. 1919. Z tab. 2 vyplýva, že rozvoj chemických vlákien v uplynulých rokoch zaznamenal u nás vysokú dynamiku a že ich výroba do r.1989 vzrástla viac ako 8-násobne. Prevažná časť výroby bola viazaná na bývalé trhy RVHP a trhy západných štátov. Po roku 1990 dochádzalo k poklesu odbytu vlákien a tým aj ich produkcie. V predchádzajúcom období najviac sa rozvíjali PA, PET a PP vlákna. Množstvom výroby chemických vlákien v danom období na 1 obyvateľa sme sa zaradili medzi popredné priemyselne vyspelé krajiny.

Chronológia zavádzania výroby jednotlivých druhov chemických vlákien a zakladania nových podnikov na ich výrobu je uvedená v tab. 4.

Rozvoj výroby chemických vlákien na Slovensku od r. 1989 je uvedený v tab. 3.

Tab. 2 Rozvoj výroby chemických vlákien na Slovensku a v Čechách

Rok výroby	Výroba chemických vlákien v tonách		
	celulózové	syntetické	chemické vlákna spolu
1919	250	–	250
1920	430	–	430
1925	900	–	900
1930	2 300	–	2 300
1935	300	–	3 000
1940	5 100	–	5 100
1944	15 113	–	15 113
1945	3 662	–	3 662
1950	26 587	52	26 639
1955	48 066	910	48 976
1960	58 905	3 361	62 266
1965	69 138	9 820	78 958
1970	69 308	31 490	100 798
1975	70 980	69 250	140 230
1980	54 532	120 700	175 232
1985	56 112	154 468	210 580
1986	56112	155 202	211 314
1987	54 992	160 992	215 984
1988	57 708	166 848	224 556
1989	60 441	168 804	229 245
1990	56 822	165 476	222 298
1991	40 929	118 261	159 190
1992	45 793	111 936	157 729
1993	47 565	122 800	170 373
1994	48 621	152 546	201 167

vo výrobe vlákien sú uvedené údaje vrátane fóliových typov a rún

Rozvoj výroby chemických vlákien u nás bol zabezpečovaný do r. 1950 predovšetkým na podkladoch zahraničných firiem. Po roku 1950 sa začína realizácia výroby vlákien i na podkladoch vlastného výskumu a vývoja a to na nasledujúcich typov vlákien:

- Polyamidový hodváb v Silone Planá n/Lužicí v r. 1951.
- Polyamidová striž v Chemosvite vo Svite r. 1955 a 1963.
- Viskózový kordový hodváb S1a S2 na strojoch KVKH-36 v Rudníku u Hostinného v r. 1959 a SČCHZ Lovosice v r. 1960–63. Výrobok predstavoval v tomto období strategickú surovinu pre národné hospodárstvo.
- Viskózový hodváb na odstredivkových strojoch v Závode mieru (CHZJD-Istrochem) r. 1951 a na kontinuálnych strojoch KVH-84 v SH Senica v r. 1988.
- Polypropylénová striž v Chemosvite vo Svite v r. 1965 a v Istrocheme (CHZJD) v Bratislave v r. 1970 a v r. 1979 a v SLZ v Hnúšti v r. 1967.
- Polypropylénový káblik v Istrocheme (CHZJD) v r.1975 a 1981.
- Polypropylénový technický hodváb v Chemosvite vo Svite v r. 1965 a v Istrocheme (CHZJD) v r. 1970, jeho výroba bola prebudovaná na káblik.
- Polypropylénový hodváb v Chemosvite vo Svite v r. 1980.
- Špeciálne riešenie farbenia v hmote polypropylénových vlákien.
- Polypropylénové rúno – Tatratex v Tatraľane v Kežmarku v r. 1977.
- Polyetylénové rúno – Izotex v závode Upice v r. 1967 a Texizol v Chemosvite vo Svite v r. 1970 a v r. 1967 v Tatraľane Kežmarok.
- Polyamidový káblik – farbenie vo hmote v Chemlone Humenné v r. 1969 a kompletnú výrobu polyamidového káblika v Chemosvite vo Svite v r. 1972.
- Polyamidový kordový hodváb v Chemlone Humenné postupná realizácia od r. 1967 a pre vysokopevný kordový hodváb v r. 1977 dĺžiaco-skacie stroje (DSKH).

Tab. 3 Rozvoj výroby chemických vlákien (t) na Slovensku od r. 1989

Druh vlákna	Rok výroby									
	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
celulózové										
viskózový txh	8317	7775	6343	6522	6565	6921	7400	7100	7000	3804
Polyestérové	17552	17372	14123	16004	14701	17584	16694	15447	13931	12036
PES txh	17208	16830	13765	15319	13374	16003	14594	13341	11628	9210
PES th	344	542	358	685	1327	1581	2100	2106	2303	2826
Polyamidové	57442	59665	45054	42250	32500	42122	37988	37124	40355	35005
PA txh	21085	21775	14501	16328	11315	17510	16167	17791	19371	18271
PA th, kord	17996	20140	18729	16630	14890	17890	18585	16469	19826	15441
PA káblik	17187	16788	11064	9012	6295	6722	3236	2864	1128	1293
PA striž	1204	962	760	280						
Polypropylénové	50339	43274	23167	15714	13417	16240	15410	14494	14422	12742
PP striž	27057	21674	9055	6687	4604	6166	6250	6240	5670	5630
PP káblik	14682	13360	8827	4734	5113	5674	4300	3090	3300	2150
PP txh	4700	4460	2785	1793	1700	2000	2360	2664	2952	2462
PP rúna	3900	3800	2500	2500	2000	2500	2500	2500	2500	2500
Polyetylénové	1752	1712	694	663	730	483	500	500	500	500
drény	482	446	42	70	57	90				
PE rúna	1270	1266	655	593	673	393				
Celková výroba	**135 402**	**129 798**	**89 384**	**81 153**	**67 913**	**83 350**	**77 992**	**74 665**	**76 208**	**64 087**

- Mikrovlákna – filtračná hmota (PVC a PS) v SLZ Hnúšťa v r. 1964.
- Polyesterová striž – čiastková účasť pri realizácii výroby na základe licencie firmy ICI v r. 1959 v Silone Planá n/Lužnicí. Vyriešené a realizované farbenie vo hmote.
- Polyesterový technický hodváb v SH Senici v r. 1986.
- Uhlíkové vlákna – poloprevádzková linka vo VÚCHV Svit v r. 1985.
- Kontinuálna výroba viskózového hodvábu v Senici po r. 1985.

Tab.4 Chronológia zavádzania výroby jednotlivých druhov chemických vlákien a zakladanie podnikov na ich výrobu na Slovensku a v Čechách

	Druh vlákna		Podnik, lokalita	Rok
1.	Viskózový hodváb	1)	Moravská Chrastava	1920
2.	Viskózový hodváb		Továreň na umelé vlákna	1919
			Slovenský hodváb Senica	1920
3.	Viskózový hodváb		Umelé vlákno	1920
		2)	Theresienthal, dnešný Rudník u Hostinného	
4.	Viskózový hodváb		Severočeské chemické závody *	1922
		3)	Lovosice	1936
5.	Viskózový hodváb	4)	Chemosvit Svit	1934
				1936
6.	Viskózová striž	5)	Vistra Dynamit Nobel – Istrochem	1942
7.	Viskózová striž		Závod Spolana Neratovice **	1947
8.	Viskózový hodváb		Závod Mieru – Istrochem Bratislava •••	1951
9.	Polyamidový hodváb (PA 6)		Silon Planá nad Lužnicí	1951
10.	Polyamidová striž (PA 6)		Chemosvit Svit	1951
11.	Viskózový kordový hodváb S_1		Umelé vlákno	1959
	a S_2, kontinuál		SCCHZ Rudník u Hostinného	1962
12.	Polyamidový hodváb (PA 6)		Kapron, pozdejšie Chemlon Humenné *	1959
13.	Polyesterová striž (PET)	7)	Silon Planá nad Lužnicí	1959
14.	Viskózový kordový hodváb S1 a S2	6)	Severočeské chemické závody Lovosice	1960
15.	Polyamidový kordový hodváb (PA 6)		Chemlon Humenné ***	1962
16.	Polyamidová striž (PA 6)	8)	Chemosvit Svit	1963
17.	Mikrovlákna – filtračná hmota (PVC)		Slovenské lúčobné závody Hnúšťa	1964
18.	Polypropylénová striž a technický hodváb (PP)	9)	Chemosvit Svit	1955
19.	Polypropylénové vlákna (PP)	10)	Slovenské lúčobné závody Hnúšťa	1967
20.	Polyamidový kobercový káblik (PA 6)		Chemlon Humenné	1969
21.	Polypropylénová striž a technický hodváb (PP)		Istrochem (CHZJD)	1970
	Polyesterový hodváb (PET)		Slovenský hodváb Senica	1970
22.	Polyamidový káblik (PA 6)		Chemosvit Svit	1972
23.	Vysokopevný polyamidový kordový hodváb (PA 6)		Chemlon Humenné	1975
24.	Polypropylénový káblik (PP)		Istrochem (CHZJD) Bratislava	1975
25.	Polyetylénové rúno Texizol (PE)		Tatraľan Kežmarok	1976
26.	Polypropylénové rúno Tatratex (PP)		Tatraľan Kežmarok	1977
27.	Polyesterový hodváb		Chemlon Humenné	1977
28.	Polypropylénová striž (PP)	11)	Istrochem (CHZJD) Bratislava ••	1979
29.	Polypropylénový hodváb (PP)		Chemosvit Svit	1980
30.	Polypropylénový káblik (PP)	12)	Istrochem (CHZJD) Bratislava •	1981
31.	Polyesterový technický hodváb (PET)		Slovenský hodváb Senica	1986
		13)	Slovenský hodváb Senica	1992,
			****	1998

Komentár k Tab. 4

1) Spracovanie viskózového hodvábu vyrábaného v Senici, ktorá zanikla v r. 1935
2) V r.1953 výroba hodvábu prebudovaná na viskózový kordový hodváb odstredivkový a v r.1959 na kontinuálny pôsob prípravy
3) Po r.1960 výroba odstavená
4) Striž v r.1967 a hodváb r.1980 odstavená výroba
5) Vistra odstavená v r.1979
6) V r.1960 zavedená výroba na KVKH-36 kordového hodvábu Super 1 (S_1) a v r.1963 Super 2 (S_2)
7) V r.1966 zavedená kontinuálna výroba prvá časť, a v. r.1971–1972 druhá časť výroby
8) Kontinuálna polymerizácia a zvlákňovanie na cievky a káblikové dĺženie
9) Výroba strižе odstavená v r.1972
10) Pôvodná výroba PP-gumožine prerobená na PP striž a v r. 1984 odstavená z dôvodov veľkovýrob PP vlákien v Istrocheme (CHZJD)
11) Veľkokapacitné linky
12) Veľkokapacitná výroba
13) Veľkokapacitná výroba zavedená v r. 1992

* teraz Nylstart, ** výroba odstavená v r. 2000, *** teraz Rhodia, po r.1998 zavedená výroba PA 66, **** rozšírenie kapacity
• po r. 1993 inovácia výroby, •• po r.1993 inovácia výroby a rozšírenie sortimentu, ••• Výroba odstavená po r.1995

- Po r. 1992 došlo k inovácii výroby sortimentu vlákien PP, PET, PA

Veľká pozornosť vo výskume bola venovaná zámerným fyzikálno-chemickým modifikáciám základných typov vláknotvorných polymérov a vlákien a novým postupom prípravy vlákien.

V oblasti celulózových vlákien výskum bol zameraný na prípravu nových typov viskózových strižových vlákien ako je vysokopevná, vysokomodulová a polynozická striž a tiež ich príprava na báze domácej bukovej buničiny. Nemalá pozornosť vo výskume bola orientovaná na prípravu celulózových vlákien bezsírouhlíkovým postupom pomocou derivátov celulózy a nových rozpúšťadiel celulózy. V príprave vysokopevných viskózových kordov smerovanie výskumnej činnosti bolo na vývoj technológií pre vyššie generácie týchto vlákien (Super 1, Super 2, Super 3), ktoré boli reprezentované vyššími pevnosťami, modulmi pružnosti a ostatnými úžitkovými vlastnosťami. Bola vyriešená a realizovaná regenerácia Zn pri tejto výrobe.

U viskózového hodvábu pripraveného kontinuálnym spôsobom bola riešená technológia prípravy pri zvýšených rýchlostiach zvlákňovania, rovnomernosti vlastností, zušľachťovacieho procesu spracovateľnosti, bezzákrutového typu, preparácii ekologicky nezávadných a vlákien o rôznej jemnosti. U klasických postupov prípravy viskózového hodvábu výskumná činnosť bola zameraná na znižovanie spotreby a regeneráciu sirouhlíka, farbenie vo hmote, zníženie jemnosti, zvyšovanie životnosti zvlákňovacích hubíc, rovnomernosti vlastností a poslednú dobu overovanie bezsírouhlíkových postupov prípravy hodvábu (karbamát celulózy) a nové rozpúšťadlá celulózy.

U polyesterových vlákien boli práce zamerané na prípravu modifikovaných typov vlákien zmenou molekulovej štruktúry, ďalej jemných a mikrovlákien, farbenie vo hmote na vlákna pre nové generácie pórométrov, nové postupy prípravy objemných priadzí a na prípravu vlákien na báze aromatických kopolyesterov, ďalej na vysokorýchlostné zvlákňovanie a prípravu profilovaných a dutých typov vlákien.

U polypropylénových vlákien v oblasti modifikácie hlavná pozornosť bola sústredená na riešenie tepelnej a svetelnej stability, farbenie vo hmote a farbenie z roztoku farbív, príprava veľmi jemných a mikrovlákien, zmesných vlákien, profilovaných a dutých typov, vlákien so zníženou horľavosťou a bakteriostatických, vlákien pre riešenie čistenia ovzdušia, povrchových a odpadných vôd (EKO-vlákna), filtračných materiálov, príprave vysokopevných vlákien a vlákien pre nové generácie pórometrov a príprave káblikov na báze mechanických zmesí PP/PA, PP/PE, PP/PET a využitie novej generácie PP polymérov najmä metalocenových na prípravu vysokopevných vlákien.

U polyamidových vlákien bola výskumná činnosť orientovaná na riešenie farbenia v hmote u káblikových typov, termostabilite, rôznym spôsobom tvarovania, príprave objemných priadzí, jemných a mikrovlákien na báze zmesných polymérov, najmä pre nové generácie pórométrov a príprave vlákien z aromatických polymérov.

Realizované výsledky vlastného výskumu a vývoja v našich podnikoch umožnili odpredať licencie, technológie a zariadenia do zahraničia na :

- výrobu vysokopevných viskózových kordov do bývalej NDR v r. 1964 a PĽR v r. 1966
- výrobu polyamidového kordového vlákna Ukrajine v r. 1967
- výrobu polyamidového káblika do Rumunska v r. 1968
- výrobu polyamidového vysokopevných vlákien pre siete do ČLR v r. 1963
- výrobu rúna z polyamidu do bývalej NDR v r. 1967
- prípravu farebných koncentrátov do Švajčiarska
- kontinuálne filtre tavenín polymérov do NSR
- technológiu späť získavania Zn pri výrobe viskózových kordových vlákien do bývalej NDR
- dokumentácia na kontinuálne stroje pre výrobu viskózového hodvábu NSR.

Z uvedeného prehľadu vyplýva, že vlastné kapacity výskumu a vývoja prispeli veľkým podielom k budovaniu nových výrob chemických vlákien u nás.

V šesťdesiatych rokoch, keď nastúpil prudký rozvoj syntetických vlákien vo svete, dochádzalo k úzkemu spojeniu strojárskych firiem s vláknarským výskumom a vývojom. Toto spojenie umožnilo vyvinúť širokú škálu moderných strojno-technologických zariadení na výrobu chemických vlákien. U nás po r.1968 sa podarilo len čiastočne uskutočniť prepojenie výskumu a vývoja technológie a zariadenia s partnermi čsl. Strojárstva. Z týchto dôvodov bolo rozhodnuté, že určité druhy chemických vlákien budú budované zakúpením licencie, know-how a zariadení zo štátov s vyspelou strojárskou a vláknárskou výrobou. Vlastné výskumné a vývojové kapacity po uvedenom období boli orientované na vývoj kontinuálnych strojov a technológie na prípravu viskózového hodvábu a viskózovej striže, PA striže, káblika a technického hodvábu a vývoj dĺžiaco-skacích strojov pre vysokopevné PA vlákna, ďalej pre všetky druhy PP vlákien (s čiastočným doplnením zariadenia zo zahraničia) a pre prípravu PET technického hodvábu, ďalej pre prípravu netkaných materiálov z PP, PE a PA pre výrobu špeciálnych druhov vlákien a vláknitých materiálov.

Nákup licencií, know-hov a techniky pre prípravu chemických vlákien bolo realizované najmä s firmami :

- ICI Anglicko, Zimmer NSR, Teijin Japonsko, AKZO Holandsko, Barmag NSR, Plantex Taliansko, Fleissner NSR, Neumag NSR, Allied Chemical USA.

Uplatnenie výsledkov vlastného výskumu a vývoja v rozvoji výroby chemických vlákien u nás sa opieralo o vysokú technickú kvalifikáciu pracovníkov pôsobiacich v oblasti chemických vlákien. V priebehu 50-ročnej činnosti bolo udelené okolo 2 000 patentov, z ktorých značná časť bola realizovaná doma i v zahraničí. V odbore vlákien u nás bolo publikované cca 95 monografií a učebných textov, cca 3 500 publikácií v domácich a zahraničných periodikách.

Dobrá vedecká a technická úroveň našich pracovníkov sa prejavila i v účasti s cca 1200 prednáškami na kongresoch, konferenciách a sympóziách na domácich a zahraničných fórach. [1,19,20,24–114] Vydávanie našich časopisov Chemické vlákna, Textilná chémia, a Textil umožňovali dobrú prezentáciu našich prác. V tomto období vychádza časopis Vlákna a textil, v ktorom sa publikuje prevážna časť príspevkov v anglickom jazyku, čo umožňuje väčšiu propagáciu v zahraničí.

Od založenia zamerania chemických vlákien na CHTF STU v Bratislave bolo vychovaných 760 inžinierov pre potreby priemyselných organizácií t.j. výrobcov vlákien a vláknitých materiálov a pre výskumné a vývojové organizácie.

Katedra vlákien v spolupráci s VÚCHV pripravili 72 CSc. (PhD) a 2 DrSc. V odbore vlákien a textilu (technológia makromolekulových látok) habilitovalo 12 Doc. a 3 Prof.

Absolventi CHTF so zameraním chemických vlákien v predchádzajúcom období tvorili základné piliere vo výrobných podnikoch chemických vlákien, VÚCHV a v ďalších príbuzných výskumných a vývojových inštitúcií. Absolventi tohoto zamerania i v tomto období predstavujú veľký technický potenciál, ktorý umožňuje i udržať produkciu chemických vlákien na Slovensku v silnej medzinárodnej konkurencii a vplyve globalizácie.

Výroba chemických vlákien v doterajšom rozvoji na Slovensku a v Čechách mala veľký význam pre národné hospodárstvo. Podstatne ovplyvnila štruktúru textilného priemyslu a ostatných odvetví národného hospodárstva. Rozvoj výroby vlákien sa opieral o silný technický potenciál tvorený VÚCHV, VVZ s technickými útvarmi podnikov, CHTF SVŠT Katedru vlákien a textilu, VŠCHT v Pardubiciach, ÚZCHV, VÚTCH, ÚP SAV, ÚMCH ČSAV, VÚP. VÚV, VÚB, VÚLV, VÚMCH a o ďalších VŠ a VÚ na Slovensku a Čechách.

Doterajší rozvoj chemických vlákien i vlastná vedecká a výskumno-vývojová činnosť obohatila našu spoločnosť produktami širokej spotreby, mala veľký ekonomický prínos, zvýšila sa zamestnanosť a riešila i reštrukturalizáciu výrob v niektorých lokalitách, čím prispela k ich ozdraveniu. Najcennejšou devízou sú však vedomosti, ktoré by sa mali zúročiť v ďalšom období.

Dôležitým faktorom, ktorý už v tomto období podmieňuje i rozvoj vlákien je celosvetová globalizácia, ktorá vyvoláva koncentráciu výrobcov vlákien a integráciou výrobných odborov, t.j. vertikálne prepojenie od výroby monomérov, polyméru, výroby vlákien a odborov ich aplikácie. Tento proces by sa mal vhodne využiť jednak v rámci Slovenska a v medzinárodných vzťahoch s cieľom využiť náš technický potenciál pre zachovanie progresívnych výrob.

5. ZÁVER

Rozvoj chemických vlákien na Slovensku má predpoklady predovšetkým u PES, PA, PP a celulózových vlákien, ich špeciálnych typov, najmä pre technické textílie.

Zakladateľom výučby chemických vlákien na CHTF SVŠT a jej budovateľom pedagogického a vedecko–výskumného potenciálu vyslovujeme vďaku a úctu. Rovnako budovateľom VÚCHV Svit a jej pracovníkom, ktorí svojou činnosťou zabezpečovali výskum a vývoj procesov prípravy vlákien a realizácie v priemyselnej výrobe patrí naša úcta a vďaka.

6. LITERATÚRA

1. Jambrich,M., Marcinčin,A., Budzák,D., a iní : „História rozvoja chemických vlákien na Slovensku a v Čechách“ KP CHTF STU Bratislava 1996
2. Fiber Organon, Vol. 71, No.6, June 2000
3. Johnson,T.: Chemical Fibers International, 49, December (1999), pp. 455–459
4. Yamanaka: Chemical Fibers International, 49, December (1999), pp. 501–503
5. An.: Chemical Fibers International, 50, April (2001), pp. 104–105
6. Colin M. Purvis: „Der Herausforderung begenen – Die europäische Chemiefaser – und Textillindustrie an der Jahrtansende“ 39. Chemiefasertagung, 13–15.Sept. 2000 Dornbirn/Austria
7. Ji Guobiao: „ The – Man-made Fiber and Textile industry in China“ 39. Internationale Chemiefasertagung, 13.–15. Sept. 2000 Dornbirn/Austria
8. Matsuzaki, M.: „Japanese Man-made Fiber and Textilie Industry Toward 21 st Century“ 39. Internationale Chemiefasertagung, 13.–15. Sept. 2000, Dornbirn/Austria
9. Schenek, A.: „Production of Natural Fibers at the Turn of the Milleneum “ 39. Internationale Chemiefasertagung, 13.–15. Sept. 2000, Dornbirn/Austria
10. Whitaker, P.B.F., Gandhi, K.L.: „Man-made Fibers – the next Generation“ 39. Internationale Chemiefasertagung, 13.–15. Sept. 2000, Dornbirn/Austria
11. Koslowski, H.-J.: Technische Textilien, 43. August (2000), s. 161
12. An.: „ Polyolefinfaser – Kapazität 7 Mill. t “ Technische Textilien, 43. August (2000), s.162–163
13. Bürger, H.: Technische Textilien, 43. August (2000) s. 164–166
14. Nywlt, M.: „Schnellspinnen Viscose Filament, Die wirklichen Grenzen“ 39. Internationale Chemiefasertagung, 13.–15. sept. 2000, Dornbirn/Austria
15. Dartee, M.: „Nature Works PLA: A Sustainable Performace Fiber“ 39. Internationale Chemiefasertagung, 13.–15. sept. 2000, Dornbirn/Austria
16. Schäfer, K.: „New economical Technologies for the Production of textile PES filament Yarns“ 39. Internationale Chemiefasertagung, 13.–15. sept. 2000, Dornbirn/Austria
17. Bürger, H.: „Alternative clellulose, Herstelen Verformen und Eigenschaften“ 4. Internationale Symposium, 6.–7. 9. 2000

TITK Rudostadt BRD

18. Hu, x.: „Aktuelle Marktsituation für LYOCELL – Fasern in der Volksrepublik China“
Klemm, D. Udhardt, U., Schumann, D., Morsch, S.: „Cellulose – Biomateriälen durch supramolekulares Strukturdesing“
Weigel, P., Fink, H. – P.: „Verwendung alternativer Zellstoffe im NMMO – Verfahren“
Michels, CH. ,Kosan, B.: „Das LYOCELL – Verfahren gegonwärtige Leistungs grenzenaus stofflicher und technologischer sicht“
Luo, M., Roscelli, V., Neogi, A., Sealey, J., Jewell, R.:„High Yield Lyocell Pulp from the Kraft Proces“
Woodings, C.: „LYOCELL STAPLE FIBRE IN INDUSTRIAL APPLICATIONS“
Riedel, B., Taeger, E.: „ Cellulosische Matrixfibrillenfäden“ 4. Internationales Symposium – Alternative Cellulose, 6. – 7. Sept. 2000 Rudolstadt – Schwarza Thüringen BRD
19. Jambrich, M. Sroková, J., Čema, J., Jambrich, P., Lučivjanský, J., Michlik, P.: „THE DEVELOPMENT OF FIBRES FOR TECHNICAL TEXTILES“
Urbanowski, A.: „ Progres in chemical Fibres“ THE FIRST CENTRAL EUROPEAN CONFERENCE ON FIBRE GRADE POLYMERS, CHEMICAL FIBRES AND SPECIAL TEXTILES, 3.–4. Okt. 2000 LÓDŽ Poland
20. Ciechańska, D., Struszczyk, H., Guzińska, K., Wawro, D.: „Biotechnological Methods for Manufacture of Cellulosic Fobres, Film and other Products“
Struszczyk, H.: „Some Aspekcts of the Modification of Natural Polymers“
Murárová, A., Hodul, P., Jambrich, M.: „Geometric Modification of PET Fibres on Dyeing“
Perepelkin, K.E.: “Principal physics – chemical and Technological Regularities of Fiber formation and New Ways of Chemical Fibres Forming Processes Development„
Matchalaba, N.N, Perepelkin, K.E.: Aramide Fibres Development – Today and Future
Heineman, K., Mensel, E., Seyfarth, H.E., Taeger, E.: „Reactive – LCPs as Blend Component in Polyamid and Polyester Fibres„
THE FIRST CENTRAL EUROPEAN CONFERENCE ON FIBRE GRADE POLYMERS, CHEMICAL FIBRES AND SPECIAL TEXTILES, 3.–4. Okt. 2000 LÓDŽ Poland
21. Klatt, R.,Chodák, L., Ríša, V. a iní: „Výroba umelých vlákien“, vyd. Práca, Bratislava 1949
22. Romanov, A., Jambrich, M., Diačik, I., a iní: „Polypropylén“, vyd. SVTL, Bratislava 1965
23. Klatt, R.,: Polyamidové vlákna, SVTL, 1959, Bratislava
24. Kolektív VÚCHU: Výroba a spracovanie polypropylénu, VÚCHV, 1966, Svit
25. Lacko, V.: Polyesterové vlákna, SVTL, 1959, Bratislava
26. Lacko, V.: Výroba a vlastnosti polyesterových vlákien, ALFA, 1968, Bratislava
27. Wiesner, E.: Akrylové vlákna, SVTL, 1959, Bratislava
28. Beseda, V.: Výroba viskózového hodvábu, Práca, 1950, Bratislava
29. Tomašovič, Š.: „Príručka vláknara“, Vyd. SVTL, Bratislava 1960
30. Fabka,K.: Modifikácia a farbenie, VÚCHV, 1964, Svit
31. Jambrich, M.: Fyzikálne metódy pre výskum vlákien, VÚCHV Svit, CHTF SVŠT, Bratislava, 1969
32. Jambrich, M.: Základné vzťahy pri príprave vlákien, ES SVŠT, 1971, Bratislava
33. Jambrich, M.: Štruktúra a vlastnosti vlákien, ES SVŠT, 1982, Bratislava
34. Jambrich, M., Diačik, I.: Príprava nových a modifikovaných druhov vláken, Inštitút pre výchovu ved. pracovníkov – ZZCHP Slovchémia, 1984, Bratislava
35. Jambrich, M., Pikler, A., Diačik, I.: Fyzika vlákien, ALFA, 1987, Bratislava
36. Hodul, P., Jambrich, M., Marcinčín, A.: spoluautori knihy POLYPROPYLENE AN A–Z REFERENCE, EDITED BY y. KARGER, KLUWER, ACADEMIC Publishers Dordrecht / Boston/ London, 1999
37. Foltýn, J.: „Praktická príručka pre vláknara“, vyd. SNTL, 1975, Praha
38. Foltýn, J., Pospíšil, Z.,Suchomel, Z.: „Technické textílie ve stavebníctví“,vyd. SNTL, 1984, Praha
39. Fučík,J.: „Tex. techn. encyklopédia“, vyd.TN, 1948, Brno „Teória a prax spriadania“,vyd. PV, 1951, Praha
40. Hladík, V.: „Textilné vlákna“, vyd. SNTL, 1970, Praha
41. Beťko: „Skúšanie textílií“, vyd. ALFA, Bratislava, 1980, „Skúšanie Textílií“, SVŠL, Bratislava, 1961
42. Blažej, A. a iní: „Štruktúra a vlastnosti vláknitých bielkovín“, vyd. ALFA, 1978, Bratislava
43. Blažej, A., Šutá, Š.: „Vlastnosti textilných vlákien“, vyd. ALFA, 1982, Bratislava
44. Blažej,A., Hodul,P., Prchal,V., Očadlík,J., Markušovská,E.: „Špeciálne chemické úpravy textílií“, vyd. ALFA, 1986, Bratislava
45. Čapek, J.: „Textilné vlákna“, vyd. Práca, 1951, Praha
46. Čirlič, J.: „Veda a výskum v textilnom priemysle“, vyd. VÚP Brno, 1972
47. Černjak, V.: „Fyz. techn. vlastnosti vlákien“, vyd. PV, 1951, Praha
48. Lapšanská, A., Šutá, Š., Dubasová, A.: „Chemické vlákna“, vyd. ALFA, Bratislava, 1986
49. Chalupský, J., Blažek, J.: „Polyamidové vlákna„ , vyd. SNTL, 1962, Praha
50. Ježek, J.: „ Spracování PES vláken“, vyd. SNTL, 1969, Praha
51. Kébl, F.: „Viskózový kordová hodváb“, vyd. SPN, 1962, Praha
52. Kébl, F.: „Technológie chemických vláken“, vyd. SNTL, 1977, Praha
53. Klatt, R., Chodák, L., Kébl, F., Ríša, V., Liška,L., Šorel, A., Nesvadba, A., Štepan, M., Volek, J.: „Výroba umelých vlákien“, vyd. Práca, 1949, Bratislava
54. Kudláček, L., Blažek, J., Lauruský, K.: „Technológia“, vyd. ALFA, 1983, Bratislava
55. Kryštufek, J., Militký, J.: „Barvení akrylových vláken“, vyd. SNTL, 1986, Praha
56. Lesyková, A.: „Přehled chemických vláken„
57. Lodesová, D.: „Vlákna na báze prírodných polymérov“, vyd. ES SVŠT, 1983, Bratislava
58. Marcinčin, A.: „Procesy prípravy syntetických vlákien“, vyd. ES SVŠT, 1989, Bratislava
59. Mihalik, B., Farkašová, K.: „Ručne farbené a matované textílie“, vyd. ALFA, 1983, Bratislava
60. Miklas, Z.: „Polyesterová vlákna“, vyd. SNTL, 1974, Praha
61. Militký, J., Vaníček, J., Kryštufek, J., Hartych, V.: „Modifikovaná polyesterová vlákna“, vyd. SNTL, 1984, Praha
62. Pajgrt, O., Reichstädter, B. a iní: „Polyesterová vlákna“, vyd. SNTL, 1973, Praha
63. Pajgrt, O., Reichstädter, O., Ševčík, F.: „Polypropylénová vlákna jejich vlastnosti, textilní zpracování a užití“, vyd. SNTL, 1977, Praha
64. Pikler, A.: „Chemické a fyzikálne procesy prípravy syntetických vlákien“, vyd. ES SVŠT, 1979, Bratislava
65. Pikler, A.: „Základy modifikácie chemických vlákien“, vyd. ES SVŠT, 1985, Bratislava
66. Pikovský, D. J.: „Nová technika v textilnom priemysle“, vyd. Práca, 1961, Praha
67. Pikovský, D. J.: „Textil budúcnosti“, vyd. SNTL, 1977, Praha
68. Piller, B.: „Bulked Yarns, Production, Processing and Aplication“, vyd. SNTL, 1973, Praha
69. Piller, B. a kol.: „Syntetická vlákna“, vyd. SNTL, 1967, Praha

70. Piller, B., Trávniček, O.: „Syntetická vlákna I., II., III.,“, vyd. SNTL, 1956, Praha
71. Poliščuk, I.: „Len a konopí“, vyd. PV, 1952, Praha
72. Pospíšil, Z. a iní: „Textilní příručka“, vyd. SNTL, 1965, Praha
73. Řepňák, O.: „Výroba viskózového hedvábí“, vyd. SNTL, 1966, Praha
74. Robinson, I.: „Nekrčivá úprava textílií“, vyd. SVŠL, 1961, Bratislava
75. Rychlík, V.: „Stroje a zařízení ve výrobě chemických vláken“, vyd. SNTL, 1981, Praha
76. Stoy, A., Novotný, J.: „Nové syntetické vlákna“, vyd. SNTL, 1953, Praha
77. Šedivý,J., Blažek, J.,Vondrák, J.: „Technológia chemických vlákien“, vyd. ALFA, 1972, Bratislava
78. Táborský, L., Šebo, P.: „Konštrukčné materiály spevnené vláknami“, vyd. ALFA, 1982, Bratislava
79. Trávniček, B.: „Vlákna budúcnosti“, vyd. TL, 1958, Brno
80. Tomáš, V.: „Rozvoj chemických vlákien v ČSSR„. In: Zborník „Príspevky k histórii chemického priemyslu SSR“, zväzok č.8, január 1990, s.108–122 ČSVTS, SVSPCH, pobočka ČSVTS pri k.p. Slovnaft Bratislava
81. Jambrich, M., Murárová, A., Štupák, A., Jambrich, P., Lalík, J., Klátik, J.: Ropa a uhlie - Slovnaft dnes. 37,1,1995, s. 72–77
82. Ďurčová, O., Gróf, I., Jambrich, M.: Polymer Testing, 11, 1992, s. 193
83. Šimo, R.: Chemické vlákna XXXIX., č. 3,1989, s.73
84. Ríša, V.: Výroba chemických vlákien, CHTF SVŠT, Bratislava, 1952
85. Pikler, A., Jambrich, M., Pavlačka, E.: Chemické a mechanické skúšky celulózových a syntetických vlákien, CHTF SVŠT, Bratislava, 1954
86. Pikler, A., Jambrich, M., Pavlačka, E.: Cvičenie z technológie umelých celulózových vlákien, CHTF SVŠT, Bratislava, 1954
87. Chodák, L.: Technológia výroby chemických vlákien, CHTF SVŠT, Bratislava, 1957
88. Pikler, A.: Makromolekulárna chémia celulózy a jej derivátov, CHTF SVŠT, Bratislava, 1962
89. Pikler, A.: Syntéza a procesy spracovania vláknotvorných polymérov I.,II., CHTF SVŠT, Bratislava, 1968
90. Marcinčin, A.: Seminárne cvičenie z makromolekulovej chémie, Inštitút pre výchovu vedúcich pracovníkov združených závodov chemického priemyslu - Slovchémia, Bratislava, 1970
91. Pikler, A.: Základy reológie tavenín vláknotvorných polymérov a procesy zvlákňovania, Inštitút pre výchovu vedúcich pracovníkov združených závodov chemického priemyslu – Slovchémia, Bratislava, 1971
92. Pikler, A., Ondrejmiška, K., Šimo, R., Marcinčin, A.: Modifikácia vláknotvorných polymérov a chemických vlákien, Inštitút pre výchovu vedúcich pracovníkov združených závodov chemického priemyslu – Slovchémia, Bratislava, 1971
93. Očadlík, J., Markušovská, E., Hodul, P.: Laboratórne cvičenia z predmetov textilnej chémie, ES SVŠT, Bratislava, 1980
94. Jambrich, M.: Štruktúra a vlastnosti vlákien, ES SVŠT, Bratislava, 1982
95. Svitek, J.: Základy polymérneho inžinierstva, ES SVŠT, Bratislava, 1982
96. Sroková, I.: Návody pre laboratórne cvičenia z koloristiky, ES SVŠT, Bratislava, 1982
97. Prchal, V., Hodul, P.: Chemické technológie textilu, ES SVŠT, Bratislava, 1983
98. Markušovská, E., Líška, M.: Skúšobníctvo, ES SVŠT, Bratislava, 1983
99. Jambrich, M.: Vývojové tendencie chemických vlákien vo svete, Inštitút pre výchovu vedúcich pracovníkov združených závodov chemického priemyslu – Slovchémia, Bratislava, 1983
100. Očadlík, J.,Markušovská, E.: Textilné vlákna, ES SVŠT, Bratislava, 1984
101. Lodesová, D.: Základné procesy prípravy celulózových vlákien, Inštitút pre výchovu vedúcich pracovníkov združených závodov chemického priemyslu - Slovchémia, Bratislava, 1984
102. Marcinčin, A., Ondrejmiška, K.: Farbenie syntetických vlákien v hmote, Inštitút pre výchovu vedúcich pracovníkov združených závodov chemického priemyslu – Slovchémia, Bratislava, 1985
103. Blažej, A., Szilvová, V.: Prírodné a syntetické polyméry, ES SVŠT, Bratislava, 1985
104. Šutá, Š.: Laboratórium odboru II. Textilné a úžitkové vlastnosti, ES SVŠT, Bratislava, 1985
105. Pikler, A.: Chemické a fyzikálne procesy prípravy syntetických vlákien, ES SVŠT, Bratislava, 1986
106. Lodesová, D.: Laboratórium odboru II. Vlákna na báze prírodných materiálov, ES SVŠT, Bratislava, 1987
107. Sroková, I.: Koloristika, ES SVŠT, Bratislava, 1987
108. Svitek, J.: Laboratórium odboru I. Procesy prípravy syntetických vlákien, ES SVŠT, Bratislava, 1987
109. Krištofovič, M.: Laboratórium odboru I. Syntéza a vlastnosti vláknotvorných polymérov, ES SVŠT, Bratislava, 1989
110. Militký, J., Hartych, V., Vaníček, J., Kryštofek, J.: „Modified Polyester Fibres“, Internat. 1991, Praha

WATER-DILUTABLE COATINGS DERIVED FROM POLYESTERS FOR TEXTILE USE

Adler, H-J.*, Jansen, I.*, Hardtke, G.**, Fuchs, H.**

**Dresden University of Technology, Institute of Macromolecular Chemistry and Textile Chemistry,*
Mommsenstr. 13, D-01062 Dresden

***Saxon Textile Research Institute, Annaberger Straße 240, D-09125 Chemnitz*

1. INTRODUCTION

Technical textiles were coated on a large scale with the goal of obtaining waterproof and strengthened textiles. Applications among other things are technical tarpaulins for buildings and vehicles as well as tents, conveyor belts and home textiles.

Despite the outstanding price-performance ratios of PVC-coatings (Fig. 1) on technical textiles there is increasing interest in alternatives which do not contain chlorine, because of their ecological acceptance. PVC is being discussed, because it is suspected, that the monomeric vinylchloride is carcinogenic and there are problems with the recycling process due to the chlorine. Hydrogen chloride is released and the building of dioxine is possible under unfavourable conditions. Chlorine-free coatings, for instance polyacrylates and polyurethanes, have already been successful applied in some special fields[1-3].

However, the new replacement coatings with equivalent properties to those of PVC, have not been able to achieve the economic efficiency of PVC-plastisoles. The properties of PVC-plastisoles have only been reached, after the addition of additives, such as coupling agents, softening agents and anti-agers. These products are able to diffuse out of the coatings and they are partly toxic. The advantages and disadvantages of PVC-, PUR- and acrylate-binders are outlined in tab. 1.

The project behind the new technique, which will be discussed, involves the so called water varnish technology for metal and wood coatings. In water varnish technology, water dilutable polymer binders are able to

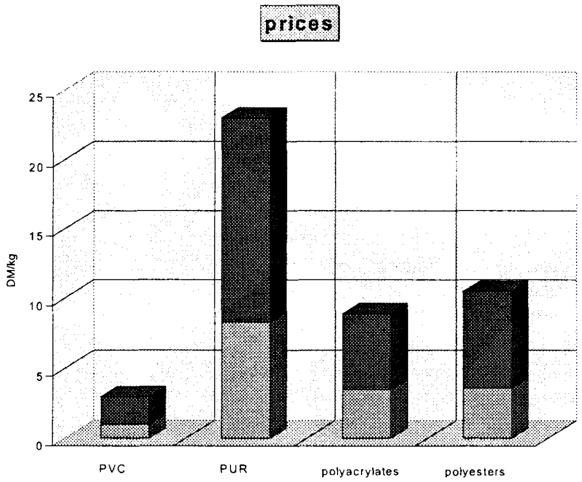


Fig. 1 Prices of binders (March 97, Germany, from: Farbe Lack 1998, 98 (3), 2; without PVC)

Table 1 Advantages and disadvantages of already used binders

binders	advantages	disadvantages
PVC-plastisole	• good price-performance ratios • simple processing • broad application • non-ageing • weldable	• problems by the recycling process (it is not possible to completely seperate the coatings from the support) • danger of dioxine formation by uncontrolled burning • formation of hydrogen chloride during thermal disposal • good properties obtained only after the addition of additives (coupling agents, softening agents, anti-agers)
polyurethane-dispersions	• high extension at break and elasticity • good wear properties of clothes • good abrasion resistance • high flexibility at low temperatures (without softening agents) • low specific weight • wash and try cleaning resistance	• high price • possibility of recycling is restricted • disposal through burning • defects in the waterproofness
polyacrylate-dispersions	• good weatherability • good light fastness • resistent to bacteria and moulds	• high price • tendency towards stickiness • disposal through burning • defects in the waterproofness

form durable coatings on the substrate through chemical crosslinking.

With a 34 % share of the market polyester is the leading manmade fibre for technical textiles in West Europe.

Because of the similarity between the coating and the supporting material, polyester containing polymers should be given priority. These polymers have a good adhesion to the textile support and the coated textiles can be recycled easily.

The problem involves the formation of coatings, which have the necessary elasticity for textiles, while maintaining both the water and light stability. This can be achieved through the crosslinking process.

2. SYNTHESIS, CROSSLINKING AND COATING

Binders for the coatings were formed through the melt condensation of aliphatic dicarboxylic acids and glycols. After the addition of amines salts were formed, which are water soluble. Low molecular polyesters cannot be cured by a physical process (Fig. 2), they must be cured by a chemical process (Fig. 3). We describe in this paper thermal and radiation hardening$^{4-6}$.

The thermal crosslinking took place with different melamine resins at a temperature of 170 °C.

Through optimization of the composition of the starting mixture as well as the crosslinking strategy, it was possible to form highly elastic and water stable coatings on technical textiles.

The universal hardness of the crosslinked binders was determined with the Fischerscope H 100$^{7-11}$. Apart from the hardness it is possible to calculate further parameters, e.g. the elastic deformation (Fig. 4, 5).

Coatings for technical textiles should have a low hardness and a high elasticity.

The coating of polyester resins on polyester textiles and the thermal hardening was made with a continously coating line (Mathis, Swiss, Fig. 6).

The coatings have almost the same properties as PVC (Fig. 7–9) without the use of additives.

In addition to the thermal crosslinking with melamine resins suitable binders have been crosslinked with ultraviolet irradiation. Figure 10 showes the problems of heat- and UV-curing.

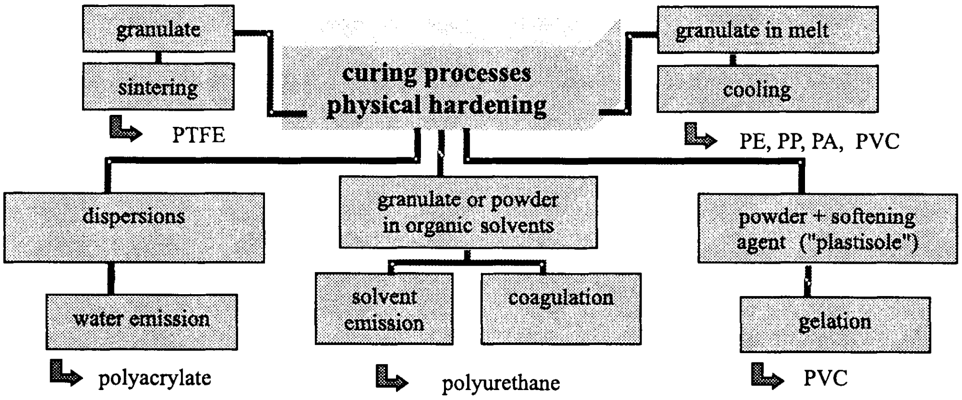


Fig. 2 Physical hardening

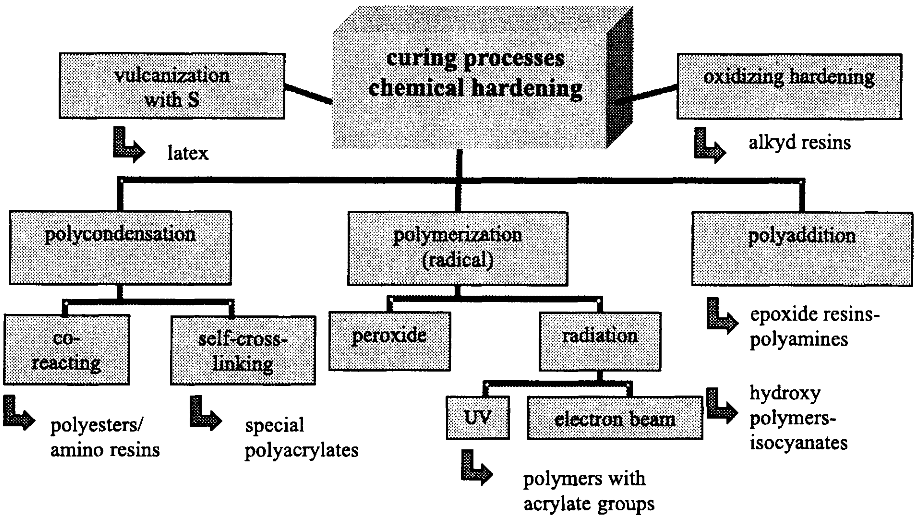


Fig. 3 Chemical hardening

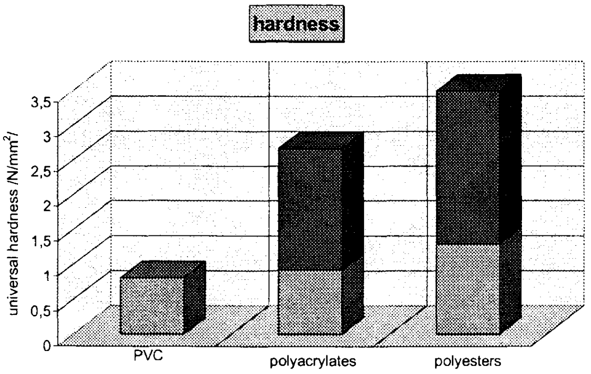


Fig. 4 Universal hardness (Fischerscope H 100) of crosslinked polyesters in comparison with PVC and polyacrylates

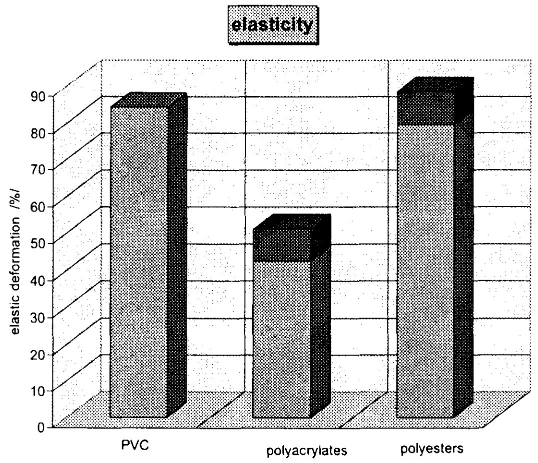


Fig. 5 Elastic deformation (Fischerscope H 100) of crosslinked polyesters in comparison with PVC and polyacrylates

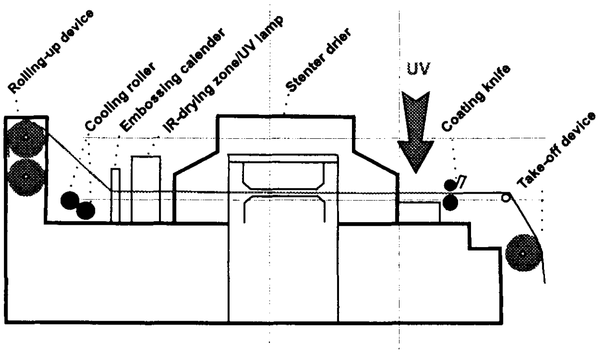


Fig 6 Continously working coating line

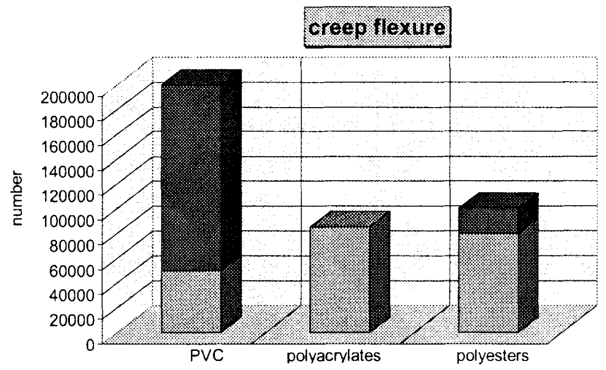


Fig. 7 Creep flexure test of coated polyester fibre fabrics

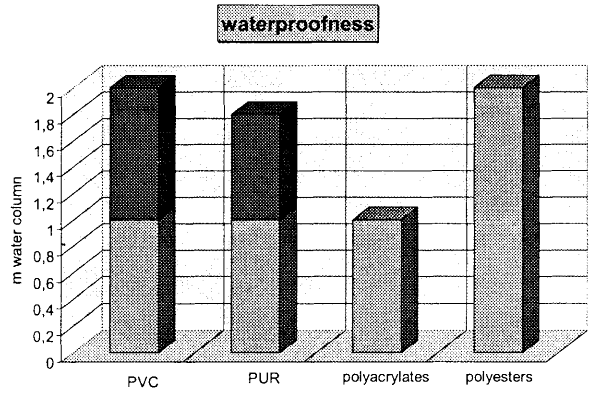


Fig. 8 Waterproofness (hydrostatic pressure)of coated polyester fibre fabrics

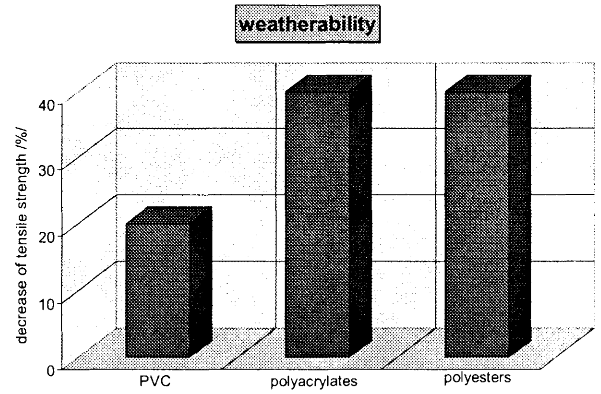


Fig. 9 Weatherability (Xenontest) of coated polyester fibre fabrics (decrease of tensile strength after 3000 h)

The advantages of UV-curing are:

- fast curing and processing,
- low energy consumption,
- high solid content, no solvents or water needed,
- low environmental pollution,
- no heat treatment for drying or curing, suitable for heat-sensitive substrates.

In figure 11 you can see a schema of UV curing.

UV-crosslinkable polyester acrylates or polyurethane acrylates were coated and then hardened with an UV-facility from IST (Germany).

To sum it up it can be said, the flexural strength, low-temperature resistance and processability of the suitable binder systems are comparable. PVC reach good values for the low-temperature resistance, however only after the addition of cold resistant softening agents. In order to obtain a good waterproofness, layer thicknesses of 200 μm are enough in the case of polyesters and acrylates. In the case of PVC layers with a thickness of 450 μm are required.

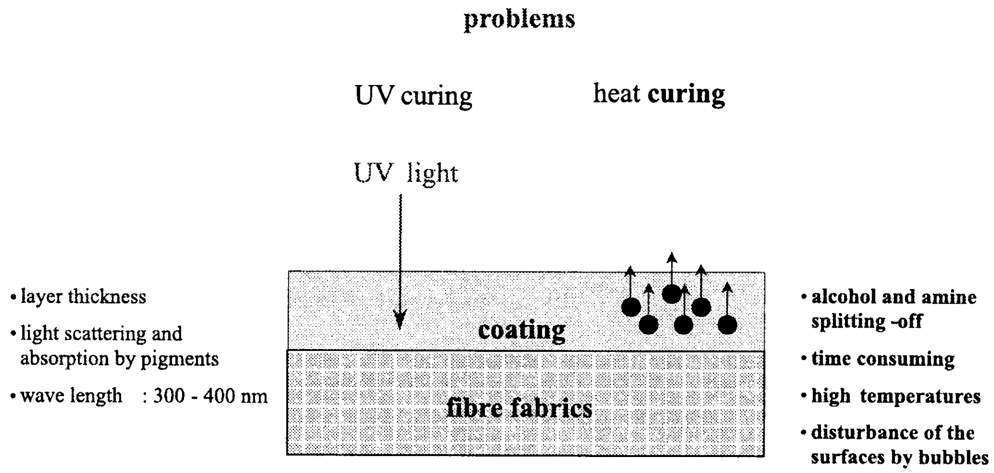


Fig. 10 Problems of UV- and heat-curing

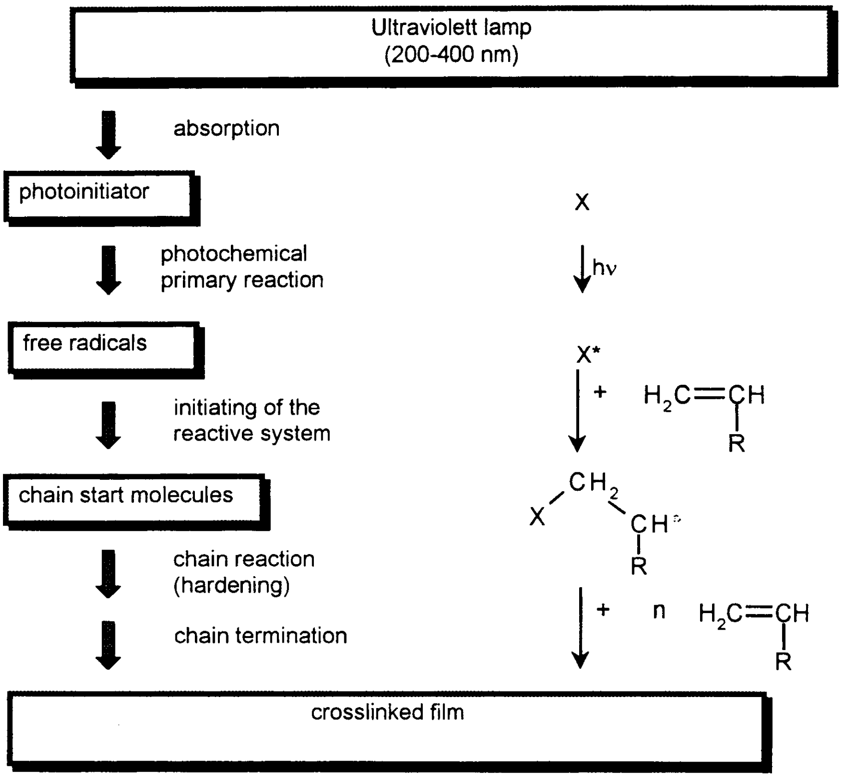


Fig. 11 Schema of UV curing

3. APPLICATION

The binders, that we have developed, could be used in the following applications (table 2). Some preliminary tests are already being carried out in medium sized and small enterprises.

4. SUMMARY

The aim of the research is the development of chlorine-free coatings for polyester textiles. The coatings which are used for tends, carpets and tarpaulins are nowadays PVC. It is not only used because of its good properties but also because of its low price-performance ratio.

For the recycling of technical textiles, it would be advantageous if the textile and the coating are of the same chemical structure.

Polyesters are used in the coating industry as water-dilutable coatings. The films are formed through the reaction with Melamine resins at high temperatures.

These coatings have excellent mechanical properties and good weather resistance. So it is obvious to relate this technique to textile coatings.

Table 2 Applications of produced binders

Applications	Reached properties
light tarpaulins	• waterproof • flexible • good flexibility also at low temperatures
home textiles table covers covers carpet backing	• back side: slip-resistant, top side: waterproof • besides oilproof and soil-repellant, for instance resistent toward inks of ballpoint • use of pile goods for the fixing of knobs (1x back side) • slip-resistant

Therefore, it is necessary to modify the extremely hard and brittle polyester-melamine-films to obtain flexible and elastic coatings for textiles.

If polyurethanes or polyacrylics are combined with polyester the properties of the films can be modified to obtain more flexible and less brittle films.

We synthesized modified polyesters derived from flexible diols and dicarboxylic acids.

The processing conditions, emissions of the water and of the produced alcohol from the crosslinking reaction as well as filmthickness, flexibility, water resistance and the mechanical properties have to be optimized.

We also investigated radiation-curable water-borne systems.

The new coatings have similar properties to the PVC coatings and in some cases they are even better.

Acknowledgement

We thank the Forschungskuratorium Textil e. V. for their financial sponsorship, which originated from funds of the Bundesministerium für Wirtschaft und Technologie (BMWi) via the Arbeitsgemeinschaft industrieller Forschungsvereinigungen "Otto von Guericke" e. V. (AiF).

LITERATURES

1 Tanaka, T.; Ohmikachima, S.; Kitamura, M.; Shimogyo, K. (Dai-Ichi Kogyo Seiyaku Co., Kyoto, Japan); DE 3 543 217 1986

2 Stukenbrock, K.H.: *Melliand Textilber.* 1984, *65,* 756

3 Harris, D.: *J. coated Fabr.* 1995, *24*, 210

4 Dowbenko, R.; Friedlander, C.; Gruber, G.; Prucnal, P.; Wismer, M.: *Prog. Org. Coat.* 1983, *11*, 71

5 Sellmer, H.: *Farbe Lack* 1989, *95*, 324

6 Fries, W.: *Farbe Lack* 1985, *91*, 19

7 DIN 50 359 1997

8 Behncke, H.-H.; Weiler, W.: *Materialprüfung* 1988, *7-8*, 239

9 Weiler, W.; Behncke, H.-H.: *Materialprüfung* 1990, *32*, 301

10 Behncke, H.-H.: *HTM, Z. Wärmebehandlung Werkstofftechnik* 1993, *48*, 3

11 Heermant, C.; Dengel, D.: *Materialprüfung* 1996, *38*, 374

DEVELOPMENT OF TECHNICAL TEXTILES FOR THE SLOVAK TEXTILE INDUSTRY

Šesták, J, Papajová, V.

VÚTCH-CHEMITEX, spol. s r.o., Žilina, Slovak Republic

1. INTRODUCTION

Textile industry belongs to segments with a long tradition in Slovakia. The oldest companies are 80 to 100-year-old, some of them were founded in the 1930s and 1940s. A dynamical development of the segment began in the period of industrialization of Slovakia (mainly knitting mills). The youngest companies were founded in the beginning of 1980s. Number of subjects engaged in textiles increased severalfold after transformation of the Slovak economy due to delimitations, privatization and development of small and middle business. The basis of textile industry consisted of 14 state enterprises (4 in cotton sector, 3 in linen sector, 3 in wool and 4 in knitting sector) in 1989. Nearly 49 000 employees worked in these organizations.

At present, 112 companies with 18 800 employees operate in the field of textile manufacture (organizations with more than 20 employees) in Slovakia according to data of the Slovak Statistical Office. Organizations with 1–19 employees manufacture textiles in amount of further about 2,1 mld. Sk according to estimates. They employ about 5 000 employees. Estimated number of such manufacturing units is 650. The overwhelming number of the subjects and their employees are engaged in the field of knitting manufacture. Structure of subjects of the Slovak textile industry is according to number of employees as follows:

over 1000 employees – 4 companies (2 cotton sector, 1 wool sector and 1 knitting sector)
500–1000 employees – 4 companies
100–500 employees – 11 companies
20–100 employees – 93 companies
1–19 employees – 650 companies

Textile industry belongs to category of middle-sized economic segments regarding share on manufacture of the Slovak industry. It is on the 16th place in the ladder of 28 segments according to the output. Share of textile segment on industrial production of the Slovak Republic decreases permanently (1,87 % in the year 1996, 1,37 % in the year 1999). Total output of the segment decreased in the years 1996–1998, however it shows increase (on the base of receipts from industrial activity) in the years 1999–2000.

Textile segment produces 1,58 % of added value of the industry. Share of the added value on manufacture amounts to 37,6 % in textiles while the average is 32,5 % in the Slovak industry. This index amounts even to 47,1 % in knitting manufacture.

Textile manufacture is on the 10th place from among 28 industrial segments regarding number of employees. The highest employment is in the manufacture of woven cloths. Empolyment decreased by more than 4 500 persons in the segment in the years 1996–1998, it increased slightly in the years 1999–2000.

Share of the segment on export of industry exceeds by 0,62 percentual point position of the segment on manufacture of the industry. The highest export value shows manufacture of knitted fabrics and woven cloths.

A typical assortment of products manufactured by textile industry is as follows:

- cotton sector – carded cotton yarns, combed cotton yarns (classical, open-end spun yarns) and sewing threads, cotton grey cloths and finished cotton cloths, linings and dress cloths, nonwovens;
- wool sector – worsted yarns, semi-worsted yarns, woollen yarns, a wide assortment of dress cloths and coat woven materials, textile floor coverings;
- linen sector – glass cloths, linen cloths and nonwovens, linen piece goods, rope products;
- knitting sector – knits, knitted outerwear, knitwear, knitted underwear, small knitted products, hosiery.

The offer of sophisticated assortments of the segment is restricted. Fine types of cotton yarns and light cotton cloths with a mass of up to 100–120 g/m^2, linen yarns and blended yarns (linen/synthetics) up to 65 tex are missing. Modern finishing technologies (dyeing in supercritical CO_2, infrared drying, hydrophobic and softening finishes) have not been installed in the finishig mills. One third of knitting production is realized in the form of wage work for foreign customers. The assortment of wool and filament yarns and woven cloths is wider and on a higher qualitative standard after certain modernization of technologies.

Qualitative aspect of the production of the Slovak textile industry is a result of available level of technique and technology in the segment. Present level is marked with investment underdimensioning of the segment. Standard of technique and technology in the Slovak textile industry is behind that of the highly-developed countries.

Open-end spinning prevails in cotton spinning mills. The technology is suitable mainly for processing coarser and blended yarns. Position in ring spinning

Table 1 Share of textile industry on indicators of industrial manufacture in the frame of the Slovak Republic (year 1999)

Sub-sector	Name	share on industrial manufacture in %	share on added value of industry in %	share on employment of industry in %	share on export of industry in %
171	Preparation and fibre spinning	0,13	0,10	0,33	0,08
172	Cloth weaving	0,74	0,80	1,66	0,53
174 + 175	Manufacture of textile products and other textile manufacture	0,19	0,24	0,70	0,10
177	Manufacture of knit goods	0,26	0,39	1,20	1,23
	Textiles total	**1,37**	**1,58**	**4,09**	**1,99**

frames is worse, in addition their productivity is behind the world top due to the age of the machines. Preparation machines which are a basis for a quality output of spinning frames are very old as well as combing and winding machines. Absence of attachment results in inferior yarn quality (low number of splicers, autolevers etc.).

A more favourable situation is in woollen spinning mills. In the beginning of 1990s investments were made in carding process (high-performance carding machines mostly of Italian origin), in drawing machines, doubler-winders, combing machines and ring spinning frames.

Technological devices for preparation of fibres in linen segment are out-of-date. Spinning, winding and rewinding is carried out on machines with substandard output parameters. Availability of technologies to manufacture finer yarns is insufficient.

Shuttleless looms are prevailing in weaving mills. Their age structure is worse than that of competitors (EU, Far East). Preparation machines, mainly sizing machines are old.

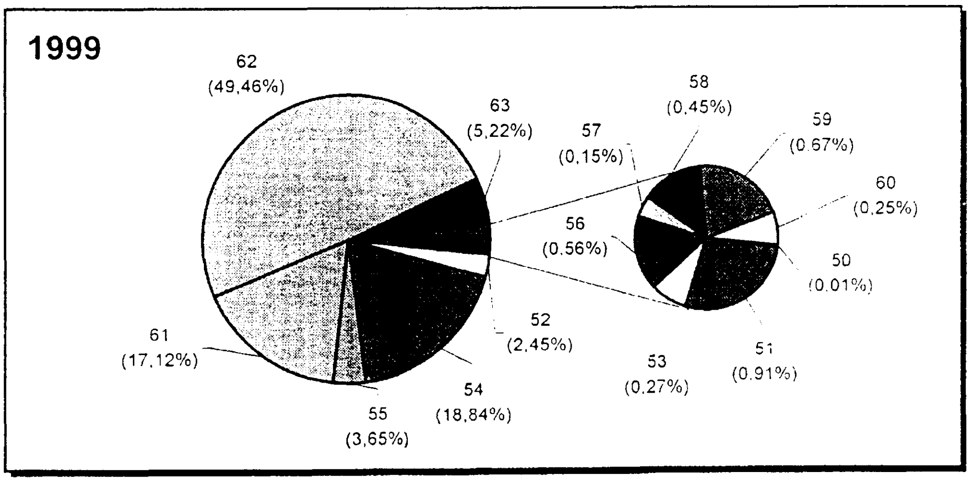
The weakest link of the Slovak textile original production in general is technological equipment in preparation and especially in finishing. Technological and capital intensity of modern finishing equipment is high. Present state in this field is a result of undercapitalization of the sector; this state shows then a negative impact on quality of products.

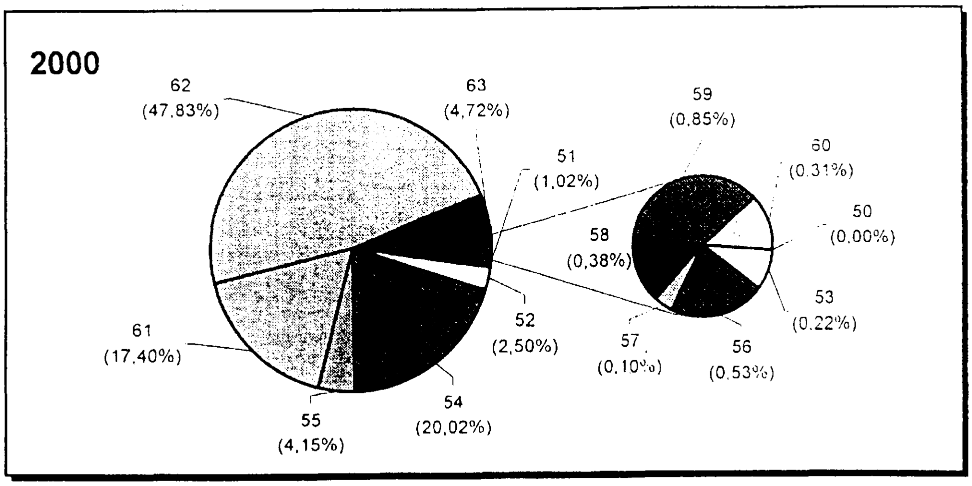
Machinery in knitting production is out-of-date in comparison with highly-developed competitors. Number of electronic patterning devices is lower in comparison with the competitors. Thus possibilities of patterning and speed of response of the Slovak knitting mills are limited. Age structure of machines in manufacture of knitted clothing is maintained proportional due to lower investment intensity.

This short summary of the present state of textile industry in Slovakia was presented with the purpose to provide actual information in a more general outline. Certain fragmentation of interests prevailing in the last 10 years does not contribude to stabilization of the sector. An impulse for a reversal can be a common interest of the Slovak manufacturers in cooperative produc-

Export of the Slovak Republic in the class 11 (textiles and textile products) in the years 1999 and 2000

	Chapter	1999 in thousands FCO	2000 in thousands FCO
50	Natural silk (silk yarn and woven cloths made of silk)	2 582 Sk	633 Sk
51	Wool, fine or coarse animal hair, bristle yarns and woven cloths made of bristle	298 034 Sk	367 565 Sk
52	Cotton (combed cotton yarn, carded cotton yarn, cotton sewing threads, cotton woven cloths)	801 275 Sk	903 421 Sk
53	Other vegetable textile fibres, paper yarn and woven cloths made of paper yarn	87 139 Sk	78 385 Sk
54	Man-made filament yarn, synthetic or man-made silk	6 171 438 Sk	7 246 791 Sk
55	Chemical (synthetic or man-made) staple fibres	1 194 018 Sk	1 502 392 Sk
56	Cotton wool, felt and nonwovens, special yarns, ropes, twines, cords and cables and products made thereof	182 465 Sk	190 578 Sk
57	Carpets and other textile floor coverings	20 286 Sk	37 100 Sk
58	Special woven cloths, tufted textiles, braids, tapestries, trimmings, embroideries	145 970 Sk	137 055 Sk
59	Impregnated, coated, layered and laminated textiles, textile products suitable for industrial applications	220 397 Sk	308 317 Sk
60	Knitted fabrics or crocheted textiles	80 396 Sk	111 006 Sk
61	Clothing and clothing accessories, knitted or crocheted	5 608 330 Sk	6 297 327 Sk
62	Clothing and clothing accessories other than knitted or crocheted	16 200 967 Sk	17 313 333 Sk
63	Other finished textile products, ensembles, worn-out clothing and second-hand products, rags	1 710 682 Sk	1 707 348 Sk
	Class 11 – Total:	**32 753 979 Sk**	**36 201 251 Sk**





tion of selected assortment of technical textiles based on:

- application of domestic raw materials (PAD, PP, PES, technical fibres and staple yarns) and imported special types of fibres;
- utilization of domestic capacities for cotton and wool spinning and rather unexploited weaving and knitting capacities;
- integrated investment policy in the field of finishing technologies.

2. DEVELOPMENT OF TECHNICAL TEXTILES IN SELECTED ASSORTMENTS

Research Institute for Textile Chemistry – CHEMITEX spol. s r.o. in Žilina is a complex facility engaged in development in the field of technical textiles as well as optimization of their parameters. In the 1990s the original environmental aspect, processing and utilization of secondary raw materials, technological waste from textile and clothing production was extended by development of new products from primary raw materials, mainly special fibre types and development of new technologies to manufacture them.

This research and development is naturally limited by technological possibilities of the Slovak manufacturers. In spite of it the assortment of developed products realized partly also in practice is rather wide:

- geotextiles, materials for reinforcing, stabilization, protection
- filtration materials for industrial filtration
- geosynthetics for dumping sites
- agrotextiles
- medical textiles
- textiles for protection of human health and technical equipment
- textiles for rubber production

We would like to present some selected results in the following part of the paper.

2.1 Medical textiles

Assortment of therapeutical wound dressings

The range includes three products with brand names SATOZA, CARTOZA, JOTOZA.

Properties of the therapeutical wound dressings with healing and bacteriostatic effect exceed basic functions required from a common wound dressing especially when healing serious dermatological troubles.

Table 2 Parameters of the therapeutical wound dressings and comparison with rival products

	SATOZA	CARTOZA	JOTOZA
Composition	Core: nonwoven made of antibacterial PP staple and superabsorptive fibre Sheath: nonwoven with a bacteriostatic additive	Core: absorbent textile material made of carbon fibres Sheath: nonwoven with a bacteriostatic additive	Core: cotton knitted fabric impregnated by PVP iodine ointment Sheath: sheet from plasticized PVC
Weight per unit area	2,1 ± 0,5 g	2,7 ± 0,5 g	4 ± 0,5 g
Absorption capacity	min. 10 ($g.g^{-1}$)	min. 10 ($g.g^{-1}$)	–
Rival product	**VLIWIN** PP woven cloth, absorbent cotton, cellulose Rauscher, Austria	**ACTISORB PLUS** knitted fabric with active carbon with 0,15 % by mass of elementary Ag PAD nonwoven Johnson and Johnson, USA	**INADINE** woven cloth with efficient substance PVC iodine between two sheets Johnson and Johnson, USA

SATOZA – a multilayered planar structure with sheath and inner layer made of textile material with bacteriostatic effect. Core of the wound dressing is made of a nonwoven with high absorbency and with bacteriostatic effect.

CARTOZA – a multilayered planar structure with sheath made of a textile material with bacteriostatic effect. The inner layer is made of a carbonized textile material containing active carbon. This wound dressing is capable of retaining liquids and removing smell of wounds which require long healing.

JOTOZA – this wound dressing is made of a perforated textile material impregnated by a well-tried depot iodine antiseptic. The wound dressing exploits antibacterial efficiency of iodine minimizing at the same time its undesirable effects.

The above-mentioned wound dressings were clinically tested in dermatological wards of selected hospitals on territory of the Slovak Republic with a very good result. They were applied on local infested defects of the lower limbs. Bacteriostatic effect and absorbency of the therapeutical wound dressings were valued highly above all. Health institutes recommended the new assortment of therapeutical wound dressings from own development. Manufacture of the products is prepared as well as complete documentation for approval of this new medical aid.

2.2 Textiles for rubber manufacture

Liners and protective technical textiles

Technical textiles are used in rubber manufacture mainly as protective textiles and liners in manipulation and storage of rubber semi-products where they fulfil function of separating and protective materials ensuring convenient quality of semi-product surface in manufacture of tyres mainly from the point of view of sufficient adhesiveness and cleanliness.

Decisive factors for selection of quality of fibres suitable for manufacture of liners and protective woven cloths were as follows: strength, abrasion resistance, sufficient durability and minimal adhesion of the surface of the woven cloth to the rubber semi-product.

Requirements regarding final quality of the textile material were fulfiled by combination of high-strength PES filament 167 dtex in warp and PES filament 333 dtex in weft.

The assortment of textile materials developed as liners for cord plies and tyre threads was evaluated in conditions of rubber manufacture in a.s. Matador

Table 3 Comparison of required parameters and achieved quality of the developed liner and protective cloth Uruk G

Parameter/specific unit			Required parameters of the technical textile liners	protective cloth	Achieved parameters URUK G
Strength min. [$N.5\ cm^{-1}$]		warp	1 000	1 000	1 688
		weft	800	800	1 080
Elongation max. [%]		warp	30	–	26.4
		weft	30	–	32.1
Thermal resistance [°C]			–	160	160
Change of dimensions under thermal effect [%]	100 °C/1 hour	warp	–	0	0
		weft	–	0	0
	160 °C/1 hour	warp	–	± 3	– 1.5
		weft	–	± 3	– 1.5

Table 4 Parameters of textile membrane GUPLET for tyre building

Parameter Material composition		Required parameters	Achieved parameters GUPLET PAD 6/Dorlastan 44 dtex
Weight per unit area [g.m^{-2}]		–	257
Strength[N.5 cm^{-1}]	– length	300	835
	– width	550	477
Elongation [%]	– length	280	146
	– width	250	256
Thickness [mm]		–	0.9
Width [cm]		–	130
Durability – number of cycles of the membrane		5 000	1. test 9 893 2. test 11 480

Púchov and woven cloth with working name URUK G proved to be the best. The technical woven cloth was recommended after regular tests and evaluations to be included into the rubber manufacturing programme in a.s. Matador Púchov.

Expected durability of the woven cloth determined on the basis of tests is 3 years. It will be used in rubber manufacture mainly as substitution of commonly used PE sheet with substantially lower durability (max. 2-3 months) and it will economize expenses of the final consumer regarding regeneration of the sheet and increasing service life of the material.

Textile membranes for tyre building

Technical knitted fabrics with special properties, i.e. membranes for tyre building are used in technological process of tyre manufacture. Principal requirement which must be fulfiled by the membrane is outstanding durability during use in manufacturing cycles. Minimal durability set up according to the imported material from MLLIKEN was 5 000 cycles.

Our development was focusing mainly on investigation of suitable combination of technical fibres and construction of the knitted fabric. We have developed a knitted fabric made of PAD 6 in combination with Dorlastan 44 dtex.

The parameters shown in the table demonstrate that the knitted fabric GUPLET has about twice durability than required. The above-mentioned type of textile membrane for tyre building has been included into manufacturing programme of Matador a.s. Púchov.

2.3 Filtration materials for industrial application

Technical nonwovens with filtration efficiency help to overcome adverse effects of industrial production on living and working environment. A range of nonwoven filtration materials INOFIL and NEFIL designed for filtration of gaseous and liquid substances was developed by VÚTCH-CHEMITEX, spol. s r.o. Žilina. Decisive influence of technological factors on achievement of final quality of the filtration material was taken into account during the development. The factors are as follows:

- quality of fibrous raw materials and optimization of the material composition
- selection of suitable armouring material for proposed applications
- influence of surface finish of the textile material on final filtration properties

Result of our development is a range of filtration materials based on PP, PES and PAN conductive fibres and their blends designed for various fields of application. The range includes materials as follows (Table 5):

Table 5 Assortment of filtration textiles INOFIL and NEFIL

Name of the filtration material	Application possibilities
INOFIL PES - 1 NEFIL PES - 1/700	– metallurgy – metallurgical treatment – cement factories
INOFIL PES - 2/PP NEFIL PES - 2/500/PP INOFIL PP - 2/VP NEFIL PP - 2	– food industry – feeding mixtures – dyes and paint industry – building industry
INOFIL PES – 2/M 2 NEFIL PES – 2/500/ M2	– building industry – manufacture of fireproof materials – food industry
INOFIL ST 550	– metallurgy – galvanization – zinc coating
INOFIL PES – 2/ANT	– grinding mills – timber mills

Qualitative parameters of the new range of filtration materials are given in Table 6. They document a great diversity of filtration characteristics of the materials developed for a range of possible applications. The filtration materials are designed to meet requirements of the customers regarding size and quantity of polluting particles to be captured.

2.4 Antibacterial textiles for bed linen

Hygienical/epidemiological situation of living and working environment is going from bad to worse. It results in increase of allergies and skin diseases. Therefore the effects of textile materials as articles of

Table 6 Selected parameters of filtration textiles INOFIL and NEFIL

Parameter	Filter type									
	INOFIL PES-1	INOFIL PES-2/PP	INOFIL PES-2/M2	INOFIL PP-2/VP	INOFIL PES-2/ANT	INOFIL ST 550	NEFIL PES-1/700	NEFIL PES 2/500/PP	NEFIL PES 2/500/M2	NEFIL PP-2
Weight per unit area (g.m^{-2})	630	590	580	500	430	550	700	530	530	590
Thickness (mm)	2,28	2,4	2,43	2,5	1,8	2,42	4,5	2,4	2,1	4,4
Strength (N/5 cm)										
– length	870	600	570	1 100	600	680	1 300	870	670	700
– width	1 700	910	1 200	1 100	820	1 320	1 100	820	450	500
Elongation (%)										
– length	80	15	30	14	15	15	60	15	15	15
– width	70	11	70	11	10	10	70	10	10	10
Air-permeability at 200 Pa (mm.s^{-1})	580	300	540	500	360	600	500	380	600	300
Thermal resistance (°C)	150	100	150	100	150*	160**	150	100	150	100

* surface resistivity < $1.10^6\Omega$, ** short-time 180

Table 7 Influence of care on bacteriostatic efficiency of the textile material

Material	Staphylococcus aureus		Klebsiella pneumoniae	
	growth of bacteria %	bacteriostatic efficiency %	growth of bacteria %	bacteriostatic efficiency %
DOMESTIK bleached – AMIDO				
after 1 washing	15	85	70	30
after 10 washings	8	92	72	28
after 20 washings	38	62	26	74
The textiles are bacteriostatic ones				

daily use are being followed incerasingly. The materials are evaluated among others from point of view of their direct influence on a man when protecting human health and preventing from proliferation of diseases caused by resistent or pathogenous microorganisms.

Application of textile materials with special antibacterial properties proved useful when evaluating these influences because they can substantially contribute to inhibition of the growth of microorganisms and to hygienic protection of the customers.

The basis of structure of the antibacterial textile materials are special fibres containing a suitable type of antibacterial additive effective against a wide range of microorganisms with minimal content of the additive in the fibre.

VÚTCH-CHEMITEX, spol. s r.o. has developed a range of efficient antimicrobial additives with brand name BIOSTAT suitable for fibre-forming polymeric systems on the base of PP, PES and PAD. The additives were tested in manufacture of staple fibres and filaments on the base of PP and PES in cooperation with fibre producers.

Staple fibres containing the additives were used to manufacture a range of blended yarns and woven cloths by technology of spinning and weaving.

Five types of bacteriostatic yarns have been developed as blends of synthetic fibres with cotton 20–42 tex. They were then used to manufacture two kinds of woven cloths – drill BIERN and bed linen called DOMESTIK.

Percentual comparison of the growth of bacteria on commonly used and bacteriostatic textile materials

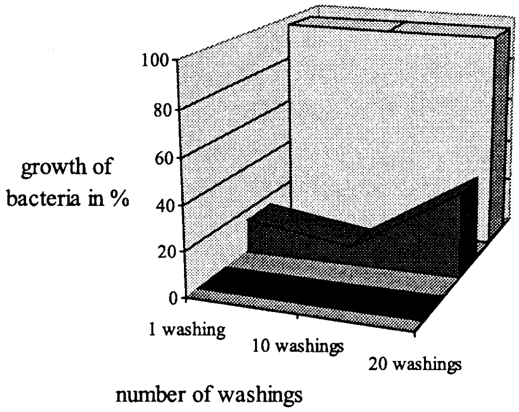


Fig. 1

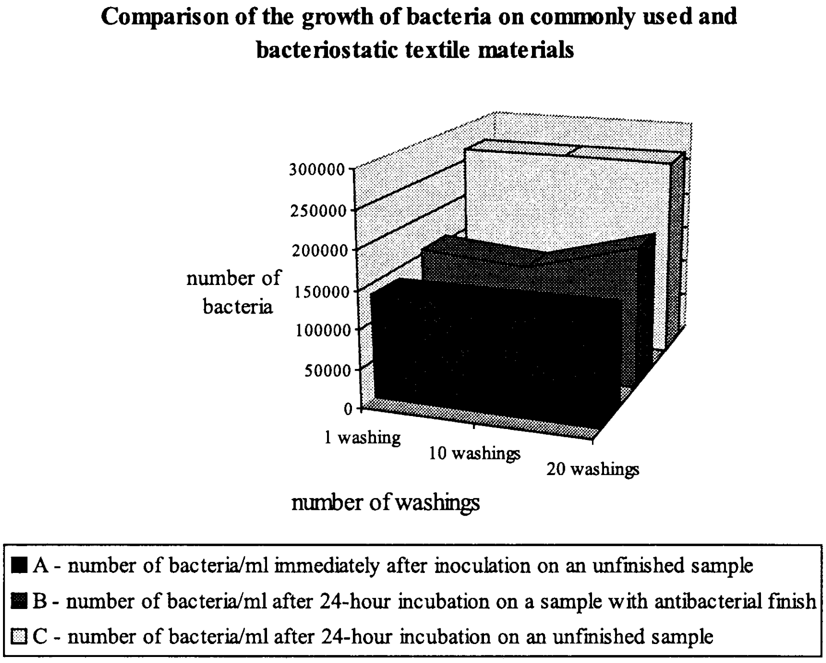


Fig. 2

Final bacteriostatic efficiency of the textile material Domestik – AMIDO containing 15 % PPsBST in the woven cloth is given in Table 7.

Comparison of the growth of bacteria on standard textiles and bacteriostatic ones is shown schematically on Fig. 1 and 2.

Fibres with antibacterial additives are being used increasingly in the assortment of textile materials. Need of prevention and protection of human health from risk of disorders call for application of antibacterial textiles with various construction mainly in fields as follows:

- bed linen for hospitals, hotels and lodging-houses
- protective workwear with increased hygienic safety
- underwear and piece goods (socks, gloves)
- leisurewear and sportswear
- filtration materials for food manufacture
- textiles for transport means

3. CONCLUSION

We have not presented all assortments of technical textiles developed in VÚTCH-CHEMITEX, spol. s r.o. in Žilina lately. For instance geotextiles, agrotextiles and other protective textiles have not been mentioned here.

At the same time it is necessary to say frankly that some of the developed assortments have not been put into manufacture yet.

There are several reasons for it. However, the basic one is instability in the textile sector and insufficient technological equipment. Technical textiles will continue to be underestimated in the conditions of the Slovak textile industry and it will fall more and more behind the world unless this situation turns.

TEXTILE MATERIALS IN THE LIGHT OF INNOVATIVE DEVELOPMENTS FOR LIGHTWEIGHT CONSTRUCTIONS

Offermann, P.

Technische Universitat Dresden, Institut fiir Textil- und Bekleidungstechnik, D-01062 Dresden,
e-mail: offerm@tud-itb.ipfdd.de

It is the vision to get lightweight construction solutions close to natural constructions. The most freedom of design is achieved by combination of reinforcing fibres and matrix fibres in a single yarn. Based on this only thermoplastic composite constructions are possible. Main focus of the research efforts is on the control of the commingling process. Textile processing of the commingled yarns leads to textile performs which can be immediately formed to composite parts. Minimal flow paths of the matrix material between the reinforcement fibres are essential for good internal bonding. Production of near-net shape performs can be achieved by special development of textile manufacturing techniques. Components of complex shape further require textile processing of free-form surfaces. To come to major advances (material laws, failure analysis) it demands research co-operation of all engineering disciplines involved.

1 DEFINITION AND THESES

Textile materials are fibres, filaments, and threads manufacturable by a textile process. Textile semi-finished fabrics in the form of plane fabrics, 2 D-, 3 D-structures, and free-form planes of complicated geometry's are also called textile materials in lightweight construction. Textile fibre materials must fulfil special technical and/or economic criteria to be interesting for lightweight construction.

The two major groups of textile fibre materials for lightweight construction are

a) the so-called high performance fibre materials and

b) the newly growing fibre materials

Selected physical characteristics demonstrate the application potential of textile materials for lightweight construction. Textile materials are used in lightweight construction as reinforcement materials.

Composites make possible the optimal combination of the reinforcement fibre architecture with a matrix component.

The choice of the high performance fibres partner is determined by the physical (mechanical, thermal) and/ or chemical and/or biological requirements.

2 MOTIVATIONS AND CONSEQUENCES

The most important motivation for the development of lightweight construction parts is the improvement of the weight-performance ratio.

The most progressive solutions are, thus, to be found in air and space travel. Increased safety at a low weight and, at the same time, low energy costs, there fore, justify the generally higher total costs of lightweight construction.

The extensive use of lightweight construction structures with textile materials in general vehicle construction, ship building, machine – and plant construction is failing so far due to the too high production costs and insufficient Know-how.

The performance potential of high performance fibre materials constitutes, on the other hand, a continuing motivation for the development of a new kind of lightweight construction strategies.

The way the system is looked at concerning composite part definition moves more and more into the center of the procedure. Modeling, calculation, design, textile manufacturing processes, matrixes, and consolidation processes, composite part construction, integral insert technology, quality assurance, and tests under pressure are a part of the complete process.

For the textile technology the challenge calls for:

- Development of cost-effective manufacturing technologies
- Reaching a high degree of pre-manufacturing of textile semi-finished fabrics
- Assuring the reproduceability of the semi-finished structures in regard to geometry and physical characteristics in the composite part.

3 THE STATE OF TECHNOLOGY

Textile materials have been used for lightweight construction for decades. In the area of high performance composites UD-lay-ups, UD-tapes and bi-directional woven structures are normally used.

Duroplastics dominate as matrix materials. With the classical lay-ups and tapes the highest fibre volume fraction can be reached (60 % and more). The degradation degradation of sensitive carbon fibres, for instance, can be calculated.

Orthogonal fabrics constitute a higher degree of manufacturing. Similarly, this goes for braiding. The strength of filament yarns, however, can already no longer be used in the same measure as UD-structures. Nevertheless, this causes a construction cost advantage. By weave construction and the fineness of the filament yarn optimisations become possible. The composite parts call for many layers. These must be layered to each other at different angles.

The handling part and the cutting waste cause important negative cost factors.

The layers also have no form-determining connections among themselves. The delimitation of the composite constitutes a greater danger. In airplane construction "fearrivets" are therefore set.

In the last ten years extensive research was done concerning the use of multi-axial fabric structures for integral lightweight construction. The ITB is and was involved in this work.

The cost advantages of the higher degree of construction, however, must be covered by quality characteristics which, at least, correspond to the comparable woven fabrics. This could be proved.

Apart from the plane textile semi-finished fabrics also 3 D-structures are being used. Profiles are manufactured in the braiding technique or the weaving technique. For the reduction of the delimitation danger and as a compound technique, the textile sewing methods are lately moving into the centre of research and development. The results reached so far lead to the expectation of applications in the widest technical sense.

4 VISION AND TEXTILE SOLUTION STARTING POINTS

The great model for lightweight construction is nature. Its way of lightweight construction favours a fibre reinforcement architecture which orientates itself on the three dimensional fibre arrangement in the path of force.

With minimal input outstanding lightweight construction characteristics are reached.

The vision orientates itself on this example. The goal is to find nature-analogous technical lightweight construction solutions. For this, textile technology, in principal, offers a wide range of designs. But also with the classical materials like steel and aluminium innovative solutions are worked on to move closer to the engineering principle of nature. Metallic foams and the thinnest folded tins will suffice as examples here.

The textile solution starting points orientates themselves on the given materials and technological advantages.

The material advantages have already been named. In principal, the possibility exists to consider the reinforcement frame of a light-weight construction structured in the areas of Fibre, Thread, Fabric.

The mixture of the reinforcement components with the matrix component is thinkable in the same manufacturing areas.

The technological advantages of the design multiplicity first of all consist in the textile construction possibilities in the manufacturing of textile fabrics. Beyond that, there are methods by which textiles can be manufactures fully fashioned and in complicated-geometry's. Hereby the classical textiles braiding, weaving, knitting, and embroidering techniques offer themselves especially.

The IPF has been working successfully for some years now on the technical optimisation of the embroidering process for the manufacturing of so-called Tailor-Fibre-Placement-Structures (TFP). The technological and constructive changes on the basis machine were the subject for a doctoral degree [1]. The technical standard reached and the quality assurance in the manufacturing of textile semi-finished fabrics for high performance composite parts led to the foundation of a company.

The ITB is pursuing textile solution starting points on the basis of the warp and weft knitting techniques which will be reported about (a. o.) in the following.

5 RESEARCH DIRECTIONS CHOSEN

5.1 Further Developments of the Commingling Process

The highest freedom of design is reached with mingling reinforcement and matrix fibres in the thread. (The mingling in fibre fleece is exempted here as, apart from the freedom of design for high performance composites, also the best possible fibre arrangement in the path of force will be dealt with).

The principal limitation of course consists there-in that on this basic only thermo-plastic composite construction methods can be performed. In the basic investigations carried out during the last few years, the high performance potential of the commingling-technique, as compared to other methods, could be shown. The essential advantage hereby consists of the mixture of the components. Thus, the flow paths of the thermoplastic matrix are minimised. This leads to close adhesion among the individual fibres. The structure really does come quite close to nature.

The goal now is to further optimise the commingling-technique. During the mingling the, as a rule, very brittle high performance fibres succumb to high stress, which leads to filament breaks. Besides, the filaments then no longer lie ideally aligned in the thread and, thus cannot bring their performance potential in to play 100 %.

One can easily imagine which design possibilities for textile construction are given already alone due to the variation of the commingling portions of the fibre components in the thread and its normal textile-.technical further manufacturing into fabrics.

5.2 Development of Bi-axially Reinforced Flat Knittings

The flat knitting machines are, as known, preferably used for the manufacturing of tricot products. The main reason for this consists in the technological advantages of the fully-fashioned manufacturing of pullovers, sweaters, and other similar items, (in the extreme case even completely ready-to-wear).

The formgiving possibilities have been used for some time now also in connection with aramid threads (e. g. Kevlar) for the manufacturing of composite parts for the ballistic sector (e. g. helmets).

A further increase of the number of layers is technically thinkable but calls for the development of a completely new machine.

The second step of research shall serve the integration of the bi-axial technology into the knitting process for the productions of near net-shape and free-form preforms. Since the beginning of 2000 the ITB is in possession of such a basic machine.

The integration necessitates innovative solutions. Starting with the technological requirements for fully-fashioned relevant freeform surfaces, constructive, and control technical concepts are to be implemented.

The introduction of stress-admitting threads into the warp direction can for example, theoretically take place after three variants.

Mono-axial reinforcements in weft direction however already make possible a multitude of structure manipulations.

The deep drawing ability of such textile semi-finished materials is excellent.

With the example of the construction of a ball preform can be shown after which geometric principles the form is created out of segments and how the technical knitting program is to be written.

The vision of a nature-adequate textile lightweight construction method will remain the goal.

The possibilities of the, for the most part, freely selectable setting of the mingling ratio of the reinforcement and matrix filaments in the yarn, the path of force reinforcement, and the near-net shape composite construction bring the aim a good bit closer.

The present focal pointplans consist of the development of the basics for user-efficient, failure-tolerant high performance rotors in the textile hybrid construction style. The complicated geometric design, the requirements on to the textile construction including the sewing technique and the complex demands constitute an extreme challenge.

6 VIEW TO THE FUTURE

The development potential of textile materials in lightweight construction seems immeasurable at this time, on the other hand, there exists hardly any basis in regard to material behaviour, especially in the failure characteristic. Thus, alone in quasi-static processes the present state of development in material laws is estimated at 30 % and for the failure criteria at 10 %. [2]

Thus, there are plenty of research and development tasks for all of the professional disciplines needed on the team. International competition, on the other hand, is escalating at such a pace that really relevant progress in the technological sector concerning the mastery of concrete product innovation can hardly be published.

7 LITERATURE

1 Feltin, D.: Entwicklung von textilen Halbzeugen für Faserverbunde unter Verwendung von Stickautomaten. – Technische Universität Dresden, Diss., 1998

2 Hufenbach, W. et. al: Variable-Axial Composites for Complexly Loaded High-Speed Rotors Proceedings of the Twelfth International Conference on Composites Materials (ICCM12), Paris 1999, S. 73

ULTIMATE STRENGTH OF FIBRES AND FIBROUS BUNDLES

Militký, **J.**

Department of Textile Materials, Technical University of Liberec , Halkova 6, 46117 LIBEREC, Czech Republic,
e-mail: jiri.militky@vslib.cz

The main models for description of fibers ultimate strength based on the probabilistic approach are discussed. For identification of fiber strength type and estimation of corresponding parameters the modified quantile regression is proposed. The bundle strength predictions based on the simplest approach of uniform share of loading and knowledge of fiber strength distribution is described. The simulation approach starting from reliability of parallel system is used as well. These predictions are used for estimation of basalt roving strength. Predicted values are compared with experimental data.

1. INTRODUCTION

Strength at break is one of basic properties of fibers. This parameter is important both for textile technologists and textiles designers. Generally it is assumed that fiber strength is in nature stochastic variable and corresponding distribution confirm to mechanisms of failure. Classical theories lead to unimodal distributions skewed obviously to the right [1].

For polymeric materials, where more types of cracks appear, the polymodal strength distribution results. Number of modal values is indicator of specific defects (obviously surface defects and volume ones) [2]. In contribution [3] the discrete spectrum of defects has been identified. By the proper statistical technique the polymodality has not been proved for modified PES, carbon, aromatic polyamides and ceramic fibers [4–5]. These fibers exhibit typically unimodal and very broad tensile strength distribution by the risk functions $R(\sigma)$.

This contribution is devoted to the selection of risk function of failure $R(\sigma)$ for description of the tensile breaking strength σ distribution. For parameters estimation and right model selection the method based on the order statistics and nonlinear regression is proposed. The simple models for prediction of bundle strength are discussed. These predictions are used for estimation of basalt roving strength. Predicted values are compared with experimental data.

2. STATISTICAL ANALYSIS OF FIBRES STRENGTH

The fracture of fibers can be generally described by the micro mechanical models or on the base of pure probabilistic ideas [2]. The probabilistic approach is based on these assumptions:

(i) fiber breaks at specific place with critical defect (catastrophic flaw),
(ii) defects are distributed randomly along the length of fiber (model of Poisson marked process),
(iii) fracture probabilities at individual places are mutually independent.

The cumulative probability of **non-fracture** $C(V,\sigma)$ depends on the tensile stress level σ and fiber volume V. For very small body ($V \rightarrow 0$) no defects are present and therefore $C(0,\sigma) = 1$ is valid. For the very large body ($V \rightarrow \propto$) is $C(\propto,\sigma) = 0$.

The simple derivation of the stress at break distribution described below is a modification of deductions of Kittl and Diaz [6]. By using of independence assumption the probability of non-fracture of body composed from volume V and volume ΔV without common points has the form

$$C(V + \Delta V,\sigma) = C(V,\sigma)\, C(\Delta V,\sigma) \qquad (1)$$

Eqn. (1) is based on the assumption of independence of non-fracture probability in volume V and in volume ΔV. By using of Taylor linearization the $C(\Delta V,\sigma)$ may be written as

$$C(\Delta V,\sigma) = C(0 + \Delta V,\sigma) = C(0,\sigma) + [dC(0,\sigma)/dC]\, \Delta V \qquad (2)$$

and the $C(V + \Delta V,\sigma)$ as

$$C(V + \Delta V,\sigma) = C(V,\sigma) + [dC(V,\sigma)/d\sigma]\Delta V \qquad (3)$$

Using eqns. (2) and (3) and the boundary condition $C(0,\sigma) = 1$, the following expression results

$$\begin{aligned} C(V + \Delta V,\sigma) &= C(V,\sigma)\{1 + [dC(0,\sigma)/d\sigma]\Delta V\} = \\ &= C(V,\sigma) + [dC(V,\sigma)/d\sigma]\Delta V \qquad (4) \end{aligned}$$

After rearrangements of eqn. (4) the final form is obtained

$$\frac{dC(V,\sigma)\,/\,d\sigma}{C(V,\sigma)} = \frac{dC(0,\sigma)}{d\sigma} = -R(\sigma) \qquad (5)$$

The $R(\sigma)$ is known as the <u>specific risk</u> function. This function is positive and monotonously increasing as $C = (0,\sigma)$ must be negative. Therefore in eqn. (5) must be negative sign at the term $R(\sigma)$. Integration of eqn. (7) with boundary condition $C(0,\sigma) = 1$ gives

$$C(V,\sigma) = \exp[-R(\sigma)] \qquad (6)$$

The cumulative probability of break $F(\sigma)$ is complement to the $C(V,\sigma)$. Then the distribution of stress at break is expressed as

$$F(\sigma) = 1 - \exp[-R(\sigma)] \qquad (7)$$

For famous Weibull distribution [1] (model WEI3) has $R(\sigma)$ form

$$R(\sigma)] = [(\sigma - A)/B]^C \qquad (8)$$

Here A is lower strength limit, B is scale parameter and C is shape parameter. For brittle materials is often assumed A = 0 (model WEI2).

Weibull models are physically incorrect due to unsatisfactory upper limit of strength $C(\propto,\sigma) = 0$. To overcome this limitation Kies [7] proposed more general risk function (model KIES) in the form

$$R(\sigma)] = [(\sigma - A)/(A_1 - \sigma)]^C \qquad (9)$$

Here A_1 is upper strength limit. For brittle materials is again assumed A = 0 (model KIES2). Occasionally the single Weibull distribution is inconsistent with experimental data. A multi-risk model is then used for analysis of strength distribution. For a bimodal distribution (fracture is result of two distinct kinds of defects) with zero lower limiting strength the risk function is

$$R(\sigma)] = [(\sigma/B) + (\sigma/B_1)]^C \qquad (10)$$

Generalization of Kies risk function has been proposed by Phani [8] (model PHA5)

$$R(\sigma) = \frac{[(\sigma - A)/B_1]^D}{[(A_1 - \sigma)/B_1]^C} \qquad (11)$$

In this equation are C and D two shape parameters. It can be proved that the B and B_1 cannot be independently estimated. Therefore, the constraint $B_1 = 1$ is used in sequel. Simplified version of eqn. (4) has A = 0 (model PHA4). For well-known Gumbell distribution (GUMB) is $R(\sigma)$ expressed as

$$R(\sigma) = \exp[(\sigma - A)/B] \qquad (12)$$

The selection of right $R(\sigma)$ depends critically on the estimated number of modes and on the presence or absence of non zero lower limiting strength.

3. ESTIMATION OF R(σ) TYPE AND PARAMETERS

Main aim of the statistical analysis of strength data σ_i i = 1,...N is specification of R(s) and estimate of its parameters. Owing to their special structure the parameters of Weibull type distributions can be estimated by using of the maximum likelihood, quantile based and moment based methods. Sometimes is attractive to combine these and other methods for simplification of estimation process. We propose quantile based methods for their simplicity Methods of this type use the so-called order statistics $\sigma_{(i)}$. Denote that $\sigma_{(i)}$ # $\sigma_{(i+1)}$ i = 1,...N–1. It is well known that $\sigma_{(i)}$ values are rough estimates of sample quantile function for probabilities [9]

$$P_i = F(\sigma_{(i)}) = \frac{i - 0.5}{N + 0.25} \qquad (13)$$

By using of eqn. (8) and order statistics $\sigma_{(i)}$ the parameter estimation problem can be converted to the nonlinear regression task [10].

So-called Weibull transformation method uses the rearrangement of eqn. (8) for order statistics

$$\ln[R(\sigma_{(i)})] = \ln[-\ln(1 - P_i)] \qquad (14)$$

The parameter estimates of $R(\sigma)$ model can be then obtained by nonlinear least squares, i.e., by minimizing of criterion

$$S(a) = \sum_{i=1}^{N} (y_i - \ln(R(\sigma_i))^2 \qquad (15)$$

where $y_i = \ln[-\ln(1 - P_i)]$. Denote that graph of y_i on the $\ln(\sigma_{(i)})$ is so-called Weibull plot. This plot is for two parameter Weibull distribution straight line but for three parameter the concave curve results.

Strictly speaking, this method is based on the incorrect assumption that the y_i are uncorrelated random variables with constant variance. More logical is to use the estimated sample quantiles $\sigma_{(i)}$ as explained quantities. Corresponding least squares criterion for the quantile regression has the form

$$S(a) = \sum_{i=1}^{N} [\sigma_{(i)} - Q(Z_i)]^2 \qquad (16)$$

where $Z_i = \exp(y_i)$ and $Q(Z_i)$ is theoretical quantile function. For three parameter Weibull distribution is $Q(Z_i)$ expressed as [9]

$$Q(Z_i) = A + BZ_i^{1/C} \qquad (17)$$

For three parameter Kies model is valid

$$Q(Z_i) = \frac{A + A_i Z_i^{1/C}}{1 + Z_i^{1/C}} \qquad (18)$$

and for Gumbell one is

$$Q(Z_i) = A + B \ln(Z_i) \qquad (19)$$

According to the roughness of $\sigma_{(i)}$ and their no constant variances the special weights can be defined [9].

For selection of right risk function the statistical criteria for selection of the optimal regression model form can be used [10]. To distinguish between models with various number of parameters M the Akaike information criterion AIC is suitable

$$\mathrm{AIC} = \mathrm{N}\ln\left[\frac{\mathrm{S(a^*)}}{\mathrm{N-M}}\right] + 2\mathrm{M} \qquad (20)$$

where S(a*) is minimal value of S(a). The best model is considered to be that for which this criterion reaches a minimum. The predictive ability of regression type models may be examined by the mean quadratic error of prediction

$$\mathrm{MEP} = \frac{1}{N}\sum_{i=1}^{N}[\mathrm{y_i} - f(\mathrm{x_i}, \mathrm{a_{(-i)}})]^2 \qquad (21)$$

where $f(x_i, a)$ is model function. Parameters $a_{(-i)}$ are least squares estimates when all points except the i-th one were used. Criterion MEP is equal to the mean of the squared predictive residuals [10]. The best model with maximum predictive ability reaches a minimum of MEP

4. BUNDLE STRENGTH

Let us consider a fibrous system where n fibers (or filaments) form a parallel bundle with no interaction between individual fibers. Daniels [11] developed theory to estimate the maximum strength of bundles using order statistics $\sigma_{(i)}$. The maximum strength of bundle made from N fibers would be defined by relation

$$(\mathrm{N} - \mathrm{i} + 1)\sigma_{(\mathrm{i})} \geq (\mathrm{N} - \mathrm{i})\sigma_{(\mathrm{i}+1)} \qquad (22))$$

Peirce [12] examined five models in relation to the strength of bundles. His second model requires uniform tension among the fibers and is based on the distribution of breaking load. Maximum load P occurs when number M fibers of the n ones breaks. Let the fibers have ultimate strength distribution characterized by probability density function **(pdf)** p(s) and cumulative probability function **(cdf)** F(σ). For large n is then valid

$$\frac{n-M}{n} = 1 - \mathrm{F}(z) \quad \frac{\mathrm{P}}{n} = z[1 - \mathrm{F}(z)] \qquad (23)$$
$$z = [1 - \mathrm{F}(\sigma)]/\mathrm{p}(\sigma)$$

For the Weibull distribution (see eqn. (5)) is valid

$$z = \mathrm{BC}^{-(1/\mathrm{C})} \qquad (24)$$

Daniels [11] extended Pierce's work (fibers have the same elongation characteristics, and share the load equally). The strength distribution of bundle is approaching to the normal distribution for large n independently on the distribution of fibers probability density function. The expected bundle strength is

$$\mathrm{E}(\sigma_\mathrm{B}) = nz[1 - \mathrm{F}(\sigma)] \qquad (25)$$

and the standard deviation is

$$\mathrm{D}(\sigma_\mathrm{B}) = z\sqrt{\mathrm{F}(z)n[1 - \mathrm{F}(z)]} \qquad (26)$$

Here z is the value maximizing σ[1 – F(σ)]. For Weibull distribution is z defined by eqn. (24). Form limiting normal distribution of bundle strength and Weibull cdf of fibers is then mean bundle strength

$$\mathrm{E}(\sigma_\mathrm{B}) = \mathrm{BC}^{-(1/\mathrm{C})}\exp(-1/\mathrm{C}) \qquad (26)$$

Harter [13] provided an exact formula for expectation of Weibull order statistics in the form of series

$$\mathrm{E}(\sigma_{(\mathrm{i})}, \mathrm{B}, \mathrm{C}, n) = \mathrm{B}n\binom{n-1}{i-1}\Gamma(1 + 1/\mathrm{C}) \times$$
$$\times \sum_{\mathrm{j}=0}^{\mathrm{i}-1}\binom{i-1}{j}\frac{(-1)^{1+J-1}}{(n-j)^{1+1/C}} \qquad (27)$$

These mean values can be substituted into relation (22) instead of values $\sigma_{(i)}$ and the maximum bundle strength is value fulfilling this inequality.

Simulation based computation of bundle strength based on the reliability defines bundle as system composed from parallel-organized units. The reliability is understood as a resistance of the system against a load applied to it. It is assumed that reliability is tested in such a way that the load increases from 0 to the level causing the failure of all units or up to maximal load. Further it is assumed that the experiment is relatively fast, so that the time of duration of the load does not influence the survival. The standard survival analysis approach and counting processes models are used, however, instead of time-to-failure, the breaking load of fibers is variable of interest. The concept and relevant theory of counting processes is described in the book [14]. Let the survival of fibers is described by i.i.d. random variables U_j j = 1..m with distribution given by f(u), F(u), h(u), H(u) denoting the density, distribution function, hazard function and cumulative hazard function, respectively. It is assumed that at each moment the force applied to the fiber is divided equally among the (unbroken) ones. The global force stretching the fiber is observed. However, as the break of fiber leads to an immediate re-distribution of the force to the other fibers (so that to the abrupt increase of the force affecting each individual fibers), the consequence can be the break of several of remaining fibers. For such a set of fibers broken practically at the same moment the precise level of the strength causing the break of some of them is actually not know. Thus, a part of data is interval-censored. If the sufficient number of fibers is observed the sufficiently large set of uncensored data are registered. Let the bundle of n identical and independent fibers are tested. Denote by U_i random variables - survivals, by $N_i(u)$, $I_i(u)$ related individual counting and indicator processes for the i-th filament (i = 1...n). Further denote

$$N(u)=\sum_{i=1}^{n} N_i(u) \qquad I(u)=\sum_{i=1}^{n} I_i(u) \tag{28}$$

The common estimator of the cumulative hazard function is the Nelson-Aalen one

$$\hat{H}_N(u)=\int_0^u \frac{dN(v)}{I(v)} \tag{29}$$

where is set 0/0 = 0. The ability of the estimator to approximate well the true H(u) depends on the indicator processes for all values of strength *u* in the interval of interest. Proof of asymptotic uniform consistency and asymptotic normality of this estimator is derived in [15].

5. EXAMPLE

Basalt rocks from VESTANY hill were used as a raw material. The roving contained 280 single filaments were prepared. Mean fineness of roving was 45 tex. Diameter of filament was 8.63 [μm]. The individual basalt filaments removed from roving were tested. The loads at break were measured under standard conditions at sample length 10 mm. Load data were transformed to the stresses at break σ_i [GPa]. The sample of 50 stresses at break values was used for evaluation of the R(σ) functions and estimate of their parameters. Model proposed by Phani (eqn. (11)) leads to the parameter A without physical sense. Model PHA4 is more realistic but the shape estimates are very high. Kies type models (eqn. (9)) are here not better that three parameter Weibull one. The differences between MEP for WEI3 and WEI 2 are very small and therefore the simpler WEI2 has been selected. Parameters of this model are B = 3.01[GPa] and C = 1.83. The mean strength value for WEI2 is 2.67 GPa.

For roving strength measurements the TIRATEST 2300 machine was used. The 50 samples of strengths $\mathbf{P_i}$ were collected. These values were recalculated to stress at break values σ_i **[GPa]**. The strength distribution of tempered multifilament roving was nearly normal with parameters: mean σ_p = **1.02 GPa** and variance $\mathbf{s^2 = 0.0075\ [GPa]^2}$.These parameters were estimated as sample arithmetic mean and sample variance.

Bundle strength predicted from eqn. (26) is E(σ_B) = **1**. This value is very close to experimental one. From practical point of view is probably experimental value too small because the part of fibers was crushed in jaws of testing machine. Number of broken fibers at break computed from eqn (24) is **M = 118.**

The proposed simulation based model was used for prediction of the survival of bundle when the survival distribution of fibers is Weibull with known parameters. Though the overall survival can be derived from the order statistics distribution, its computation is generally complicated. The Monte Carlo simulation has been therefore used. Based on the 3000 simulations for model WEI2 the mean value **ES(σ) = 2.21 GPa** and standard deviation SS(s) = 0.22 have been computed. These values seem to be more realistic in comparison with asymptotic results.

Acknowledgements

This work was supported by the Czech Gratnt Agency; grant GACR No. 106/1184 and research project J11/98:244100003 of Czech Ministry of Education.

7. REFERENCES

[1] Weibull W.: J.Appl. Mech. **18**, 293 (1951)

[2] Goda K., Fukunaga H.: J.Mater.Sci. **21**, 4475 (1986)

[3] Baranova S.A. et. all..: Acta Polymerica **36**, 385 (1985)

[4] Militký J., Kovacic V.: Proc. Conf. IMTEX'95, Lodz, May 1995

[5] Militký J et, all: Modified Polyester Fibers, Elsevier 1992

[6] Kittl P., Díaz G.: Res. Mechanica **24**, 99 (1988)

[7] Kies J. A.: NRL Rept 5093,Naval Research Lab., Washington DC (1958)

[8] Phani K. K.: J. Mater. Sci. **23**, 2424 (1988)

[9] Meloun M., Militký J., Forina M.: Chemometrics for Analytic Chemistry vol I, Statistical Data Analysis, Ellis Horwood, Chichester 1992

[10] Meloun M., Militký J., Forina M.: Chemometrics for Analytic Chemistry vol II, Regression and related Methods, Ellis Horwood, Hempstead 1994

[11] Daniels H.E.: Proc. Roy. Soc. London **A183**, 405, (1945}

[12] Peirce F.T.:J. Text. Inst. **17**, 355 (1928)

[13] Harter H.L. : Order Statistics and their use, US governement Printing Office 1970

[14] Anderson P.K., Borgan O., Gill R.D. and Keiding N.: Statistical models based on Counting Processes, Springer New York 1993

[15] Volf P., Linka A.: Two applications of Counting Processes, Rept. UTIA Praha No, 1935, 1998

PERCEIVING OF TEXTILES

Masajtis, J.

Department of Textile Architecture, Technical University of Łódz, ul.Żeromskiego 116, 90-543 Łódz, POLAND,
E-mail: jmasajti@ck-sg.p.lodz.pl

Relations between human being and textiles are discussed. Mechanical, chemical, physical properties of textiles together with subjective emotions, feelings, senses of a man create a world of our environment which influence our life, health, state. It is like feedback which is not always under control.

At the beginning was a fibre – Fig. 1.

Fig. 1

From the birth to the dead and even after it human being has continuous contact with textiles. In whole of life we almost do not part with this type of products. With them we play, learn, pray, love, meditate, negotiate, solve problems, do a lot of various things, and at the end die. Even then this contact does not interrupt, lasting hundreds, or thousands years. Up till now tombs are one of most important sources of information about old textiles.

Similarly, as an air for us textiles are very near, vital environment.

Similarly, as parameters of natural environment influence our feeling and sometimes our health, textiles influence us in the similar way. A contact with one textile makes us to feel better. A contact with another textile create a wish to break this contact as quick as possible and with other we wish not to separate with it at all.

This intimate relationship, contact between people and textiles creates such state of us consciousness when we often forget that textiles exist around us and near us. We treat this situation as if textiles are given to us automatically.

This type of products have to hold technical and functional features which guarantee their usefulness, functionality and durability. They have to have elements of aesthetic, sometimes artistic which guarantee of stimulating of our subjective feelings too. Sometimes these feelings are so important that fully decide about a trade attraction of the products.

Usually a first contact with many textiles is visual. That is why so many of them hold elements which main task is to create a curiosity, create a positive reaction, to catch us attention and bring to nearest contact with potential user. We can see an example of that efforts on Fig. 2 [1], where a textile wall covering with curious side for is seen.

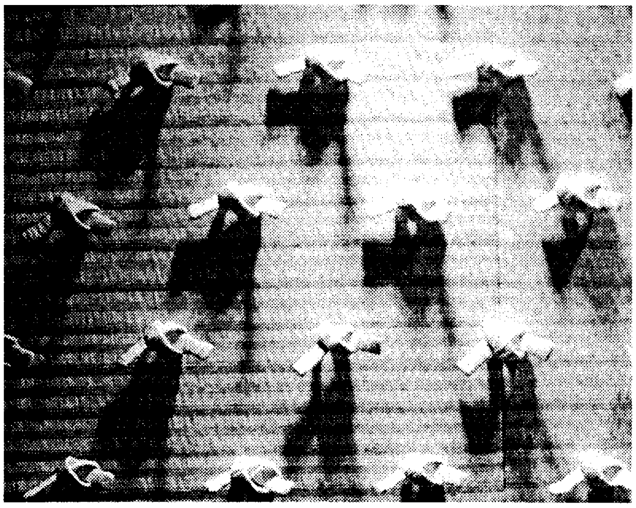


Fig. 2

A lightness, a decoration, a solidity of the background on which decoration elements were placed, a toned colours choice, a clear construction of knots is seen. We can realize that our feelings are described by certain set of features. Very strict definition of them with very precise values of parameters currently is impossibly.

No doubt textiles history proves essential role of subjective point of view on this type of products, in which construction, structure, mechanical, chemical and other properties are joined with outside form of product. In the outside form is also contained an artistic context by a pattern-designing, a texture, a composition, colours, a relief, symbols. It is area which is not easy to be described in very precise way.

All changes of textiles which are seen during thousands years, starting from the first signals of our conscious production of these type of products and ending on the present days are joined with changes of our relation to them, used opinions and criterions, our emotional states. A lot of factors had and have influence it. A state of a development of this type of production, culture, tradition, values preferred inside a community had sometimes an essential influence our point of view. It was so big influence that we could easily to determine a time and a place where textiles where produced. Specially if product was created in ancient world and in the places where were very distinct traditions of pattern designing, raw materials, compositions etc.

It is easy to differentiate Persian carpet from Caucasian or blanket of Indian Navaho from European one. It is interesting to observe how some communities keep their habits, rules and fancies. It concerns not only pattern-designing, but also raw materials, properties etc. Even nowadays when easiness of access to many types of products exists some of them are more preferred in some regions of world and another not.

This complexity of problem shows that the situation depends on a very high number of factors and our choice is not so simply. Our psyche and senses, and emotions, and cool estimation of research workers influence our behaviour. A relation between these elements is also variable and it complicates the situation more. Even in technical textiles outside form of them, colours, pattern-designing may have a specified influence on our choice.

An example of that not only visual contact is shown on Fig. 3 [2] and Fig. 4 [2]. On Fig. 3 is shown a summer tent of Bedouins and on Fig. 4 winter tent of Bedouins. These tents were in use before hundreds years and nowadays they are in use too in the same form. It means that subjective feelings and needs of Bedouins are fulfilled sufficiently in the same level up till now. Useful requirements, durability of these woven fabrics used for construction of these tents are very high.

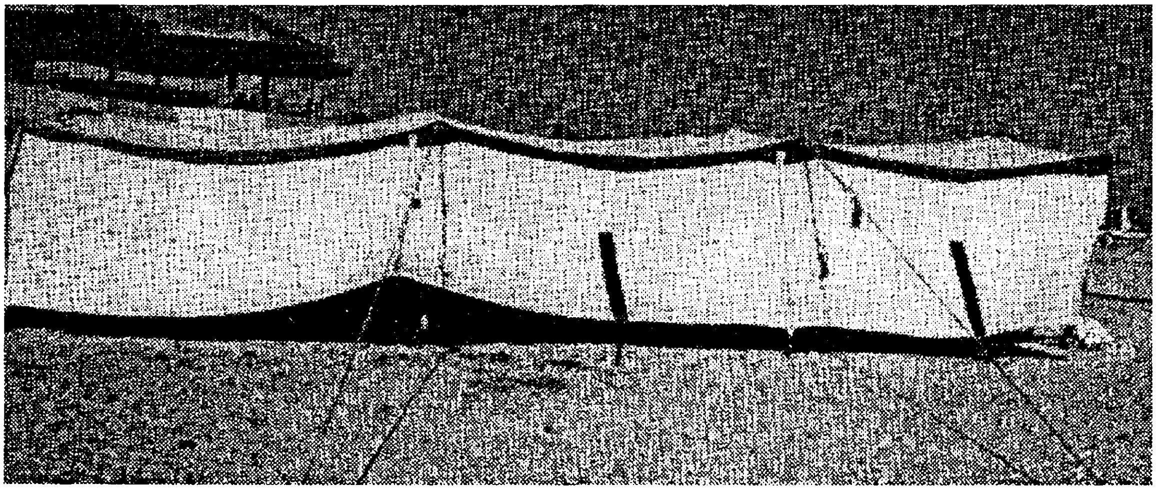


Fig. 3

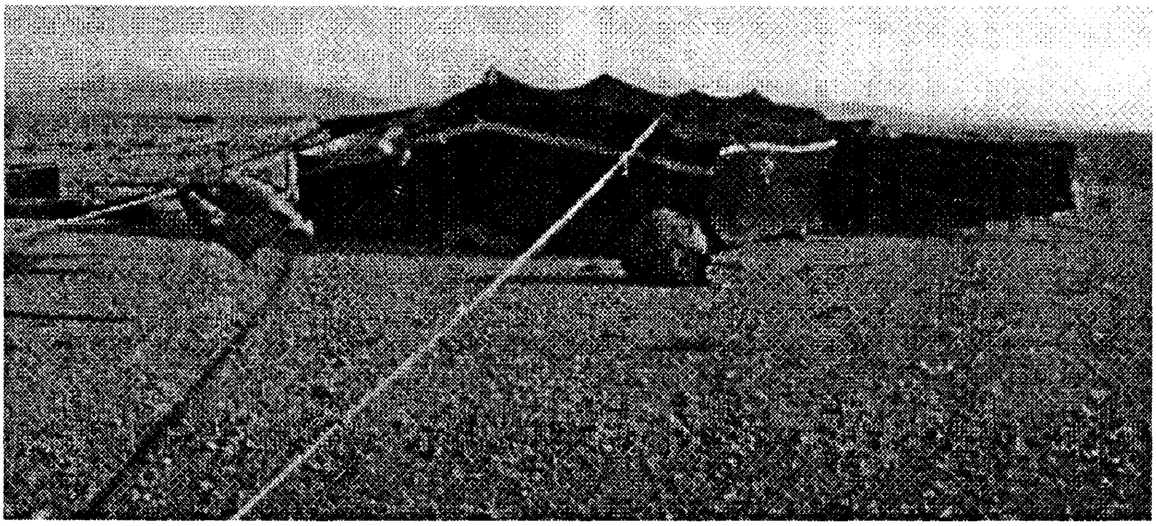


Fig. 4

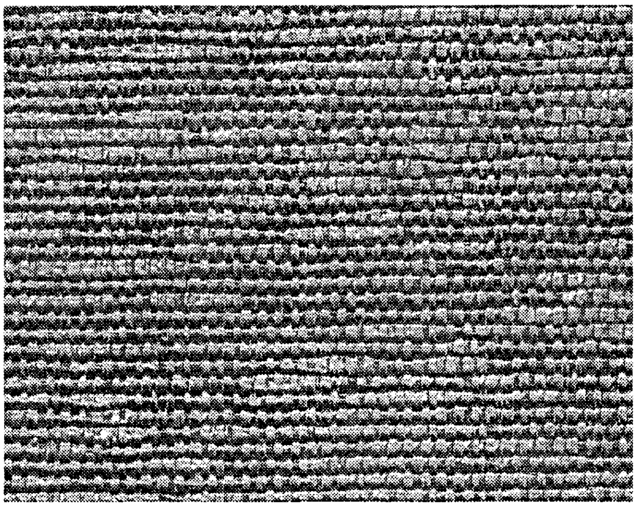


Fig. 5

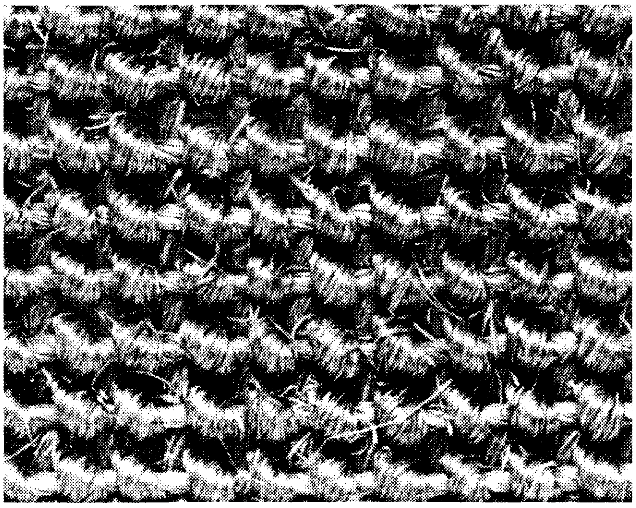


Fig. 6

These woven fabrics are rather technical textiles of special types. They are produced up till now on the hand looms and producers of them have firm stabilized economical situation today as hundred years ago.

These constructions also actuate emotions, feelings and physical senses. Fabrics should posses very important mechanical, endurance, resistance, engineering features which are a elementary base of these constructions. This base is indispensable for long period of working of these fabrics. Perceiving textiles in this case gives a impression of hardness, roughness, certainty of protection.

The summer tent Fig. 3 is made from bright cotton and assure suitable airy, sun and torrid heat protection. The winter tent Fig. 4 is made from black wool and during wet weather automatically enlargers filling of fabric (fibres swelling) and give better protection from cold and rain. Any attempt to change something, for example, colour of tent is in advance has to fail. The reason is not a suitable set of account of useful, technical parameters but of social resistance.

On Fig 5 [1] and Fig. 6 [1] two plain woven fabrics are shown. Their outside forms differs very decidedly. The difference is seen in colours, type of fibres, thickness of yarns, densities of threads, roughness. In this case a description of these fabrics use a set of factors and values of parameters which are more simple to define than before.

Type of used fibres, colours, twists, more complex structures of threads which can be enriched by bunches of fibres, additional threads and more complex systems allows to receive a gigantic number of structures, properties, influences of textiles. If we take into account constantly growing a range of new fibres, their modifications then the mention possibilities became practically infinite. This situation considerably extended our knowledge.

This knowledge constantly increases. Lately we observe an acceleration not only new information joined with old times of textile production but also impetuous increase of new textile products, their properties, functions.

Nowadays these products create group of objects which are necessary for proper functioning of people in every places of the world. However our accustom to a fact that textiles are generally accessible, cheap, various and ubiquitous makes that we treat them as always existing element and often we do not notice a very important, strategic sense of them for a single human being and for communities and countries as well.

To see this very humanistic aspect of textiles it is enough to trace history of their creating, techniques, symbolic and pattern-designing, relations between them and users.

It is possible to transform well known saying of sir Churchill that man is creating textiles and textiles influence man. It simply means that mechanical, chemical properties of textiles, their outside forms, their physical and visual perceiving have essential influence on our behaviour. Our behaviour will be different when we will be in dinner-jacket or evening dress and will be different when we will be in uncomfortable, may be devastated working dress. It will change our state of mind, thinking. Our physical and emotional feelings will change too. Then features of textiles affects, more or less, on our quality of life, our decisions, behaviour, mood. It is something like feedback which exist all the time we have a contact with textiles.

If we agreed that textile workers using these action are able to affect on people then it generates a need to analyse of this phenomena to fully consciously control of it. Something of special responsibility of textiles producers is appeared.

Nowadays we are witnesses of gigantic development of new modified fibres, methods and types of textile finishing, add to this products new sometimes very shocking features and functions, new structure, textures and this knowledge grows very quickly. A textile product has its characteristic features and is able to influence human being. It can create electricity, can be therapeutic, can keep or destroy injury microbes, can be very resistant, can be antiseptic etc.

Then beyond clear and easy visible influence, for example, visual there is also hidden, not always consciously felt and inspected affect of the textiles. The level of this force is usually no so high. In longer period of time these changes joined with textiles influence can be cumulated giving more visible effects. But noticing these effects and connection of effect with causes is difficult because of long time where these influences exist. The various others factors affects in this period of the time simultaneously and often they are not joined with textiles.

Now the question can be put. What is the level and what type of effect which is created by initiated modifications and enriching of chemical, mechanical properties of fibres, textiles, changes in mediums and technology of textiles. Mostly positive or negative? How many percents positive, how many percents negative? It is very up-to-date question and it requires more precise answer.

Bibliography

1. Jack Lenor Larsen, *Material Wealth, Living with luxurious Fabrics,* Abbeville Press, New York, 1989
2. Hala Tuffaha Al Jabi, *A possibility of using of covers and principles of traditional Bedouins tents for contemporary functions joined with living in a desert,* Doctor's Thesis, 1998.

POLYBLENDS BASED ON POLYAMIDE 6

Ducháček, V., Šimek, J., Kuta, A., Roslaniec, Z.*

Department of Polymers, Institute of Chemical Technology, Prague, Technická 5, 166 28 Praha 6, Czech Republic
(e-mail: Vratislav.Duchacek@vscht.cz)

**Institute of Materials Engineering, Technical University of Szczecin, Piastow Av. 19, 70-310 Szczecin, Poland*

New and growing demands on polymeric materials cannot be satisfied in future by an assortment extension of basic polymers since it is going to be very difficult for new macromolecular compounds to establish themselves in a group of well-positioned polymers. In the other hand, new products based on the modification of existing polymers have been fruitful areas for both scientific and commercial developments. Our present work deals with polyamide 6 modification with rubbers, especially with styrene-butadiene rubber. It has shown, that there is the possibility of obtaining modified polyamide 6 using a practically non-polar modifier in the absence of other additives at optimum processing conditions. Its thermo-oxidative stabilization is possible as well.

INTRODUCTION

Although polyamides as fibres were invented in the later 1930s and introduces commercially in the 1940s, they are still the most important thermoplastics base [1]. Among many major polyamide applications, the tough life of parts is a leader in engineering polymeric materials development [2]. For this reason, our present contribution deals with tough polyblends based on combinations of polyamide 6 (PA 6) with elastomers, especially with styrene-butadiene rubber (SBR).

The Choise of an Elastomer

Figure 1 shows effects of additions of different rubbers to PA 6 on the impact strength of polyblends as a function of concentration. It can clearly be seen that SBR was the most effective impact modifier in this case [3].

That is why we have aimed our work first of all at a study of PA 6/SBR polyblends preparation. Experimental results show that there are significant differences in the values of material properties arising form the different conditions of the melted blend processing [4].

Processing Conditions

An impact efficiency of SBR depends significantly on the conditions of mixing. Wu [5] has found that there are three basic conditions for good impact properties of polyamide/rubber blends:

- a strong adhesion between polyamide and rubber phases,
- a convenient size of rubber particles, and
- a spacing between two rubber particles smaller than critical (near the particle size, i. e., about 300 nm).

These conditions can be achieved by using powerful shear forces during polyblend preparation, i.e., mixing polymers at relatively high rotor rates and low temperatures. Figure 2 shows that a polyblend mixed at

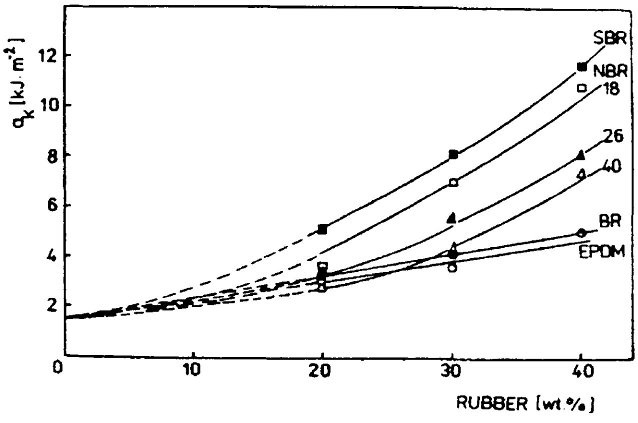


Fig. 1 Effect of the rubber type on the concentration dependence of Charpy notch impact strength, a_k, of PA 6 based polyblends mixed in a Brabender Plasti-Corder at 225 °C and 60 r.p.m. Numbers at the curves show the acrylonitrile content inacrylonitrile copolymer (NBR) used.

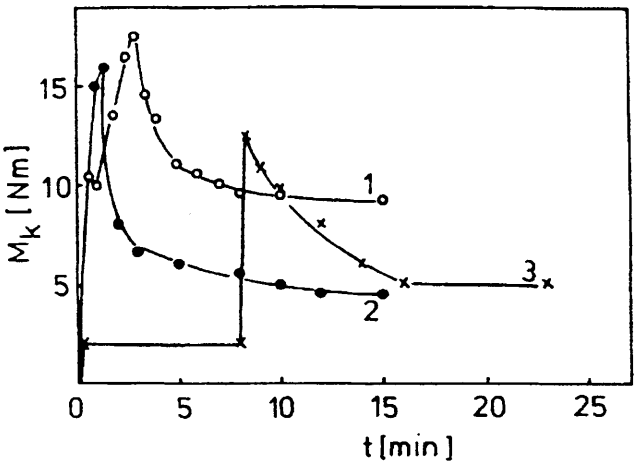
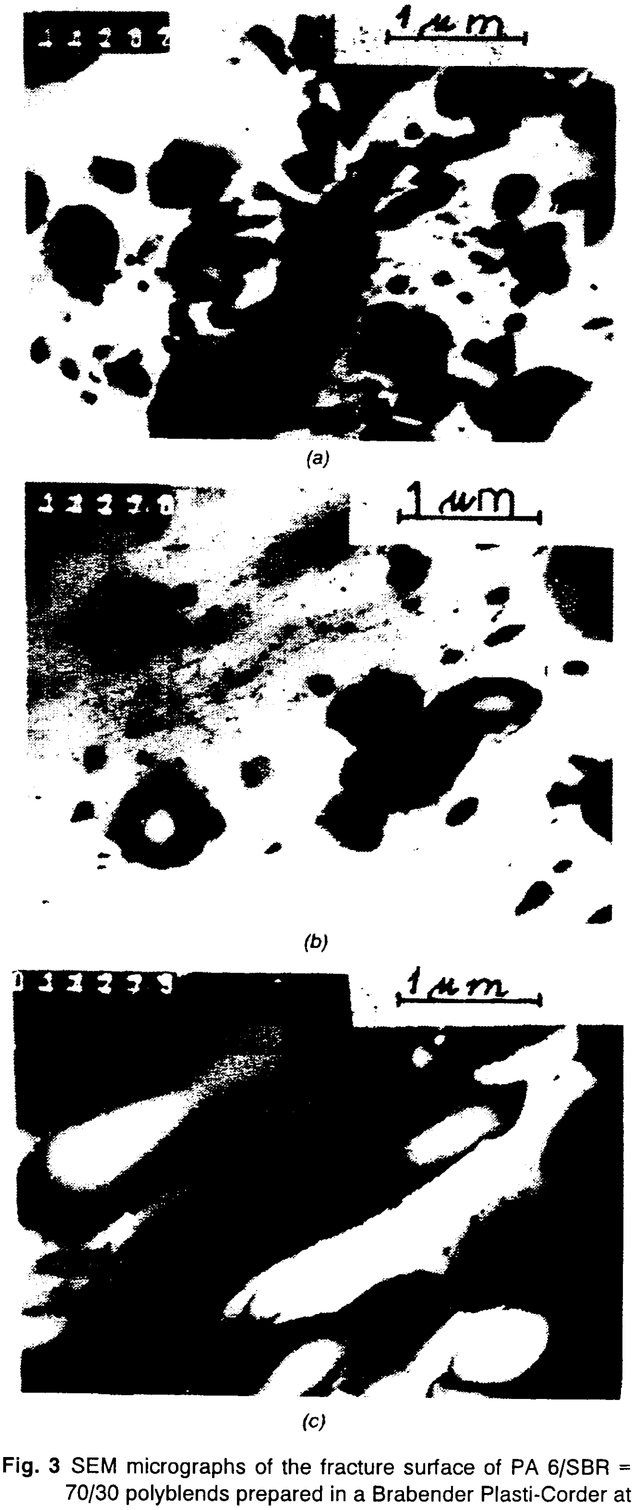


Fig. 2 Dependence of the torque, M_K, of a PA 6/SBR = 70/30 polyblend on the mixing time, t, in a Brabender Plasti-Corder at: 1–210 °C, 100 r.p.m., without rubber plastication, 2–230 °C, 100 r.p.m., without rubber plastication, 3–230 °C, 50 r.p.m., 8 min rubber plastication.

210 °C has been strained much more than that mixed at 230 °C. Also the rate of degradation processes is diminished at lower temperatures [4].

Powerful shear forces produce free-radicals via a scission of macromolecular chains. Subsequently, mechanochemical grafting takes place [6], which leads to an increase in adhesion between rubber particles and a polyamide matrix.



(a)

(b)

(c)

Fig. 3 SEM micrographs of the fracture surface of PA 6/SBR = 70/30 polyblends prepared in a Brabender Plasti-Corder at 100 r.p.m., and 200 °C (a), 210 °C (b), 240 °C (c).

Mechanical Properties of Polyblends

After mixing, ground polyblends were pre-heated at 240 to 250 °C between polytetrafluoroethylene coated steel plates for 10 minutes and then pressed 2 minutes in the form under a pressure of 30 MPa. Pressed plates were cooled 3 minutes in an unheated press before opening the form.

Charpy notch impact strength (in a Ceast Resil apparatus, 5.5 model) and tensile properties (in an Instron Universal Testing Machine, 1122 model) were measured at 23 °C. The testing methods have been fully described before [4].

An intense mixing process results in the formation of a sufficiently small rubber particle size, as well as a particle spacing smaller than critical. SEM micrographs of the fracture surfaces have shown also that the impact strength values depend strongly on the degree of distribution of rubber particles in the polyamide matrix. Figure 3 demonstrates that the finest and most uniform dispersion of the rubber phase in the PA 6/SBR = 70/30 blend [Figure 3(b)] corresponds to its highest value of Charpy impact strength shown in Figure 4, where dependence of tensile strength, elongation at break and Charpy notch impact strength on the SBR content in polyblends prepared at optimum conditions of their processing are shown. It is clear that by increasing the rubber content in a polyblend, tensile strength values decrease significantly. In the concentration range from 20 to 30 % rubber, elongation at break as well as Charpy notch impact strength values increase significantly [7]. Polyblends with 40 % SBR content have properties near those of thermoplastic elastomers. Elongation at break reached nearly 100 % and tensile strength 60 MPa [8].

Thermo-oxidative Stability of Polyblends

Because of the low thermo-oxidative stability of both polymers, some loss in impact strength values of polyblends can take place in spite of the theory and can be elucidated by an increase in the polymer blend porosity [9]. That is why the next goal of our work was to study the effects of antidegradants on the impact strength of PA 6/SBR blends [10].

SBR has lower thermo-oxidative stability than PA 6 under used mixing conditions. For this reason, our first step in the thermo-oxidative stabilization study was to evaluate the effects of rubber antidegradants on the properties of PA 6/SBR polyblends. For the same reason, the concentrations of the antidegradants used have been expressed in parts per hundred weight parts of the rubber (phr).

Amine and 1,4-disubstituted phenylene diamine types of rubber antidegradants are of less officiency than imidazole, phenol, and phosphite ones in the presence of which the Charpy notch impact strength values

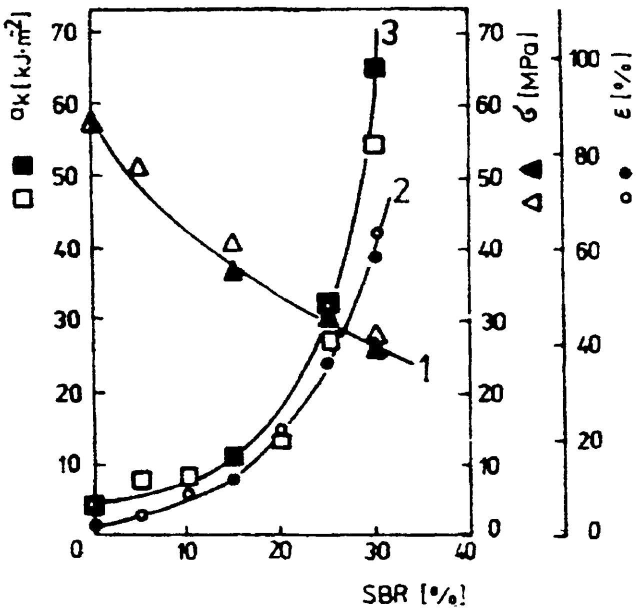


Fig. 4 SBR concentration dependence of tensile strength (1), σ, elongation at break (2), ε, and Charpy notch impact strength (3), a_k, of PA 6/SBR polyblends non-stabilized (white experimental points) and stabilized with 3 phr of the antioxidant based on a liquid blend of phenyl-ethyl-phenols (black experimental points) prepared in a Brabender Plasti-Corder at 210 °C and 100 r.p.m.

increase from 54 $kJ.m^{-2}$ to about 70 $kJ.m^{-2}$ at room temperature. The explanation of this finding can be derived from the idea that these antioxidants are effective not only in the rubber phase but also in the polyamide one [11–18]. It can be see from Figure 4 that the phenol based antioxidant does not significantly influence the courses of the concentration dependencies of either of the tensile properties, but increases the Charpy notch impact strength values at SBR concentrations 25 and especially 30% [4, 7].

CONCLUSIONS

Preparation of PA 6/SBR binary polyblends has confirmed that there is the possibility of obtaining tough PA 6 using a practically non-polar modifier in the absence of other additives at optimum processing conditions.

On the other hand, a suitable addition of rubber antidegradants, namely based on phosphites, phenols, and 2-mercaptobenzoimidazole, increases the impact strength of the polyblends based on PA 6/SBR combination up to a level corresponding to the high impact resistant types of polyamides.

Acknowledgement

The support of the Ministry of Education, Youth and Physical Training of the Czech Republic (through research grant CEZ:MSM:223100002) is gratefully acknowledged.

REFERENCES

1. Hornfeld H.: Engineering Thermoplastics - An Overview. In: Competitiveness and Best Practices in Developing Engineering Plastics Applications (Economic Commission for Europe, Ed.), p. 3. United Nations, New York and Geneva, 1999.
2. Daykin S.: Best Practices in Developing Engineering Plastics Applications. Ref. 1, p. 85.
3. Ducháček V., Mastný L., Kuta A., Kozlowski M., and Králíček J.: Modification of Polyamide 6 by Elastomers. In: 4th Polish Conference on Polymer Modification and Application, Vol. I, pp. 69–79. Rydzyna, 1990.
4. Mastný L., Kuta A., Kozlowski M., Ducháček, V., and Králíček J.: Polimery (Warsaw) 36, 71 (1991).
5. Wu S.: Polymer 26, 1855 (1985).
6. Braun B. and Eisenlohr U.: Angew, Makromol. Chem. 58/59, 227 (1977).
7. Ducháček V.: Adv. Polym. Blends Alloys Technol. 5, 217 (1994).
8. Ducháček V., Součková M.: J.Polym. Eng. 13, 305 (1994).
9. Krsová A., Čmakal J., and Neuhausl F.: The Structure of Polyamide 6 Modified with Elastomers. In: 5th Czechoslovak Conference on Polyamides, pp. 110-116. Chlum u Třeboně, 1987.
10. Ducháček V. and Mastný L.: The Significance of Thermo-oxidative Stabilization for the Impact Strength of Polyamide 6/Styrene-Butadiene Rubber Blends. In: 6th Polish Seminar on Polymers in Machine Construction, pp. 321–329. Krakow, 1991.
11. Štěpek J., Zelinger J., and Kuta A.: Processing Technology and Properties of Plastics, pp. 113–121, 247–251. SNTL/ALFA, Prague, 1989.
12. Chopff G.A., Muller A., and Venger F.: Polyamides. Goschimizdat, Moscow, 1958.
13. Ital. Patent 500,035 (1954).
14. U.S.A. Patent 2,705,227 (1955).
15. French Patent 1,001,819 (1957).
16. French Patent 1,002,254 (1957).
17. French Patent 1,002,534 (1958).
18. U.S.A. Patent 2,849,446 (1968).

INFLUENCE OF PIGMENTS ON THE PROPERTIES OF POLYPROPYLENE FIBRES AND YARNS

Van de Velde, K., Rambour, S., Kiekens, P.

Ghent University, Department of Textiles, Technologiepark 9, B-9052 Zwijnaarde, Belgium
kathleen.vandevelde@rug.ac.be

Coloured polypropylene fibres are mainly obtained by the spin-dyeing technique in which pigments are added to the polymer melt during extrusion. The addition of pigments can greatly affect the quality of the end product. This work deals with the characterisation of royal blue and dark blue yarns, the corresponding colour concentrates and pigments. Different pigments and colour concentrates are analysed with TGA (thermo gravimetrical analyses), DSC (differential scanning calorimetry) and CILAS (laser particle size analyser). The colour properties of the yarns are measured with a spectrophotometer. The thermal and optical analyses of the colour concentrates and yarns are carried out with DSC and OM (optical microscopy).

INTRODUCTION

Polypropylene fibres find major application in carpets, thanks to the good properties (low density, good chemical resistance, good antistatic properties, availability, price, ...) [1]. Coloured polypropylene fibres are mainly obtained by the spin-dyeing technique in which pigments are added to the polymer melt during extrusion. The addition of pigments can greatly affect the quality of the end product. This work deals with the characterisation of royal blue and dark blue yarns, the corresponding colour concentrates and pigments. Different pigments are analysed by means of TGA (thermo gravimetrical analyses), DSC (differential scanning calorimetry) and CILAS (laser particle size analyser). The colour properties of the yarns are measured with a spectrophotometer. The thermal and optical analyses of the colour concentrates and yarns are carried out with DSC and OM (optical microscopy).

MATERIALS AND METHODS

Royal blue and dark blue polypropylene yarns (2150 dtex) and their corresponding colour concentrates and pigments are studied [2].

The properties of the used polypropylene used are given in table 1.

Royal blue (3041) and dark blue (30293) coloured polypropylene are analysed.

Table 1 Properties of polypropylene

$\overline{M}_w$	222 600
$\overline{M}_n$	37 900
MFI (230, 2.16)	26
MFI (290, 2.16)	87
T_m (°C)	161.5
T_c (°C)	116.5

These colours are obtained by a mixture of different pigments. The colour index number of the pigments in the different masterbatches is given in table 2. The chemical class of the pigments is listed in table 3.

The thermal stability of titanium oxide and the blue, red and black pigments was recorded with a Thermal Analysis Hi-Res TGA 2950 Thermogravimetric Analyser from 30 °C till 500 °C at 10 °C/min under inert He-atmosphere. Thermal analyses on pigments, colour concentrates and yarns were carried out with a TA Instrument 2920 Modulated DSC (differential scanning calorimetry) at 10 °C/min under inert N_2 atmosphere. The pigment particles were measured with a CILAS 1064 laser particle size analyser. The colour properties of the yarns were measured with a spectrophotometer Datacolor Data Flash 100. The colour concentrates and yarns were optically analysed with a Nikon Optiphot optical microscopy and processed by means of the LUCIA Image Analysis System.

Table 2 Pigment composition of masterbatches

Royal Blue (RB)	Dark Blue (DB)
PB 15:1	PB 15 :1
PR 48:2	PR 57 :1
PW 6	PW 6
PBK 7	PBK 7

Table 3 Colour Index Number, chemical class of pigments and their concentration in mono pigmented colour concentrates

Colour Index	Chemical class	% pigment
PB 15:1	Phtalocyanine (alpha) Cu complex	40
PR 48:2	Monoazo Ca salt	30
PR 57:1	Monoazo Ca salt	30
PW 6	Titane dioxide	50
PBK 7	Carbon black	40

RESULTS AND DISCUSSION

Thermogravimetric analyses

Thermographs of the different pigments are shown in figure 1.

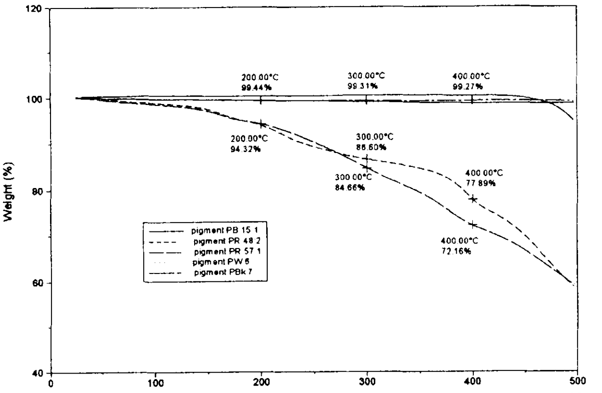


Fig. 1 Thermographs of the different pigments

The blue pigment PB 15:1 is thermally stable until 400 °C. As a maximum process temperature of 235 °C is used for the extrusion process, this pigment is perfectly usable under these conditions. Pigment red PR 57:1, the Calcium salt of 6-amino-m-toluene-sulphonic acid and 3-hydroxy-2-naphtoic acid, shows a weight loss of 5% at 200 °C. At 300 °C, the residual weight is 85 %, whereas 72 % of the initial weight remains at 400 °C. A further decrease is observed. A weight reduction of 6% was measured at 200 °C for the chlorinated pigment PR 48:2, whereas at 300 °C a weight reduction of 13% was observed [3]. The initial weight drop could be related to the water content of the red pigment. A water content of 9–16% was measured for the red pigments by Karl Fischer titration. The other pigments have water contents of about 1 %. It is advised to dry the red pigments before processing. Titanium oxide and carbon black are thermally stable up to 500 °C, as expected.

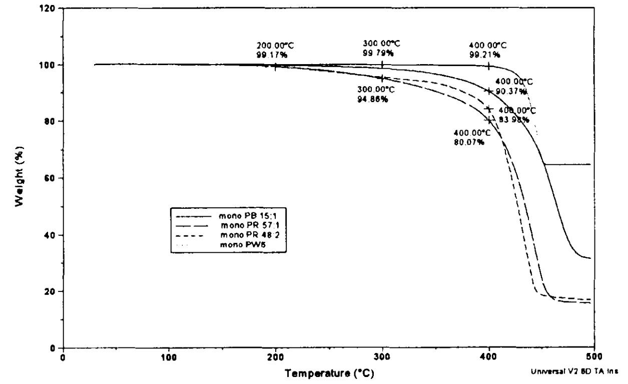


Fig. 2 Thermographs of the different colour concentrates

The colour concentrates of the individual pigments were also screened on their thermal stability (see figure 2). Due to the presence of polypropylene, all colour concentrates degrade at about 400 °C and are less stable than the corresponding pigments, except the red one. The red colour concentrates is more stable than the corresponding pigment because some weight reduction already occurred during processing.

Thermal analyses

Thermal transitions are analysed with DSC. No transitions between 20 and 200 °C were observed for the pigments.

Some thermograms of the mono pigmented colour concentrates are shown on figures 4 and 5, a detail is given in figure 3. The first endotherm is related with melting of the waxes. The second peak is a melting endotherm of polypropylene. The melting enthalpy varied between 40 and 64 J/g.

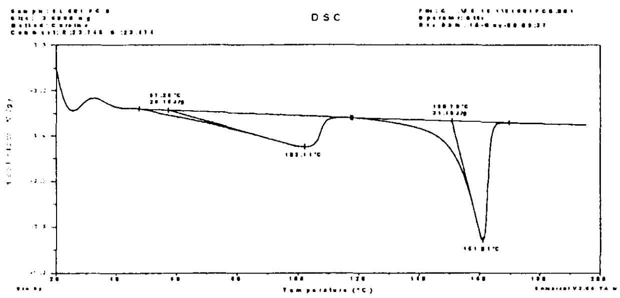


Fig. 3 Thermogram of PB 15:1 containing colour concentrate

The endotherms of polypropylene, dark blue and royal blue yarn reveal that all melting peaks are situated around 162 °C. The enthalpy is between 95 and 155J/g. The crystallinity of the blue yarns is higher than for the polypropylene yarns e.g. 51 % versus 45 %. The exotherms for the yarns and the corresponding mono pigmented colour concentrates are illustrated in figures 4 and 5. Figure 6 shows the cooling curves for polypropylene granulate and yarn. The crystallisation temperatures of the blue yarns are situated around 128 °C, which is 8 °C higher than for the polypropylene yarns. The enthalpy of crystallisation for the blue yarns is about 105 J/g, for the polypropylene yarn it is 98 J/g. A comparison between the crystallisation temperatures of the dark blue and royal blue yarns and the colour concentrates, pointed out that the blue pigment act as nucleating agent for polypropylene. The crystallisation temperatures are increased. The crystallinity of the blue pigmented colour concentrates are decreased. The nucleating role of the blue pigment was proven by microscopic analyses as smaller crystallites were seen for dark blue and royal blue polypropylene compared with lighter colours. The pigment red PR 48:2 has a slight nucleating role, whereas PR 57:1 shows no nucleating effect. Ripke classified the nucleating effect of

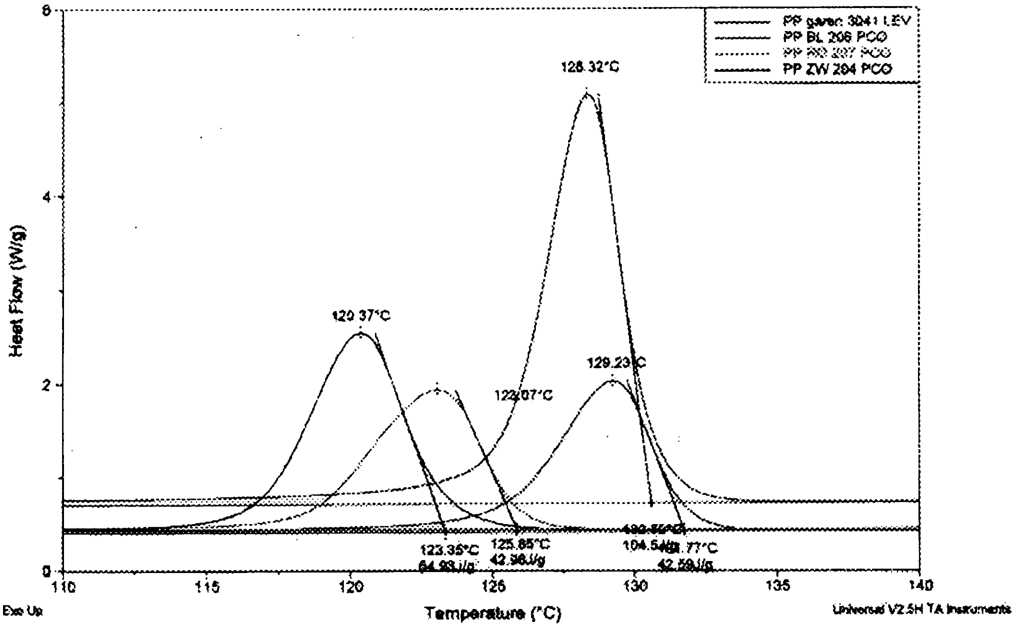


Fig. 4 Thermograms of dark blue yarn and corresponding colour concentrates

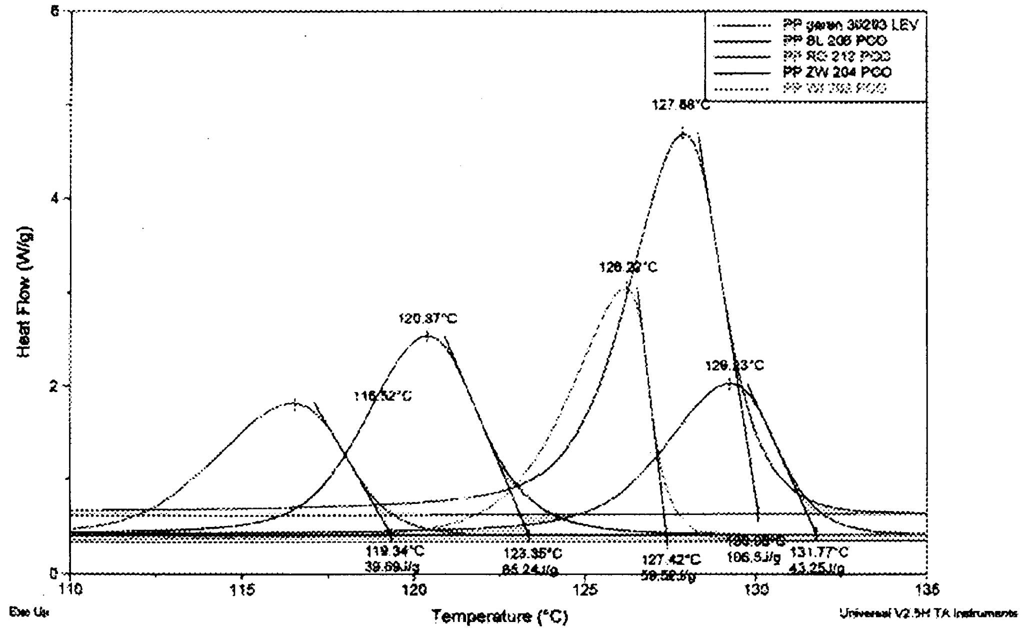


Fig. 5 Thermograms of royal blue yarn and corresponding colour concentrates

PB 15 as very high and the nucleating effect of PR 48 and 57 as very low [4]. The endotherms for second heating show a melting peak temperature of 160 °C for the polypropylene yarn and 163 °C for the blue yarns. The crystallinity of the blue yarns is 6 % higher than for the uncoloured yarn (56 versus 50 %). It can be concluded that the blue yarns crystallise at a higher temperature due to the nucleating role of the blue pigment and more temperature stable crystallites are formed.

Particle size analyses

Green pigments from different companies were compared on particle size and colour strength. 100 % colour strength was related to pigments (from company A) of which 90 % have a maximum particle size of 12 μm. The colour strength of the yarns decreased as the pigment particle sizes increased.

Optical Microscopy

Pigmented polypropylene samples were taken out of the extrusion process line, just after leaving the spinneret. These samples were first heated at a controlled rate of 20 °C/min from 20 °C to 200 °C, held at this temperature for 3 minutes and subsequently cooled down

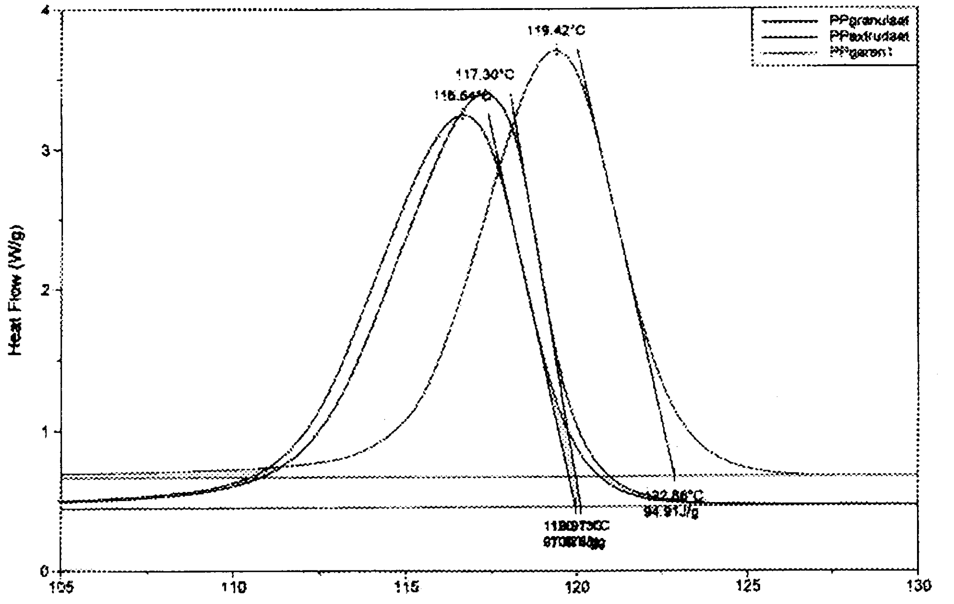


Fig. 6 Thermograms of polypropylene

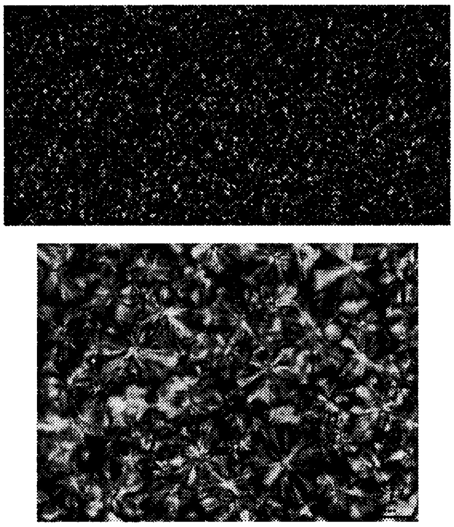


Fig. 7 Micrographs of blue and uncoloured polypropylene

to 20 °C at 10 °C/min. The polymer films obtained were optically analysed under polarised light. Optical micrographs are shown in figure 7. The blue samples are compared with pure polypropylene. Spherulites, with an average diameter of 50 μm, are determined for pure polypropylene. The crystallisation of dark blue and royal blue polypropylene resulted in the formation of a lot of very small crystallites due to the presence of some pigments acting as nucleating agent. The crystallites are formed at a higher temperature (see DSC results) and

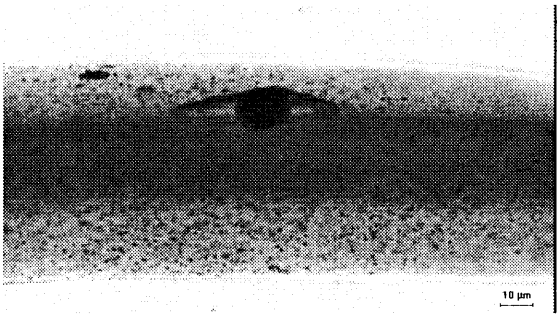


Fig. 8 Micrograph of blue polypropylene yarn

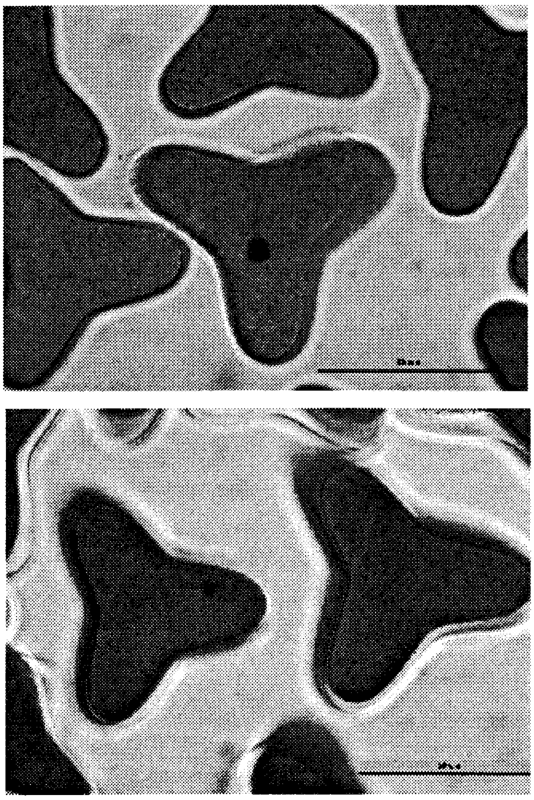


Fig. 9 Micrographs of cross sections of dark blue (a) and royal blue (b) yarn

are much smaller than for non-pigmented polypropylene.

The strengthened BCF-yarns were studied in longitudinal direction as well as crossways under the optical microscope. Pigment aggregates were observed, the longest side of which is directed along the longitudinal axis. Around the aggregates there is generally a gap in the shape of an eye in the polymer matrix, formed while drawing the fibre. Figure 8 illustrates the presence of blue aggregates in the dark blue and royal blue yarn. Infra red spectroscopy confirmed that the aggregate consists of phtalocyanine blue pigments. Few and smaller red aggregates were optically detected.

Micrographs of cross sections of embedded yarns are presented in figure 9. The dark blue yarn contains aggregates varying from 1.5 till 6.5 μm. The pigment aggregates observed in the royal blue yarn have an average diameter of 2.5 μm. The quality of dispersion is good, since only 5 % of the pigment particles are larger than 5 μm, which is one tenth of the trilobal fibre section [5]. Most aggregates are formed by the pigment blue α-Cu-phtalocyanine. The pigment red has less tendency to form aggregates.

CONCLUSIONS

Royal blue and dark blue yarns, the corresponding colour concentrates and pigments were analysed on their thermal, optical and colour properties.

Thermogravimetric results show a good thermal stability for all the pigments, except the red one PR 57:1. This could be due to the water content of this pigment. It is advised to dry this pigment before processing. Thermal and optical analyses indicate that the blue phtalocyanine pigments act as nucleating agents. Their presence leads to higher crystallisation temperatures of polypropylene. A higher thermal stability of yarns containing these pigments was observed. These phtalocyanine pigments also have the tendency to form aggregates that can lead to filter obstruction while processing. The aggregates are also possible weak points in the fibres. The particle size distribution of the pigments is in agreement with the colour properties.

REFERENCES

1. Ahmed M. (1982), Polypropylene Fibers-Science and Technology, Elsevier Scientific Publishing Company, Amsterdam, the Netherlands.
2. Sergeant C. (2000), Influence of pigments and raw materials on the properties of polypropylene fibres and yarns (in Dutch), Dissertation Master of Textiles, Ghent University, Belgium.
3. Rambour S., Van de Velde K., Kiekens P. (2001), Properties of red pigments for polypropylene, 2nd Benelux-Symposium on 'Extrusion: fibre-engineering', Ghent, Belgium.
4. Ripke C. (1996) World Textile Congress on Polypropylene in Textiles, University of Huddersfield
5. Van Wassenhove V. (2000), Analyses of pigment dispersions in colour concentrates and polypropylene yarns (in Dutch), Dissertation Master of Textiles, Ghent University, Belgium.

THE INFLUENCE OF BLEACHING AND MERCERIZATION OF COTTON ON THE CHANGES OF ELECTROKINETIC POTENTIAL

Pušić, T., Grancarić, A. M., Soljačić, I.

University of Zagreb, Faculty of Textile Technology, Pierottijeva 6, Zagreb, Croatia
tpusic@ttf.hr, amgranca@ttf.hr, isoljacic@public.srce.hr

Cotton is modified in pre-treatment finishing processes and its physical properties are changed. The intensity of these changes depends upon the conditions under which processing is done. The properties obtained are the results of changes in micro and macro structure of the cotton treated fibres. The structural differences of the modified cotton, besides other properties, results also in changes of electrical charge of its surface. This paper deals with the influence of scouring, bleaching and mercerization on the electrokinetic potential of cotton fibres expressed as zeta potential. It is measured as dependent upon the pH of the electrolyte solution, as well as upon the quantity of surfactant added in the solution with the purpose of obtaining the point of zero charge (PZC) of the fibre surface.

Scouring and bleaching are alkaline treatments, where impurities and pigments are removed from the cotton fibre, which give it yellowish and unacceptable coloration. Pre-treatment processes should be optimised in order to obtain proper hydrophility, optimal whiteness degree and minimal fibre degradation.

The advantage of mercerization over some other finishing processes is multiple effects, not aimed at a single improvement what is the case with other processes. Mercerized cotton is distinguished by high lustre, strength, adsorptivity, transparency, smooth handle and lower loss of strength in high finishing.These effects can be attributed to micro and macro changes of cellulose polymers, reflected in microstructure, morphology and conformation of cellulose chains (cellulose I is transformed into cellulose II). Cellulose swells in alkali, while its chains are shifted apart and the structure is modified. The amorphous content of the fibre is increased, and crystalline reduced. Hydroxyl groups are more accessible, which results in higher adsorptivity of the mercerized cotton, as compared to unmercerized one.

Sarko et.al., in a series of papers dealing with possible forms of cellulose conformation in mercerization, present a mechanism of mercerization which includes shifting and rotation of cellulose chains [1–4].

The intensity of these changes depends upon the concentration, temperature and wetting properties of the alkali solution used, duration of the treatment, applied tension, as well as upon construction of the cotton product treated.

The modification of the mercerized cotton is reflected in the structure changes, appearance, surface properties, accessibility of hydroxylic groups and surface charge. Surface fibre charge is important in wet processing of cotton, so it is important to describe electric properties of fibre surface applying electrokinetic methods. These methods are based on four phenomena occurring as a result of relative movement of one of the phases in the polymer/electrolyte solution system. Electrokinetic phenomena are described using a model of electric double layer created at the interface fibre/electrolyte aqueous solution. Electrokinetic double layer is characterised by its zeta potential which offers an assessment of the nature of functional groups of a fibre, type and number of dissociating groups, hydrophility, fibre surface hydrophobity, as well as ion and water adsorption from the solution used [5].

Most textile fibres are negatively charged in neutral aqueous solutions. Electronegativity of cotton fibres arises mostly from the presence of hydroxyl or carboxylic groups. S. M. Neale who was the first described the theory of mercerization, its importance in cotton finishing, and point out different zeta potential of mercerized and unmercerized cotton. There has been no systematic investigation of the influence of mercerization on the changes of zeta potential of cotton until now. The importance of mercerization in finishing processes, as well as the contribution of zeta potential in understanding and explaining dyeing process, adsorption, soiling and washing, together with quality control of cellulose in paper industry, obviously indicate the need for further investigations in the field. Zeta potential of textile fibres is determined applying electrokinetic methods of streaming potential/current and electrophoresis. It is well known that electric double layer can be created by dissociation of ionic molecule groups and/or by varied adsorption of cations and anions at the interface fibre/electrolyte solution [6].

Investigations described here deal with the influence of scouring, bleaching and mercerization on the zeta potential of cotton. Raw cotton fibres and yarn were mercerized, as well as bleached fibres and yarn. The zeta potential of cotton, mercerized at various stages was investigated, as dependent upon the pH of electrolyte solution and the amount of cationic surfactant necessary to neutralised the negative zero charge, called PZC (Point of Zero Charge). Zero charge in an aqueous medium is an important condition of the fibre, and can be expressed by two values – isoelectric point (IEP) and Point of Zero Charge (PZC) [7]. Isoelectric point (IEP) is associated with the pH value of the electrolyte solution at which zeta potential of a textile fibre is zero. Fibres have different and characteristic IEP, at particular temperature and concentration of electrolyte solution.

Point of Zero Charge (PZC) is associated with the amount of counter-ion added to the electrolyte solution at a constant pH, which results in zero zeta potential. It depends upon the type of fibre processed and ion which defines it.

EXPERIMENTAL

The influence of pre-treatment, scouring, bleaching and mercerization process on changes of zeta potentials of cotton fibres and yarns was investigated. Fibres and yarns of the following characteristics were used:

Cotton fibres	Cotton yarns
length: 28.5–29.4 mm	fineness: 62.5x2 tex
Micronaire: 3.8–4.2	*310 twists/m, Z direction*

Treatments

The following processes were used:

- scouring (S) following the AATCC Test Method 89-1985
- bleaching (B) the cotton with H_2O_2 under mild conditions
- mercerization (M) of raw and bleached fibres and yarns in slack state, using various NaOH concentrations (15%-M15, 20%-M20 and 24%-M24), as well as yarn mercerisation under tension (24%-M24S). Various NaOH solution concentrations in presence a wetting agent, TC Netzer MU2 (Textil Color), were used to obtain various degrees of mercerization. Temperature was 18 °C while the treatment lasted for 120 s. After the treatment in alkali solution, cotton was rinsed in a warm and cold water, neutralized and rinsed in water until neutral reaction was obtained.

Raw and raw mercerized cotton were scoured following the above method, while the bleached and mercerised were rinsed until a neutral reaction was obtained.

It is extremely important to prepare the sample of high purity for the purpose of zeta potential measuring. So, raw cotton after scouring was purified in methylene chloride, according to the DIN 54278. After purification, samples were rinsed in deionised water, until conductivity of 2–4 x 10^2 mS/m was obtained.

Methods

Zeta potential of cotton fibres and yarns was measured using Brookhaven-Paar electrokinetic analyser (EKA), with cells appropriate for textile fibres. The sample was placed between two electrodes (silver/silver chloride) and electrolyte solution was forced through the plug of fibres employing pressure. The potential difference created between the electrodes at the ends of the plug was the streaming potential at the applied pressure. Electrokinetic potential x was calculated from the measured solution parameters and streaming potential U_p, following Eqn 1, or from the streaming current I_p, using Helmholtz-Smoluchovsky equation (Eq. 2):

$$\xi = \frac{U_p \times L \times \eta}{\varepsilon \times \varepsilon_0 \times Q \times R \times \Delta p} \qquad (1)$$

$$\xi = \frac{I_p \times L \times \eta}{\varepsilon \times \varepsilon_0 \times Q \times \Delta p} \qquad (2)$$

where ξ is electrokinetic potential (mV), U_p is streaming potential (mV), I_p is streaming current (mA), ε_0 is permittivity of free space (Fm^{-1}) ($kgm^{-3}s^4A^2$), ε is permittivity of the test solution (Fm^{-1}) ($kgm^{-3}s^4A^2$), η is dynamic viscosity of the test solution (Pas) (kg $m^{-1}s^{-1}$), Δp is pressure difference between the inlet of the capillary system (Pa) (Nm^{-2}) and L is capillary length (m).

Zeta potential of cotton was measured at various pH of 1mmol/l potassium chloride and various amounts of

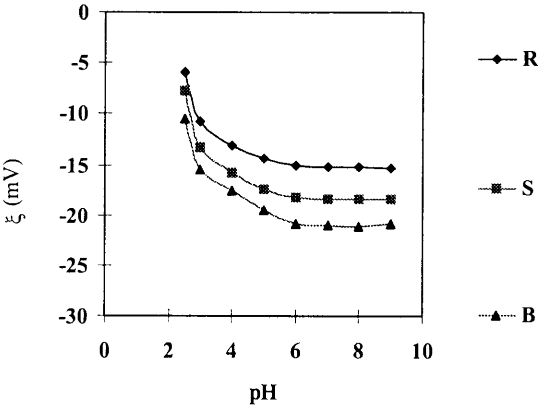


Fig. 1 Zeta potential of raw(R), scoured (S) and bleached (B) fibres against pH of 1 mmole KCl

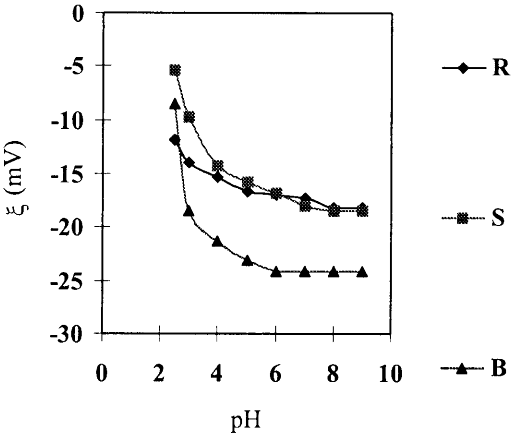


Fig. 2 Zeta potential of raw (R), scoured (S) and bleached (B) yarns against pH of 1 mmole KCl

cationic surfactant, cetylpyridinium chloride (CPC), added to the electrolyte solution under a constant pH value.

RESULTS AND DISCUSSION

Dependence of zeta potentials of cotton fibres and yarns treated in pre-treatment, scouring and bleaching processes against pH 1 mmol/l KCl can be seen in Fig. 1 and Fig. 2.

The curves in Fig. 1 show that raw fibres have the lowest surface charge in the whole pH range tested. Raw fibres are hydrophobic due to the impurities that partly cover their surface. Obvious result is absolutely lower surface charge. These impurities are partially removed in scouring, hydroxylic groups in cotton fibres are more accessible, and zeta potential is thus increased. Cotton fibres are bleached under mild conditions, but primary cell walls are removed nevertheless, carboxylate groups are present, which means further increase of charge. Pre-treatment processes, scouring and bleaching have a serious influence on the increase of electrokinetic potential of cotton fibres against pH of electrolyte solution.

The influence of scouring of cotton on its zeta potential is no significant, while the bleaching process has a definite influence (Fig. 2). Specific structure and construction of the yarn, as well as steric barrier may be possible reason of differences.

The influence of mercerization on zeta potential changes of raw mercerized cotton fibres, as well as zeta potential changes of bleached and bleached mercerized cotton fibres can be seen in Fig. 3 and Fig. 4.

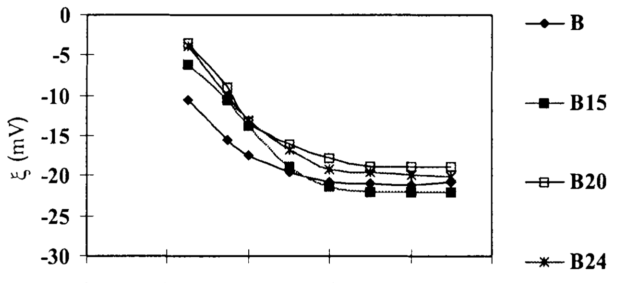


Fig. 4 Zeta potential of bleached (B) and mercerized (M) fibres against pH of 1 mmole KCl

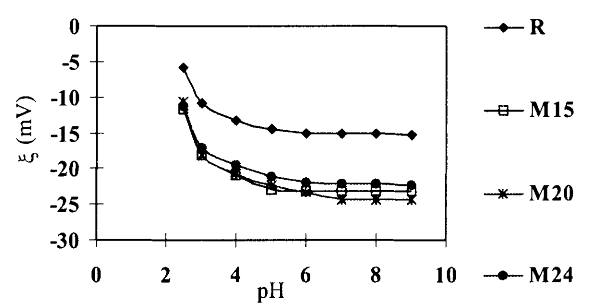


Fig. 3 Zeta potential of raw(R) and mercerized (M) fibres against pH of 1 mmole KCl

Mercerization of raw and bleached fibres definitely influences the zeta potential changes. The influence of mercerization of raw fibres is more pronounced (Fig. 3) than mercerization of bleached ones (Fig. 4), while the zeta potential variations of bleached fibres are more pronounced at pH 9 and pH 4. Generally, the influence of mercerization of bleached fibres on the changes of zeta potential is not significant, and the results obtained at lower values of pH are in accordance to those obtained by S. M. Neale [8].

The effects of mercerization on the zeta potential changes of raw yarns, as well as bleached one, can be seen in Fig. 5 and Fig 6. Raw slack mercerized yarn (M24) exhibits higher zeta potential dependent upon pH, while raw yarn mercerised under tension (M24S) shows lower zeta potential than raw yarn. The differences are due to cotton structural differences and mercerization effects. Yarn mercerized under tension is more compact in its structure, the structure is closed and more oriented in axis direction, so lower zeta potential is rightfully expected. Zeta potential differences among various degrees of mercerization (M15, M20 and M24) are more pronounced for yarns (Fig. 5) than for fibres (Fig. 3). It can be attributed to additional purification of cotton yarn in mercerization.

There is no significant influence of mercerization on changes in zeta potential of bleached yarns (Fig. 6), and the results are in accordance with those obtained for bleached mercerized fibres (Fig. 4). Bleached yarn mercerized under tension exhibits lower zeta potential, the explanation being the same as for raw yarn mercerized under tension.

Fig. 5 Zeta potential of raw (R) and mercerized (M) yarns against pH of 1 mmole KCl

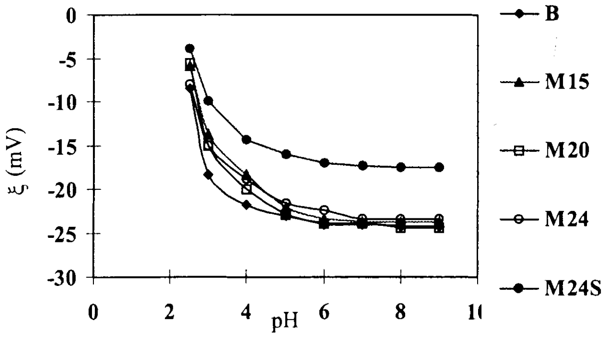


Fig. 6 Zeta potential of bleached (B) and mercerized (M) yarns against pH of 1 mmole KCl

Table 1 PZC of raw (R), scoured (S) and bleached (B) fibres and yarns

Treatment	CPC (μg/ml) fibres	yarn
R	94.08	111.00
S	78.03	84.21
B	68.37	70.03

Table 2 PZC of raw (R) and raw mercerized (M) fibres and yarns

Treatment	CPC (μg/ml) fibres	yarn
R	94.08	111.00
M15	68.00	79.97
M20	67.53	76.61
M24	68.75	77.67
M24S	–	67.66

Table 3 PZC of bleached (B) and bleached mercerized (M) fibres and yarns

Treatment	CPC (μg/ml) fibres	yarn
B	68.37	70.03
M15	59.08	62.75
M20	62.3	59.98
M24	60.03	57.67
M24S	–	57.41

The influence of pre-treatment on zeta potential changes of raw, scoured, bleached and mercerized fibres and yarns, as dependent upon the amount of CPC in electrolyte solution, at pH 8, can be seen in Tables 1–3. The amount of CPC necessary to neutralise negative surface charge of raw and bleached fibres is the same for raw and bleached yarns.

Hydrophobic raw fibres and yarns need the highest amount of cationic surfactant, CPC, to reach the point of zero charge. Scoured cotton reduces the amount CPC by some 20%, and bleaching by around 35% (Tab. 1).

More open structure of cotton fibres in scouring, bleaching and mercerisation makes better purification and lower amount of CPC necessary to neutralise negative surface charge, as compared to cotton yarn. The amount of CPC necessary to neutralize negative surface charge is directly related to the degree of hydrophility.

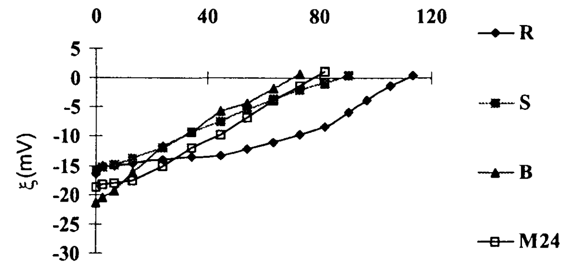


Fig. 7 Zeta potential of raw, scoured, bleached and mercerized yarns against amount of CPC in 1 mmole/l KCl at pH 8

Mercerization of raw and bleached fibres and yarns reduces the amount of CPC needed to reach the PZC. The fact has not been clearly established until now, and we consider it to be a significant contribution to the field of textile surface charge [9].

It also clearly confirms the fact that additional purification of cotton occurs during mercerisation. The amount of CPC for the cotton mercerized (M15, M20 and M24) is approximately the same, as real mercerization takes place in this range of alkali concentrations (cellulose I is transformed into cellulose II). Mercerization of yarn under tension (M24S), as compared to slack mercerization (M24), reduces the amount of CPC necessary to reach the PZC. This again indicates different effects due to changes in micro and macro structure of the fibres in mercerization.

CONCLUSIONS

Pre-treatment processes have a considerable influence on zeta potential of cotton. Raw cotton exhibits lower zeta potential due to impurities covering hydroxyl cellulose groups. Scouring increases zeta potential of cotton, as impurities are partially removed and accessibility of hydroxyl group is thus improved.

In the bleaching process raw cotton is treated by oxidative agents, causing improved purity and hydrophility and its zeta potential is increased as compared to raw one.

The changes in structure are greatly dependent on the treatment conditions. Slack mercerization rises zeta potential of cotton, while mercerization under tension tends to reduce it. It can be attributed to higher degree of fibre orientation, more closed and compact structure of the cotton mercerized under tension, as compared to the structure of slack mercerised cotton.

Pre-treated cotton posses higher hydrophility, the amount of CPC is reduced in order to reach the PZC of cotton what means that PZC is directly related to hydrophility of the material.

Bleaching and mercerization tend to lower the PZC of cotton. The influence of bleaching yarn has been more widely studied than the influence of bleaching loose fibres.

Results presented indicate that alkali treatments reduce the amount of surfactant necessary to reach point of zero charge on the surface of cotton materials.

REFERENCES

[1] T. Okano and A. Sarko, J. Appl. Polymer Sci., 29(1984) 417
[2] T. Okano and A. Sarko, J. Appl. Polymer Sci., 30(1985) 325
[3] H. Nishimura and A. Sarko, J. Appl. Polymer Sci., 33(1987) 855
[4] H. Nishimura and A. Sarko, J. Appl. Polymer Sci., 33(1987) 567
[5] H. J. Jacobasch, I. Grosse, Textiltechnik, 37 (1987) 266
[6] A. M. Grancarić, T. Pušić, I. Soljačić, V. Ribitsch, Text. Chem. Colorist, 29 (1997) 33
[7] S. Žalac, N. Kallay, J. Coll. Interfacial Sci., 149(1992)233
[8] S. M. Neale, R. H. Peters, Trans. Faraday Soc., 42(1943) 42
[9] T. Pušić, Dissertation, University of Zagreb, Zagreb, 1997

MODELING OF MASSTRANSFERE PROCESSES IN TEXTILE

Suprun, N. P.

Kiev State University of Technology and Designee

Comfortability is a key parameter of modern clothes. Heat and steam transport through the textile layers of clothing are the main physical processes occurring during clothing use. The main exchange between the underwear layer and environment is carried out due to presence of large number of pores. Those processes are similar to processes of fluid (gas, liquid or their mixture) filtration in the porous medium. The real textile materials have the certain structure with large number of defects and infringements of the ideal order in fibers disposition. For simplification, we shall consider textile material as a rectangular parallelepiped with sides H, L, l (L>>l) and the volume V= A l, where A is the area A = H.L, l – the thickness. Complete porosity m of such objects is:

$$m = V_{g,l}/V = V_{g,l}/A.l \qquad (1)$$

where $V_{g,l}$ – pore volumes, filled by fluid.

Let's enter the model of isothermal fluid filtration through textile material. Objectively, this model should display fluid configuration in all kinds of pores. The main idea of the model consists in splitting the thickness of textile material on some number of plane-parallel sublayers with the thickness d (on the Fig.1, for example, two such sublayers shown).

When modeling the fluid transport through textile material, we can consider it as a regular sieve with the effective pore having cross section area

$$\delta A \approx d^2\ [m^2] \qquad (2)$$

This assumption (2), alongside with an independent estimation of porosity m (1), gives quite reliable representation about the effective pore number (N_p/A) and their general area per surface unit of textile material:

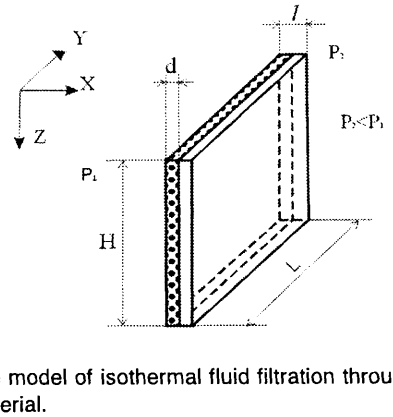


Fig. 1 The model of isothermal fluid filtration through textile material.

$$m = (N_p/A)dA \approx (N_p/A)d^2 \qquad (3)$$

Two required parameters – N_p and d connect approximately by experimentally determined values of A and:

$$N_p \approx (A/l)(1/d) \qquad (4)$$

By setting d – the basic structural parameter of textile material, it is possible to estimate N_p, then to establish a part of an open surface **m** in the unit of area of textile material, and to compare it with other independent porosity estimation.

The correctness of offered rations can be confirmed, comparing their prediction with known estimations of permeability K for regular models, Kozeny model first of all:

$$K = Cm^2/S^2\ [m^2] \qquad (5)$$

where S $[m^1]$ – specific surface, equal to the ratio of an internal surface to general volume V, C – Cozeni constant, dependent only from the form of capillary section – C = 0,5 for circular section, C = 0,5619 for the square section.

Our model of isothermal fluid filtration through textile material with plant- parallel layers predict many combinations (fig. 2), in which combination of cubic pores while displacement of one layer about another layer make possibility to give effective pores in the form of Laval's nozzle.

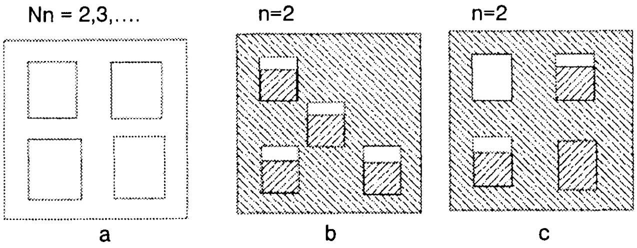


Fig. 2 Possible combinations of effective cubic pores arrangement in some neighbouring plant- parallel layers of textile material.

Thus, the developed approach is suitable for modeling as fabrics, and nonwowen materials. In the first case there is a certain regularity of structure of the threads, and, accordingly, of pore displacement. In the second case such regularity is absent, and even in this, more complete case, the model appears very useful, allowing to display any degree of randomness in fibers and pore arrangement inside textile material.

SYNTHETIC FIBRES BASED ON POLYMER BLENDS

Marcinčin, A.

Department of Fibres and Textile Chemistry, Faculty of Chemical Technology, Slovak University of Technology,
Radlinského 9, 812 37 Bratislava, Slovak Republic

The paper deals with the modification of synthetic fibers by polymeric additives. It has become apparent that chemical and physical interactions between modified polymer and additive are very important in the structure of the fiber-forming blend formation and have strong influence on its processability and properties of fibers. The significant influence of the blend structure on the processability during spinning and drawing of fibers and also on the properties of blend fibers has become a background for the elaboration and application of the rheological relations being valid for the polymer dispersion as a whole (macrorheology) and for the behavior of the dispersion phase in the mixing and deformation processes (microrheology) in shear and elongation conditions. With regard to that the first part of the contribution is devoted to role of rheology in blend fibre formation based on commercial polymers which have the greatest possibilities of exploitation.

The color concentrates as additives for colouring mainly synthetic fibers prepared by spinning from the melt are produced in large volumes, especially for polypropylene and, to a lesser extent, for polyester and polyamide fibers. With regard to their significance, they are an object for the further part of the contribution submitted. Here, attention is paid on miscibility of the concentrate with a colored polymer.

The contribution deals also with the influence of modification on the supermolecular and morphological structure and properties of fibres. In the paper some our experimental results are presented.

1. INTRODUCTION

According to the former, well-developed concept of fiber-fiber blending the conventional chemical or natural fibers are mixed into a product to obtain the combinations of individual material properties. However, if polymer-polymer blends comprise the individual filaments, they are referred to as blend fibers. Basically, blend fibers are best suited when each fiber has the desired characteristics, whereas fiber blends are more appropriate only when the product as a whole has the required properties.

At the beginning, the fibers from polymer blends were used in a very promising procedure to obtain unlimited possibilities to change the basic properties of chemical fibers. In fact, many polymer blends were applied in the fiber preparation process on the industrial scale. Some of them are applied in the mass production such as pigmenting the fiber by pigment concentrates. Other blends are used for special fibers such as polypropylene-polyethylene ones and another blends.

Taking into account the knowledge and experience of rubber blends development, the spinning of fiber-forming polymer blends was accomplished a short time after starting the commercial fiber production in the fifties. Initially, at least two targets were followed during the modification of chemical fibers by polymeric additives [1]:

a) Economic profit in the case when cheaper fiber-forming polymers (polyolefines) are mixed in the melt with more expensive ones (polyester, polyamide) before spinning without any decrease of the basic fiber end-use properties.

b) Anticipating the new properties of blend fibers in comparison with the fiber properties of pure homopolymers.

However, it was gradually found out that economic advantages resulting from cheaper polymer additives are negligible because of technological requirements for the mixing process and spinning of blend fibers.

The older patent literature reviews provide further principal modified chemical fiber properties as follows: improvement of dyeability, creating new, differentially dyed fibers, decrease of the dirtiness of fibers, decrease of electrical charge, improvement of water sorption properties, increase of elastic modulus, positive changes of the stress-strain dependence, increase of the thermal stability (light stability), improvement of fiber texturing, decrease of flammability, improvement of spinability at a high speed of spinning and replacement of the polymers [2,3].

The first PA66/PET and PA6/PET fiber-forming blends with a higher portion of the PET component (up to 30–40 %), which were characterized by the research and commercial background, laid the foundation for development of the wide scale of fiber-forming blends from other polymer pairs. A high portion of PET in the PA fibers positively influences the initial modulus of PA industrial fibers at room, but mainly at a higher temperature [4].

Besides PA/PET fibers the other blend fibers on the basis of polyamide and polyethylene, polypropylene, polystyrene, polyformaldehyde, and polyethyleneoxide were intensively investigated. The PA/Polyolefine fiber-forming blends were oriented to splitted fibers and foils owing to a very low adhesion between components [5]. After the extraction of PA/PS fibers in the organic solvent (benzene) at 75 °C, PA6 fibers have a higher porosity without any decrease of the mechanical properties. Other fiber-forming blends are used for fibers with an improved dyeability (polyester or polypropylene fibers) and a decreased electrostatic charge, and for the splitting of fibers or foils [6,7].

In general, modification of the fiber-forming polymers by polymeric additives leads to the preparation of fibers having the character of oriented polymer blends already at a low concentration of the modifier. Polymer blends are defined as mixtures of at least two macromolecular substances, polymers or copolymers, in which the concentration of each polymeric ingredient is above 2 wt. % [8]. In the last fifties, an innumerable amount of polymer blends have been presented in both the scientific and patent literature. The miscibility and compatibility of polymer components and their role in the blend fibers formation were an objective of these works.

Nowadays, an access to polymer blends in the fiber production is very realistic because only a very small part of them have found their exploitation. In spite of many positive properties, blend fibers belong to a group of special fiber types, with regard to the volume production.

2. MISCIBILITY AND COMPATIBILITY OF POLYMER COMPONENTS

The compatibility of the polymer with an additive can often play a decisive role in the physical modification of the fiber-forming polymer and has a direct influence on the modified properties, e.g. the surface tension at the interface of the polymer blend is inversly proportional to the dispersion degree of the dispersed phase particles and directly proportional to their coalescence [9].

Considering the development in the last years, several concepts have been suggested for evaluation and predicting the mutual miscibility of polymers. The most commonly used expression for the free energy of mixing of two polymers [10] per unit volume, ΔG_m, is the Flory-Huggins-Staverman form, containing interaction parameter χ_{12} as quantity for expression of the mutual interactions of polymers [11].

From the experimental point of view, it is not necessary to evaluate some uneasily available quantities, such as mixing enthalpy, interaction parameters, etc. in the modification process. The semiquantitative expression by terms of the technological compatibility is often sufficient for correlation with modified properties. It can be expressed, e.g. by a deviation of some experimental parameters from additive values such as the viscosity [12], or mechanical properties [13] and other.

This deviation can be described as follows[125]:

$$\Delta i = (\eta_{exp} - \eta_{ad})/(\eta_1 - \eta_2) \qquad (1)$$

where η_{exp} and η_{ad} are the experimentally determined viscosity and/or the calculated additive value; η_1 and η_2 are viscosities of the blend forming components.

A symmetric mixture rule for the viscosity of two immiscible components was derived by the Okoroafor et al.[12]. The rule provides a positive deviation for a blend with a disperse phase viscosity (η_d) higher than that of the polymer matrix (η_m) and with the much higher viscosity of the interface layer (η_i). A negative deviation can be expected when the interface has a much lower viscosity than the dispersed phase and the matrix in the blend.

3. MACRORHEOLOGY AND MICRORHEOLOGY OF POLYMER BLENDS

The rheological behavior of polymer blend in melt is determined by properties of the components, composition of the blend, size and orientation of deformed particles in the dispersed phase and by their mutual interactions. The two levels of rheology can be considered in the shear or in the elongation flow: a) macrorheology connected with the rheological behavior of the whole dispersion, its viscosity, elasticity and b) microrheology concerning the deformation of dispersed particles, their shape, fracture and orientation in flow conditions. The morphology of dispersion and the macrorheological behavior of blends are significantly influenced by microrheological phenomena [14].

Rheological conditions in the mixing process

Fiber-forming polymer blends are prepared on the industrial scale by mixing their components in the melt or in solution. Since the phase structure is effected by so many variables, it seems impossible to find an experimental arrangement for the exact evaluation of the influence of individual factors on the blend morphology. It is known that general rules for predicting the dependence of the phase structure on blend composition and mixing conditions have not been found yet [15]. Some rules formulated by various authors are not often in agreement with each other [16]. In any case, the considerable influence of rheological properties of both components and blends on the morphology of polymer blends and blend fibers has been shown.

In the analysis of the flow in extruders the Newtonian and isothermal flow-field is usually considered. The Newton's law (2a) for the shear flow, (2b) for the extensional flow and Ostwald de Waele power law (2c) are most often used for describing the rheological behavior of the polymer melt as follows:

$$\tau_{12} = \eta.\gamma \text{ (a)}, \quad \tau_{22} = \eta_E.\gamma_E \text{ (b)}, \quad \tau_{12} = k.\gamma^n \text{ (c)} \qquad (2)$$

where τ_{12} – shear stress, τ_{22} – axial tension, η – dynamic viscosity, η_E –elongation viscosity, γ – shear rate, γ_E – elongation gradient, k – coefficient, n – pseudoplasticity coefficient.

For the expression of elastic properties of the melt the first normal stress difference and second normal stress difference can be used [17].

The mixing and homogeneizing process of polymer components is realized under the shear stress. The process of polymer mixing in conditions of the laminar flow can be studied using a simple model. According to the three-layer model the shear stress, τ, and the shear rate in the second layer (in the dispersed phase, if the first and third layers represent a polymer matrix) can be expressed by following equations [18]:

$$\tau = \eta_1.\gamma_1 = \eta_2.\gamma_2 = \eta_3.\gamma_3 \qquad (3)$$

where τ_i – shear rate and η_i – viscosity in layer 1, 2, 3.

For the shear rate in the second layer can be written:

$$\gamma_2 = (v/H).[(K - 2h)/H + (2h/H).(\eta_2/\eta_1)]^{-1} \qquad (4)$$

where H is a distance between borders of the layers 1 and 3 , h – thickness of the layer 1 (equal to the layer 3), v – speed of the upper border, speed of the lower border v = 0, η_1 – viscosity of layers 1 and 3 (matrix), η_2 – viscosity of the layer 2 (dispersed phase), $K = \eta_2/\eta_1$.

If the viscosity of the dispersed polymer is much more higher than that of the matrix, then the shear rate γ_2 is close to zero and the conditions for the mixing process are not suitable. In the opposite case, if the viscosity of the matrix is much more higher than that of the dispersed phase, the maximum of the shear rate γ_2 is achieved [$\gamma_2 = v/(H - 2h)$] and the conditions for mixing are more convenient.

A three-layer model shows that during deformation of the polymer melt a shear gradient in the dispersed phase depends on the viscosity ratio K of the dispersed phase η_2 and matrix η_1. The viscosity ratio K is a very important parameter influencing the kinetics of mixing. At $\eta_1 = \eta_2$ (K = 1), the dispersed polymer and matrix deform to the same degree, which promotes the fiber formation and partial breaking of the dispersed phase [19]. The deviation of K from the unity causes a different degree of the deformation of mixture components.

In addition, both the deformation and break-up of droplets and their coalescence need a certain time to occur. If the break-up and coalescence of droplets need the longer time than allowed by the residence time of droplets in the position differing substantially in stress, the phase structure will be homogeneous throughout the whole volume of the extruder. In opposite conditions, the size of droplets will depend on their position in the extruder even if the steady state is reached. The presence of the compatibiliser suppresses the coalescence of droplets due to a decrease in the interfacial tension and mobility of the interface [20].

The relations show that decreasing of the dispersed phase viscosity considerably supports its deformation in a matrix. Moreover, the mixing process is positively influenced by interactions of the compatibiliser at the interface of components. Spherical particles of the dispersed phase are deformed under shear conditions into fibrils which are decomposed into smaller droplets as a result of surface forces and accumulated elastic energy. Subsequently, a deformation process repeats. The surface energy of the system increases, while a coalescence occurs during particle collisions. A balance between the dispersion and the coalescence process in shear conditions results in the formation of the dispersed phase particles in the shape of the deformed fibrils with a relatively low size of distribution.

Microrheology of polymer dispersion

The polyfibrillar morphology of "matrix – fibrils" and "sea-island" types are characteristic for blend fibers. In first case the dispersed phase forms microfibrils in the polymer matrix. The polyfibrillar fiber structure is formed under conditions of a dispersed droplets flow in the polymer medium during the mixing and extrusion of the blend melt through the spinneret. The stresses arising in the blend tend to deform and orient a droplet. This process can continue at elongation of the polymer stream in a spinning line or at the drawing of fibers. According to Taylor's theory, the pressure difference between the inside and outside of the droplets (ΔP) is responsible for their deformation [21]. If ε is the droplet deformation, $\varepsilon = (L - B)/(L + B)$, where L and B are, the major and minor axes of the deformed droplet, under equilibrium conditions the axial deformation of the droplet is given by the next relations:

$$\begin{array}{lll} \varepsilon = 5/(4K) & \text{for } K \gg 1 \text{ and } Ca \ll 1 \text{ (a)} & \\ \varepsilon = Ca(19K+16)/(16K+16) & \text{for } K \ll 1 \text{ and } Ca \gg 1 \text{ (b)} & (5) \end{array}$$

where, $K = \eta_2/\eta_1$, η_1 is the viscosity of matrix and η_2 of the dispersed phase, Ca is the Capillary, (Weber) number $Ca = 2\eta_1.\gamma.r/\sigma$, γ is the shear rate, σ is the interface tension and r is the radius of the undeformed droplet.

The similar expression was derived for the extensional (E) flow:

$$\varepsilon_E(t) = 3/2Ca_E[(19K+16)/(16K+16)].[1 - e^{19K/20Ca}.\gamma_E^t] \qquad (6)$$

where $Ca_E = \eta_1\gamma_E\, r/\sigma$, and γ_E is elongation gradient of deformation.

The length of fibrils of the deformed droplet depends not only on the deformation and orientation of the polymer blend but also on the break-up of the droplet. Particles of dispersed phase increase an instability of extensional flow and support the phenomena of elastic turbulence in spinning line [19].

If the elasticity of the polymer melt is taken into account, the droplet deformation is determined in addition by the three dimensionless criterions, besides the capillary number Ca and the viscosity ratio K, also by the reduced deformation time t^{*} [15, 22]:

$$t^{*} = t.\gamma/\mathrm{Ca} \qquad (7)$$

where t – deformation time.

In the steady-state shear flow for 0.001 > K > 3.8 the droplets can deform but not break. In the elongation flow, this limitation has not been strictly observed. Many authors confirmed the broad minimum of the dependence of ε_c (critical deformation) on the K ratio ($\varepsilon_c \cong 0.6$), at the range of values K = 0.1–1.0. Different authors give different data on the theoretical limit [23]. For the elongation flow $\varepsilon_c \cong 0.2$ at the higher viscosity ratio K = 1–5. According to work [19, 24], four types of the droplets fracture of the Newtonian fluid appear. If K < 0.2, the droplets become S-shaped and smaller droplets break away from their ends; if K > 0.2, the droplets are generated from one center and one drop is divided into several small droplets; if K < 2, the droplets extend into long cylinders and fall into many small droplets, and finally if K > 2, the fracture does not appear and the droplets become deformed and oriented. If one or both polymers exhibit some viscoelastic properties, the break-up mechanism of the fibrils may be different [19].

4. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Polyolefine blend fibers

The blend polypropylene (PP) – branched polyethylene (LDPE) fibres using PP with Melt flow index (MFI) = 27 g/10 min. and LDPE with MFI = 20, 70 and 200 g/10 min. were prepared. Despite a very similar chemical composition of the PP and LDPE, the negative deviations of the experimental melt viscosity from additive values were observed in dependence on the blend composition and also at various molecular weights of LDPE (Fig. 1). The minimum deviation of the curves of viscosity ranging within 30–60 wt. % of LDPE is connected with the phase inversion. The power law index rises with the LDPE content in the blend and with the LDPE content above 70 % and its values are close to the LDPE index. In any case, the rheological measurements reveal that the properties of individual components in the melt, i.e. the properties of both PP and LDPE, are significantly manifested. However, the low-molecular LDPE (MFI = 200 g/10 min) considerably decreases the melt viscosity of PP and improves the flow properties of the blend. Dependence of the viscosity versus content of the LDPE with a high molecular weight (MFI = 20 g/10 min) is S-shaped and the relative deviation of experimental viscosity from additive values increases in comparison with the low-molecular LDPE. Qualitative evaluation of the spinning process reveals good processing properties of PP-LDPE SA 200 (MFI = 200 g/10 min) at the range of 70–80 % of the "nonfiber-forming" LDPE. The dispersed PP in the LDPE matrix forms long microfibrils and thus the blend fibers have a polyfibrillar structure. In comparison with this, more stable spinning of the PP-high molecular LDPE (MFI = 20 g/10 min) blend was observed at a lower concentration of LDPE (about 30 %).

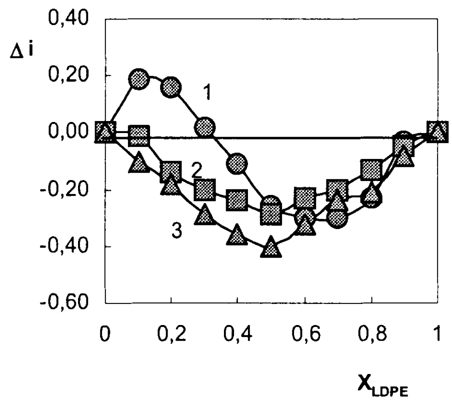


Fig. 1 Relative deviation of experimental viscosity of PP/LDPE from aditive values at 230 °C. 1 – LDPE 20; 2 – LDPE 70; 3 – LDPE 200

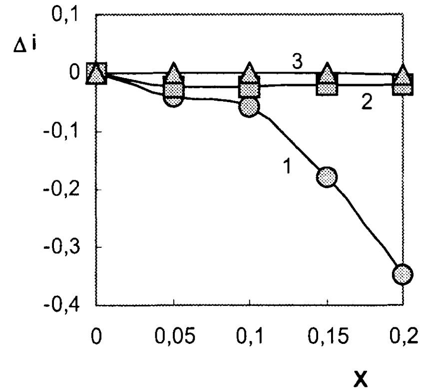


Fig. 2 Deviation of melt viscosity of PP/PET blend 3 – with compatibilizer, 2 –without compatibilizer and PP/PVA(G) (1) from aditive values at 230 °C

The tenacity of blend fibers decreases proportionally to the LDPE content, but the positive deviation from the additive value can be indicated at 20–30 % of LDPE and at 50–70 % of LDPE in PP (Table 1). The minimum tenacity and elongation of blend fibers at 30–40 % of LDPE results from the concentration range of the phase inversion. The negative deviation from the additive tenacity of blend PP/PE fibers at a lower content of LDPE and close to additive values above 50 % of high molecular LDPE were observed.

In the PP / HDPE, (high density polyethylene) blend preparation it becomes apparent that the PP (70 %)/PE (30 %) blend produces during processing the highest quality parameters of fibers. This composition has considerably thermodynamic stability which in turn translates into the excellent dimensional stability, a high degree of the crimp stability and a low shrinkage. The tenacity of PP/HDPE blend fibers exhibits the negative deviation from the additive value within the whole con-

Table 1 Mechanical properties and unevenness of PP/LDPE fibres
T – tenacity [cN/dtex], E – elongation [%], d – diameter [mm], D – diameter CV [%]

C_{LDPE}	PP-LDPE SA 200				PP-LDPE SA 70				PP-LDPE SA 20			
%	T	E	d	D	T	E	d	D	T	E	d	D
0	2.05	37.9	–	–	2.05	37.9	–	–	2.05	37.9	–	–
10	–	–	–	–	1.74	80.7	33.1	5.1	1.84	123.3	36.4	8.1
20	–	–	–	–	1.49	122.3	32.9	6.1	1.61	123.7	32.4	4.6
30	–	–	–	–	–	–	–	–	1.49	115.8	38.9	4.3
40	–	–	–	–	1.44	131.5	36.4	5.8	1.19	31.0	35.6	8.3
50	–	–	–	–	1.40	128.3	36.0	3.3	1.27	24.5	37.8	6.6
60	1.08	27.2	33.7	2.8	1.13	85.5	34.6	3.9	0.91	32.7	34.9	3.8
70	1.18	60.3	33.9	4.2	1.01	84.0	35.3	3.2	–	–	–	–
80	0.78	92.7	37.4	4.2	0.79	68.3	35.5	5.2	–	–	–	–
90	0.45	98.8	37.9	2.6	0.66	50.5	35.9	6.7	–	–	–	–
100	0.19	125.0	40.7	7.8	0.48	55.0	41.5	4.0	0.52	50.0	–	–

centration range. However, it is necessary to realize that there is approximately the three times higher tenacity of HDPE compared with LDPE. The elongation of both PP/LDPE and PP/HDPE blend fibers increases and culminates at 40–60 % of PE in PP [25, 26].

Other very important aspects in assessing PP/PE polymer blend fibers are their remarkable softness and thermobonding properties. For nonwovens from PP fibers the highest webstability was found between 142 and 147 °C. A wider temperature range (127–149 °C) for thermobonding was observed for PP/HDPE (50/50) blend fibers with a considerably higher tensile strength (about 30 %) in the machinery direction (MD) [25].

4.2 Polyamide blend fibers

Besides PA6 and PA66, most of alifatic homopolyamides and copolyamides are not used for the fiber manufacturing on the industrial scale but they are more applied for the production of specialties. Special polyamides such as PA4.6, PA6.10 and PA6.12 and some copolyamides of the ε-caprolactame may serve for the fiber-forming blend formation and blend fiber production with the improvement of the PA6 and PA66 fiber properties involving sorption activity, improved dyeability and electrical conductivity [27].

The influence of some copolyamides on sorption and on the electric properties of PA6 fibers is presented in [28]. The copolyamides were prepared on the basis of ε-caprolactam and salts of adipic acid or sebacic acid with hexamethylene diamine and 1-(2-aminomethyl)-piperazine or 1,4-bis(3-aminopropyl)piperazine [27], and also with polyamide urea [28]. The copolyamides added to PA6 in the amount of 10–70 wt % and the fibers made of them have a lower electrical charge, higher sorption of water and improved elastic properties in comparison with pure PA6 fibers. The higher amount of the nylon salts in the copolyamide causes that the better electrostatic properties and the sorption of water by blend fibers are observed. A higher content of the nylon salts in copolyamides also increases the water sorption to 6.7 wt % at 65 % of RH. The tensile strength of blend fibers is generally lower than that of PA6. It is interesting that with above 15 wt. % of copolyamides in PA6 the tensile strength of blend fibers increases in comparison with a lower concentration of additive.

4.3 Polypropylene – polyester blend fibers

Most of the PP-polyester fiber-forming blends contain a low concentration of the dispersed phase because of the clear immiscibility of the component. The blends comprising more than 10 wt. % of the other components should be compatibilized. Adhesion bonds at the interface of PP-polyester are weak and without compatibilizing the blend, the insufficient mechanical properties and fibrillation of fibers can be observed.

The reactive and non-reactive compatibilizers for polypropylene and polyester blends can be used for improving the mutual interaction at the interface. The reactive graft copolymer, polypropylene-maleic anhydride (PP-g-MAN), was used with the small efficiency. Much better results in the processing of PP/PET fibers are provided by reactive compatibilisers on the basis of 2-4(alkoxyfenyl)oxazoline [27]. However, using the reactive additive in the fiber preparation the inhomogeneity of polymer melts increases and can lead also to the branched and cross-linked structure of polymers unsuitable for fiber spinning.

Some additives such as compatibilizers and plasticizers in the PP/PET fiber preparation were used in experimental work. The commercial PP with MFI = 13 g/10 min and PET with intrinsic viscosity, IV = 0.5 L/g in phenol tetrachlorethane 1:3 were used for the preparation of blend fibers. The positive effect of ethylene distearamide (EDSA), copolymeres of poly(ethylene-vinyl alcohol) and poly(ethylene–vinylacetate) on compatibility of components and fiber preparation was found.

The influence of EDSA on the compatibility of PP and PET was investigated on the basis of the deviation of

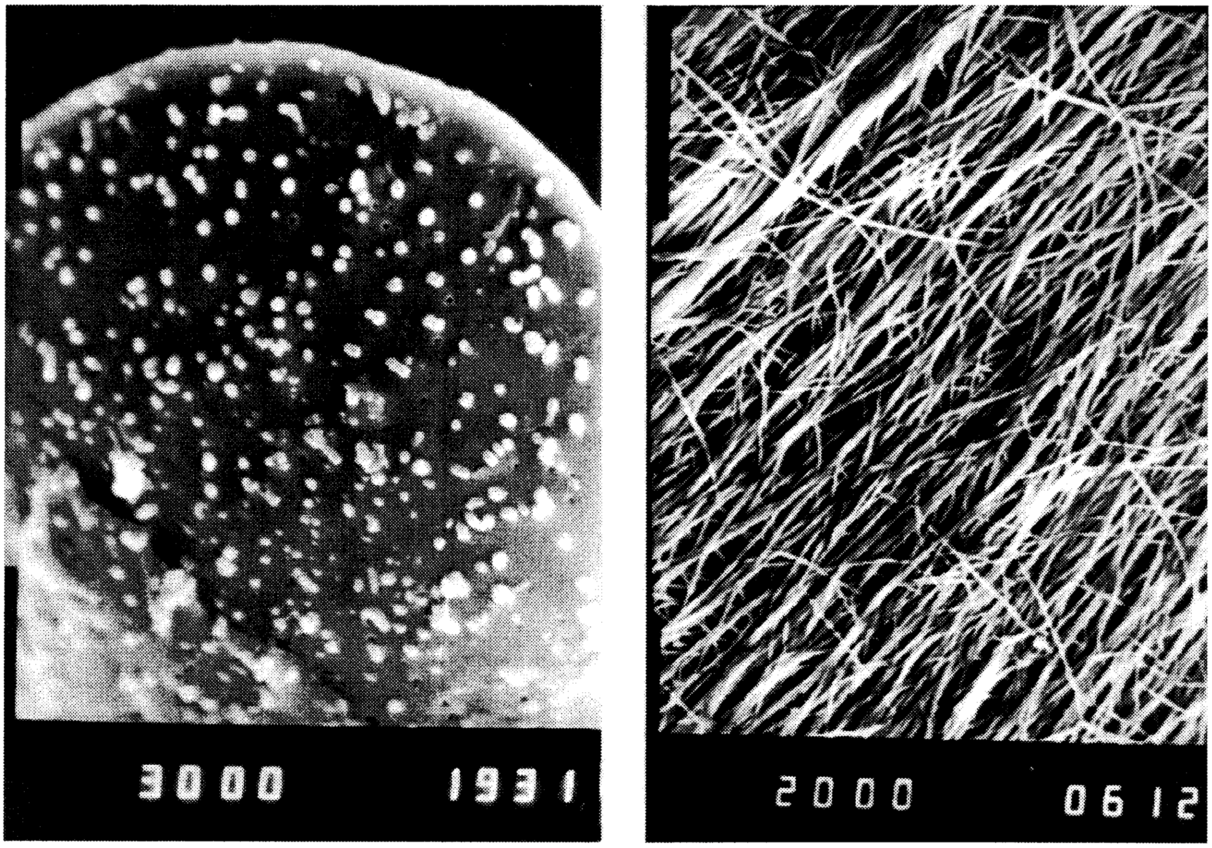


Fig. 3 Cross section (a) and polyfibrillar structure of PP-PET blend fibres after matrix disolution (b) content of PET-10%

experimental viscosity of the mixture from the additive viscosity. It has been shown that the PP/PET blend behaves as an incompatible system with a negative deviation of viscosity. The increase of viscosity above additive values by a compatibilizer (EDSA) results in the pseudocompatible PP/PET system (Fig. 2). The selected modification procedure reduces a viscosity of the polyester component, which leads to the improvement of compatibility of the components in the blend. Moreover, the mixing process is positively influenced by an interaction of the compatibiliser at the interface of components, which can result in the increase of adhesion bonds. Despite the much lower PET viscosity as a dispersed phase, the spherical particles are deformed under shear conditions into long fibrils with a relatively low-size distribution (Fig. 3)

The standard tenacity is characteristic for blend PP/PET fibers compatibilised by EDSA. The tenacity decreases with a higher additive content in PP. The fiber elongation is relatively high and slowly decreases with the PET concentration. In spite of lower tenacity the elasticity of blend fiber increases proportionally to the content of the polymer additive. The positive effect is observed in the elasticity efficiency of fibers (Table 2, 3).

The polypropylene fibers modified by a polyester additive up to 10–15 wt. % have an excellent dye uptake of disperse dyes. The color strength of modified fibers is 5–10 times higher in comparison with unmodified fibers. The dyed blend PP/PET fibers provide a good fastness to rubbing and washing.

Table 2 Mechanical properties of PP/PET blend fibres after 30 min annealing at 100 °C. Rubin SE RDL and Blau SE RDL (Bezema, Co.), dyeing 2 %, T = 100 °C

c_{PET} [%]	Tenacity [cN/dtex]	Elongation [%]	Elasticity at 50 % tenacity			Diameter CV, [%]	Dyeability, K/S	
			ε_{el} [%]	ε_{tot} [%]	ε_{el}^{0} [%]		Rubin SE RDL	Blau SE RDL
0	2.22	27.0	7.4	6.2	83.9	7.1	2.5	7.0
5	1.98	27.1	8.2	7.1	86.6	8.3	26.2	24.5
10	1.96	29.4	8.6	7.6	88.9	11.2	31.2	26.5
15	1.95	27.3	7.3	6.6	89.7	7.1	31.8	28.0
100	1.55	19.3	8.0	7.0	87.5	–	–	–

Table 3 Power law index and viscosity of polymer and polymeric additives at 270°C
ESDA – 1,2-ethylene steardiamide, PEVOH – copolymer of ethylene and vinyl alcohol,
PEVAc – copolymer of ethylene and vinyl acetate, 0.2 % dyeing of blend fibres

S.	PP and PET Additive composition	Power law index n	PP and additive viscosity hg_{100} [Pa.s]	PP/(PET Additives) blend fibres			
				Tenacity [cN/dtex]	Elong. [%]	Dyeability K/S Rubin SERDL	Gelb SERDL
1	PP TI 922	0.56	83.5	3.9	72.5	0.16	0.03
2	PET	0.59	42.6	2.7	94.2	5.27	3.95
3	PET/PBT (1:1)	0.56	32.1	–	–	–	–
4	PET/1.5%ESDA	0.70	15.9	3.1	94.5	5.02	6.00
5	90%PET/10%PP/1%ESDA	0.57	29.9	–	–	–	–
6	80%PET/20%PP/1%ESDA	0.52	42.4	3.6	103.7	5.13	4.14
7	70%PET/30%PP/1%ESDA	0.55	35.6	–	–	–	–
8	95%PET/5%PEVOH	0.62	14.9	3.1	95.1	4.32	6.35
9	90%PET/10%PEVOH	0.70	10.7	3.4	95.3	4.82	8.73
10	80%PET/20%/PEVOH	0.66	12.9	2.9	84.1	4.15	9.12
11	70%PET/30%PEVOH	0.61	17.1	–	–	–	–
12	80%PET/20%PEVAc	0.66	19.3	3.4	98.3	3.75	8.84
13	70%PET/30%PEVAc	0.53	34.9	3.3	95.2	5.18	5.92

4.4 Polypropylene-polyamide blend fibers

Modification of the fiber-forming PP by polycaproamide in dependence on its content can improve some properties of polypropylene, such as an increase of the sorption of humidity, a decrease of the electrical charge at a lower concentration up to 7 % [29] and the improvement of elastic properties and dyeability by disperse dyestuffs at a higher content up to 30 wt. %. The PP was blended mainly with PA6 and PA66 and other polyamides such as PA12 [30].

Some ionomers, mainly the polyolefine – acrylic acid or maleic anhydride copolymer, such as polypropylene grafted by maleic anhydride (PP-g-MAN), are often used to improve the adhesion between PP and PA. Using the FT-IR spectroscopy, it has recently been found that during melting a chemical reaction occurs between the maleic anhydride units and the $-NH_2$ end groups of PA6 chains [30]. The chemical interaction at the interface of PP/PA leads to the significantly higher tension in a spinning line, mainly if the concentration of the dispersed phase exceeds 30 wt. %. This means that the PP matrix is oriented under the spinneret much more than unmodified filaments and the speed of crystallization is higher with regard to the orientation effect. These phenomena were confirmed by the birefringence and X-ray diffraction analysis [30]. The positive effect of the compatibiliser was detected in the increase of the tenacity of blend fibers and in the decrease of elongation at break. At the higher content of PA6 in PP the improvement of recovery properties and exhaust dyeability by disperse dyes was ascertained.

4.5 Polypropylene – polyvinylalcohol blend fibers

The blend PP/PVA fibers (PP – MFI = 27.5 g/10 min and PVA Mowiol 8–88 with 88 % of OH-groups) were prepared in two steps: the preparation of the modified PVA blend with polypropylene and the melting and spinning of the blend.

The PVA Mowiol 88 displays unfavorable flow properties and does not form the fiber-forming system in the mixture with PP. The glycerol as a plasticizer in PVA causes a significant decrease of the polymer melt viscosity, which corresponds to the polypropylene level at 30 wt % of glycerol in PVA. Despite approximately the same viscosity of the PVA (70 %)/glycerol (30 %) mixture (PVA(G)) compared with polypropylene, the blend of these components exhibits the high negative deviation of viscosity from additive values. At a low concentration of PVA the blend displays the viscosity near to the additive value or positive deviation of the viscosity from the additive one (Fig. 2).

The higher water sorption values are connected with the porosity of fibers which can be achieved at above 10–15 % of PVA(G) in PP. The tenacity decreases proportionally to the amount of the PVA(G) component, and between 5 % and 15 % of PVA(G) the tenacity of fibers shows approximately the same values. At this range, the stability of the blend structure can be assumed (Table 4).

4.6 Color concentrate, polymer additive for fiber-forming polymer

The concentrates consisting of 5 to 40 % of pigment are used especially for coloring polypropylene, polyethylene terephthalate and polyamide fibers and can be added to the basic polymer by several procedures.

It has been demonstrated that pigment – polymer – dispersant interactions can be studied perfectly by rheological measurements using the capillary or rotary

Table 4 Mechanical properties, porosity and sorption of H_2O of the PP/PVA(G) fibres (30% G/PVA)

	After extraction		Water extract [%]	Porosity [%] [%]	Sorption of H_2O, 65% RH
	Tenacity [cN/dtex]	Elongation [%]			
PP	1.68	29.4	0.8	5.6	0.04
PP/1%PVA(G)	1.48	31.3	1.8	6.0	1.75
PP/5%PVA(G)	1.34	32.5	2.7	7.7	2.70
PP/10%PVA(G)	1.34	32.3	4.7	10.4	3.05
PP/15%PVA(G)	1.30	32.0	10.1	17.9	3.65
PP/20%PVA(G)	1.18	27.7	14.3	20.6	4.75
PP/10%PVA(G) +2%PP-g-MAN	1.37	31.2	4.8	10.7	3.20

rheometers and by the analysis of the flow of dispersion through the fine and defined holes of filtration sieves – filterability. Several models describing the dependencies of the shear quantities and viscosity on the concentration of solid particles and the structure parameters of dispersion, originally elaborated for low-molecular compounds, can be used for the dispersion of pigments in polymers [31]. The conventional term "Filterability (F)" expresses the pressure increment (ΔP) to the unit amount of the filtrate (m) at a defined holes geometry and parameters of filtration [32]. Initially, the filterability as a method was used for determination of the degree of the pigment dispersion. The proportionality was assumed between the average size of pigment particles and agglomerates and their ability to pass through holes of the filtration material. Some experiments showed an analogy between the behavior of the pigment dispersion in PP fibers and that in the oligomeric polypropylene. The proportionality between the filterability of pigments in the high-molecular polypropylene and oligomeric polypropylene (oil) enables one to utilize experiments using the oligomeric polypropylene for wider experiments with a pigment dispersibility [33].

The miscibility and/or compatibility of the pigment concentrate with polymer can be expressed by the relations created for polymer blends. The color concentrate and polymer can be considered as two individual components in the mixing process. With regard to the same chemical composition of the polymer carrier in the concentrate and basic polymer, the miscibility can be influenced mainly by the chemical composition of the dispersing agent. The works dealing with the miscibility of pigment concentrates with polymers are practically absent in literature. However, the compatibility and miscibility can substantially influence the uniformity of the pigment distribution as well as the unevenness of the structure and geometry of fibers [34].

The mixing and homogenization process of polymer and concentrate melts is realized under the shear stress and shear rate in laminar flow conditions. The viscosities of the concentrate and polymer determine the shear rate in a dispersed phase and matrix and significantly influence the kinetic of mixing. If the viscosity of the color concentrate highly exceeds the viscosity of the polymer medium the deformation of concentrate particles is small as a rule. In the opposite case, at a higher viscosity of the polymer matrix deformation conditions of the concentrate are more convenient.

Several polyester concentrates containing C.I. Pigment Black 7 were used for the preparation of spun dyed fibers in our experimental work. The concentration of carbon black pgment was within 20–30 wt %.

In the rheological measurements of carbon black (C.I. Pigment Black 7) concentrates in PET the flow properties close to the Binghamian behavior of the melt with a critical shear stress, τ_0, at $\tau \to 0$ were found. It is evident that the shear stress above the critical value of τ_0 is applicable in the mixing process in technological conditions. The critical shear stress, τ_0, significantly increases with a concentrate viscosity.

An unevenness of the fiber diameter expressed by a variance from the mean value and an unevenness of the mechanical properties of spun dyed fibers were considered as a criterion for the processing of concentrates corresponding to the kinetic of mixing and to homogenization processes. It was found that the deviation from the Newtonian flow (n), the viscosity of color concentrates (η), coefficient of agglomeration (λ) and filterability (F) correspond with the fiber diameter variance (Figs. 4, 5). Furthermore, the indirect proportionality between unevenness of fibre diameter and tenacity as well as elongation of fibers was found. It can be predicted that the lower tenacity and higher variance of tenacity and fiber diameter result from the imperfect structure and morphology, uniformity of the PET concentrate and from the insufficient distribution of the color concentrate in spun dyed fibers. From this aspect, the following points lead to the high-performance properties of PET color concentrates: a low or zero initial stress (stress interpolated at $\gamma \to 0$) under the critical value, a lower deviation from the Newtonian flow, low viscosity of the color concentrate (under the critical value), a filtration test under the limit value.

An unevenness of the fiber geometry and structure is not only influenced by the miscibility of concentrates with polymers but also by the dispersion degree and tendency to agglomerate the black pigments in polyester concentrates.

5. CONCLUSION

In the spinning process of fibers based on the polymeric blend a great importance is attributed to the polyfibrillar structure of fibers with deformed particles of the dispersed phase in the form of long fibrils. At the matrix-fibril interface oriented perpendicularly to the fiber axis, this structure allows one to achieve during deformation processes a good processability which is often characterized by an improved elasticity and recovery properties of fibers. The main influence on the formation of this structure is ascribed to the rheological properties of components, particularly to the viscosity ratio of the dispersed phase and matrix and to the adhesion at the interface.

Modification of the fiber-forming polymers by concentrated dispersions of pigments (mass pigmenting of fibers) depends to a large extent on two factors: on the dispersibility of pigment in the polymer carrier, usually in the presence of a dispersant, and on the miscibility of the concentrated dispersion with a polymer. In both cases, an important role is played by thermodynamic and kinetic processes. The process of mixing the concentrate with polymer and especially the kinetics of dispersion are defined by the relation of rheological properties of the concentrate to those of the polymer. The ratio of the concentrated dispersion viscosity to the viscosity of the polymer carrier at the constant pigment concentration can be regarded as a measure of the concentrate quality. The lower concentrate viscosity which is in relation with the polymer viscosity creates conditions for the high-shear deformation of a dispersed concentrate in the polymer matrix. Moreover it improves the structure and geometrical evenness of the spun-dyed fibers and increases their color strength.

Acknowledgements

The financial support of the Slovak grant agency VEGA (grant CHTF 126) is appreciated.

REFERENCES

1. K. Dietrich and S. Tolsdorf, *Faserforschung und Textiltechnik* **21** (7), 295–304 (1970).
2. W. Meissner and W. Berger, *Faserforschung und Textiltechnik* **16** (8), 400–408 (1965).
3. W. Berger and J. Mellentin, *Faserforschung und Textiltechnik* **21** (7), 288–194 (1970).
4. J. Repka, A. Marcicin and A. Pikler, *Chemicke vlakna* **23** (1), 4–7 (1973).
5. L. Alexandru et al., *Faserforschung und Textiltechnik* **16**, 433–438 (1965).
6. H. Krässig, *Faserforschung und Textiltechnik* **26** (3), 135–142 (1975).
7. W. Berger and H.W. Krammer, *Faserforschung und Textiltechnik* **25** (4), 140–143 (1974).
8. J.G.M.VanGisbergen and H.E.H. Meijer, J.Rheol. **35**, 63 (1991)
9. I. Fortelny, A. Zivny and J. Uza, *J. Polym. Sci., Part B* **37**, 181–187 (1999).
10. L. A. Utracki, Polymer Alloys and Blends, Hanser, Munich (1989)
11. D. J. Lohse, *Polypropylene An A–Z Reference* (J. Karger-Kocsis Edit.), p. 485, Kluwer Academic Publishers, Dordrecht (1999).
12. E. U. Okoroafor, J.P. Willemaire and F. Agassant, *Polymer* **33** (24), 5264–5270 (1992).
13. A. Marcincin, A. Ujhelyiova, E. Zemanova and T. Marcincinova, *J. Macromol. Sci. Pure and Appl. Chem.* A **35** (7–8), 1239–1247 (1998).
14. M. V. Tsebrenko, *Chimicseskaja Technologia*, (4), 3–17 (1988).
15. I. Fortelny, J. Kovar and M. Stephan, *J. Elastomers and Plastics* **28**, 106–139 (1996).
16. S. Wu, *Polymer Eng. Sci.* **27**, 335–343 (1987).
17. M. V. Tsebrenko, *Int. J. Polym. Mat.* **10**, 83 (1983).
18. V. R. Torner, In: *Teoreticeskije osnovy pererabotky polimerov*, Moskva, 210 (1977).
19. M. V. Tsebrenko, G.P. Danilova and A.Ja. Malkin, *Non-Newton Fluid. Mech.* **31**, 1–26 (1989).
20. I. Fortelny, *J. Macromol. Sci.-Phys.* **B39** (1), 67–78 (2000).
21. I. Fortelny, J. Kovar and M. Stephan, *J. Elastomers and Plastics* **28**, 106–139 (1996).
22. L.A. Utracki, *Polypropylene An A-Z Reference* (J. Karger-Kocsis Edit.), p. 601, Kluwer Academic Publishers, Dordrecht (1999).
23. C. D. Han, *Multiphase flow in polymer processing*, p. 459, Academ. Press, New York (1981).
24. G.I. Taylor, *Proc. R. Soc. London*, **A146**, 501 (1934).
25. A. Marcincin, A. Ujhelyiova, E. Zemanova and T. Marcincinova, *J. Macromol. Sci. Pure and Appl. Chem.* A **35** (7–8), 1239–1247 (1998).
26. A. Marcincin, E. Borsig and T. Marcincinova, *Six European Symposium on Polymer Blends*, P-79, p. 79, Max-Planck Institute, Mainz, Gemany (1999).
27. M. Kristofic et al., *Vlakna a textil/Fibres and Textiles* **1** (4), 201–204 (1994).
28. M. Kristofic, A. Marcincin, A. Ujhelyiova and V. Prchal, *Vlakna a textil/Fibres and Textiles* **4** (1), 14–17 (1997).
29. O. Durcova, I. Grof and A. Marcincin, *Acta Polymerica* **41** (3), 164–166 (1990).
30. I. Grof, O. Durcova and M. Jambrich, *Colloid and Polymer Science* **270**, 22 (1992).
31. A. Marcincin, K. Ondrejmiska and E. Zemanova, *Chemicke vlakna* **31**, 228–238 (1981).
32. A. Marcincin et al., *Chemicke vlakna* 33, 162–172 (1983).
33. A. Marcincin, E. Zemanova and J. Beniska, *Rheologica Acta* **26**, 323–325 (1988).
34. A. Marcincin and E. Zemanova, 8^{th} *Int. Conf. on Dyes and Pigments*, Colorchem 2000, VUOS Pardubice, CZ (2000).

WiseTex – VIRTUAL TEXTILE SOFTWARE

Lomov, S. V.*, Verpoest, I.

Department MTM, Katholieke Universiteit Leuven, Kasteelpark Arenberg, 44 B-3001 heverlee Leuven Belgium
fax +32-16-32-19-90, E-mail: Stepan.Lomov@mtm.kuleuven.ac.be

*on leave of absence from St.-Petersburg State University of Technology and Design, Russia

A software package *WiseTex*, a simulation tool for textile structures, is described. The current version of *WiseTex* covers 2D and 3D woven fabrics, 2D braids, 2D braids with inlays and unidirectional multilayered preforms. It features geometrical simulation of a textile, including 3D imaging of the repeat, and simulation of compression of the fabric.

INTRODUCTION

Software for simulation of the internal geometry of a fabric is a "must" tool for a designer of industrial or apparel textiles. Whatever is the fabric usage, its structure plays a key role in the performance parameters. One can say that fabric properties are properties of it's yarns and fibres, transformed by the structure. The precise knowledge of the internal geometry is of primary importance for such application fields as filters (find the smallest particle stopped by it), composites reinforcements (compute resin flow through the reinforcement and mechanical properties of the composite), paper-making machines clothing (compute air and water permeability through a dryer net), weaving/knitting technology (what is the length of yarns for a given fabric length) etc.

There are some CAD/CAM software tools for textiles available. The disadvantages of them are first, they cover only simple structures and yarn geometry (e.g. circular cross-sections) and that they lack generality, and, second, that they are purely geometry modelling tools, without any reference to mechanical properties of yarns [1–6]. The challenge of the *WiseTex* development is to implement a universal mechanical model of textile structure, which would handle very different and complex topologies of yarn placement and would represent the complex mechanical behaviour of yarns inside the structure.

This development can be summarised as the creation of a **virtual textile**, using knowledge of textile material science gained over the past 60 years. The software uses theories and algorithms, developed since early 90-ies [7–13] and extensively published recently [14–22].

AIM AND SCOPE

WiseTex serves as:

- Software for modelling of the internal geometry (including 3D imaging) and mechanical behaviour (compressibility in the current version) of textile structures.
- Integrated Textile Preprocessor for hydrodynamical, meso-mechanical and finite elements software packages providing description of the internal geometry and mechanical behaviour of textile structures.

The current version (1.4) covers the following textile structures (Fig.1):

- 2D woven fabrics
- 3D woven fabrics
- 2D braids
- 2D braids with inlays (can also be used to simulate multi-axial woven fabrics)
- multilayered unidirectional (non-crimp) preforms

PRINCIPLES OF THE GEOMETRICAL MODELLING OF TEXTILES

Textile materials are characterised by the distinct hierarchy of structure, which should be represented by a model of textile geometry and mechanical behaviour. In spite of a profound investigation of textile materials and a number of theoretical models existing in the textile literature for different structures, a generic model covering different structures is not available. *WiseTex* takes full advantage of the hierarchical principle of textile modelling, creating a truly integrated modelling and design tool. The simulation algorithm uses extensively the minimum energy principle. It allows handling of complex textile structure, with computer computations times counted in minutes, instead of hours or days needed for FEM implementations of the same non-linear, non-conservative behaviour of yarns in compression and bending.

WiseTex considers a single repeat (unit cell) of the fabric. Assume as given (input user data):

- Yarn properties: geometry of the cross-section, compression, bending, frictional and tensile behaviour (Fig. 2);
- The topology of the yarn interlacing pattern within the fabric repeat (Fig. 3);
- The yarn spacing within the repeat (Fig. 4).

The problem is to compute the spatial placement of all yarns in the repeat:

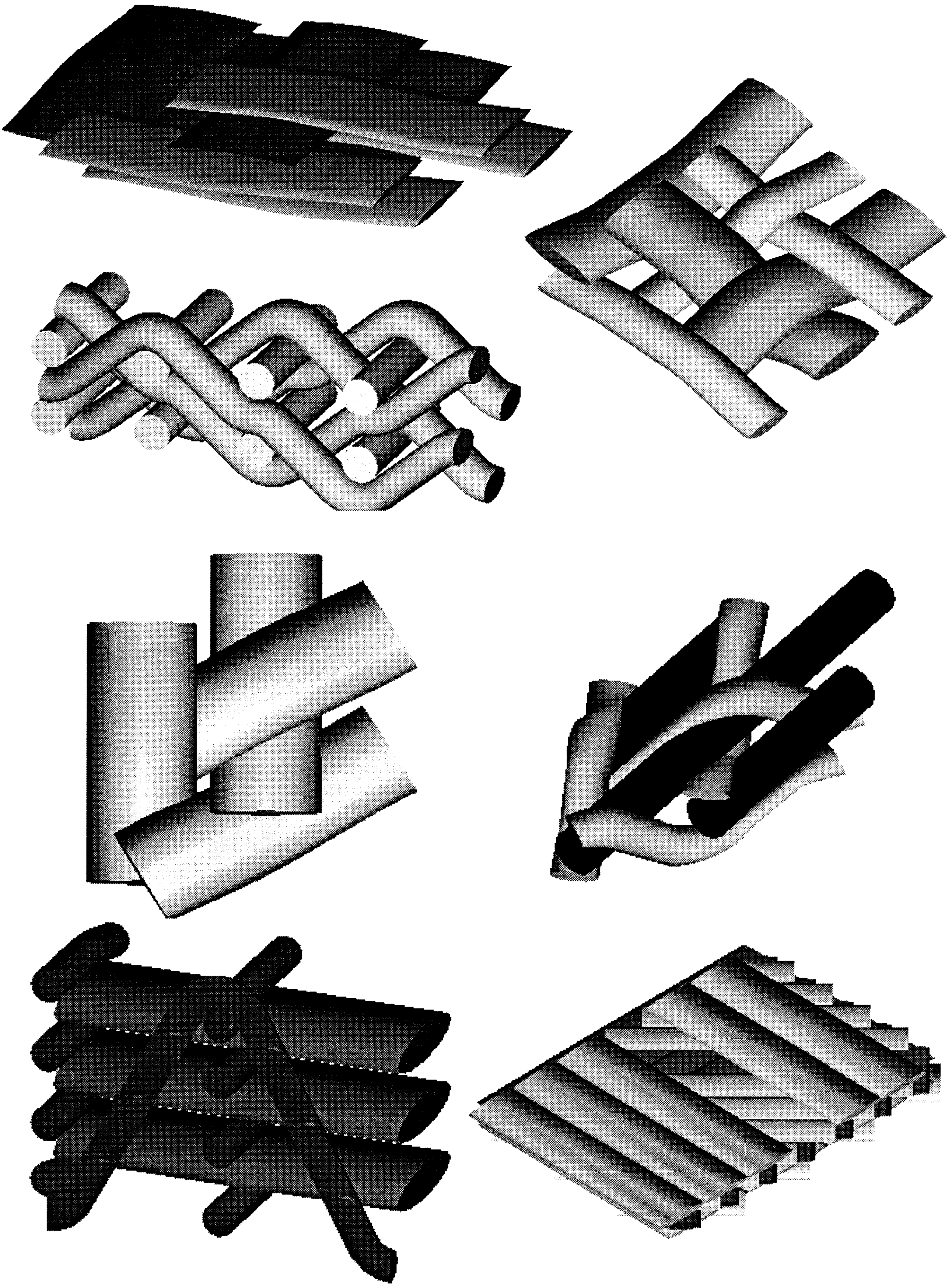
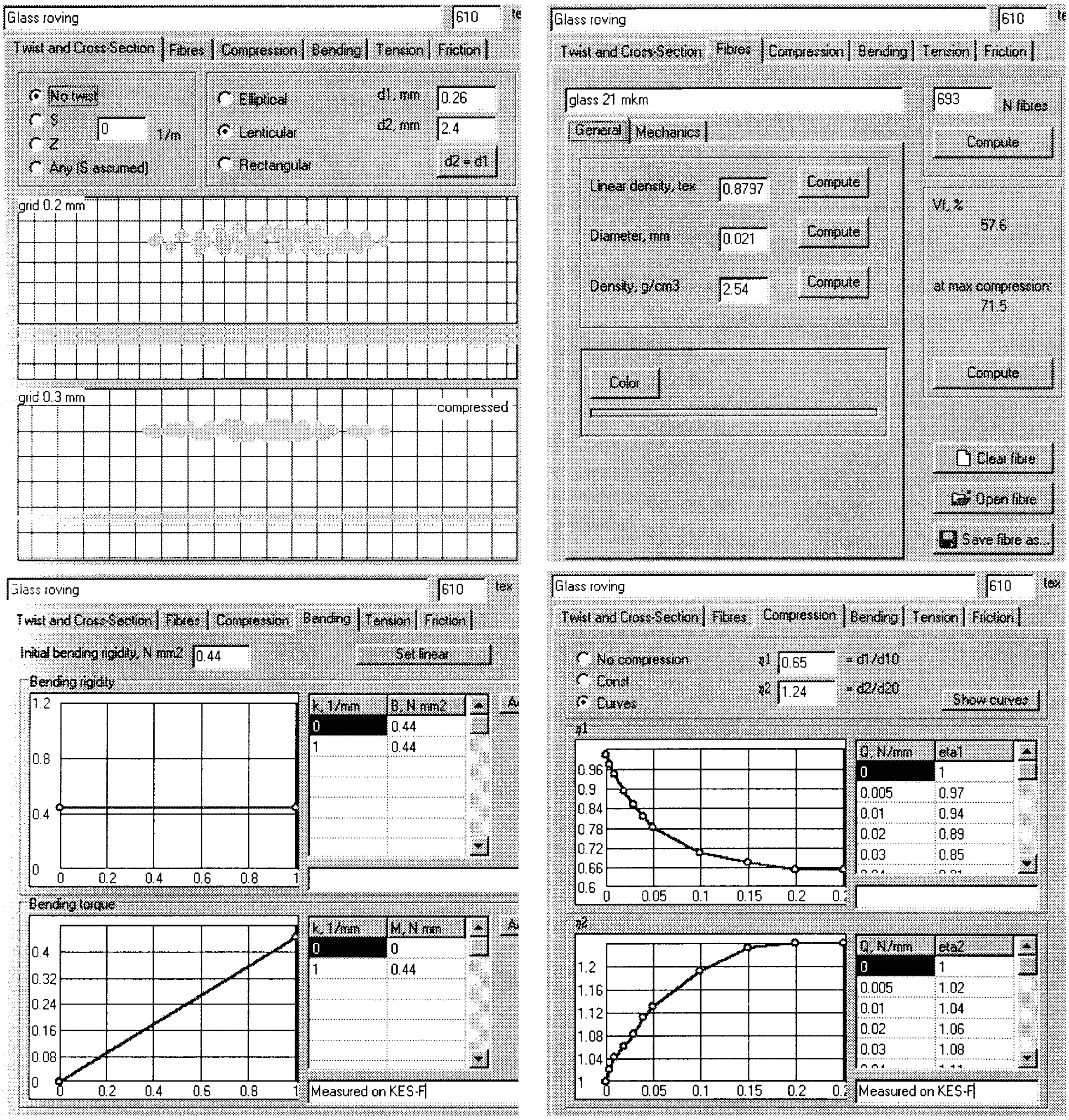


Fig. 1 Examples of structures simulated by *WiseTex*



Glass roving 610 te

● No twist
○ S
○ Z
○ Any (S assumed)

0 1/m

○ Elliptical
● Lenticular
○ Rectangular

d1, mm 0.26

d2, mm 2.4

Glass roving 610 te

glass 21 mkm

693 N fibres

Linear density, tex 0.8797

Diameter, mm 0.021

Density, g/cm3 2.54

Vf, %
57.6

at max compression:
71.5

Glass roving 610 tex

Initial bending rigidity, N mm2 0.44

k, 1/mm	B, N mm2
0	0.44
1	0.44

k, 1/mm	M, N mm
0	0
1	0.44

Measured on KES-F

Glass roving 610 tex

○ No compression
○ Const
● Curves

η1 0.65 = d1/d10

η2 1.24 = d2/d20

Q, N/mm	eta1
0	1
0.005	0.97
0.01	0.94
0.02	0.89
0.03	0.85

Q, N/mm	eta2
0	1
0.005	1.02
0.01	1.04
0.02	1.06
0.03	1.08

Measured on KES-F

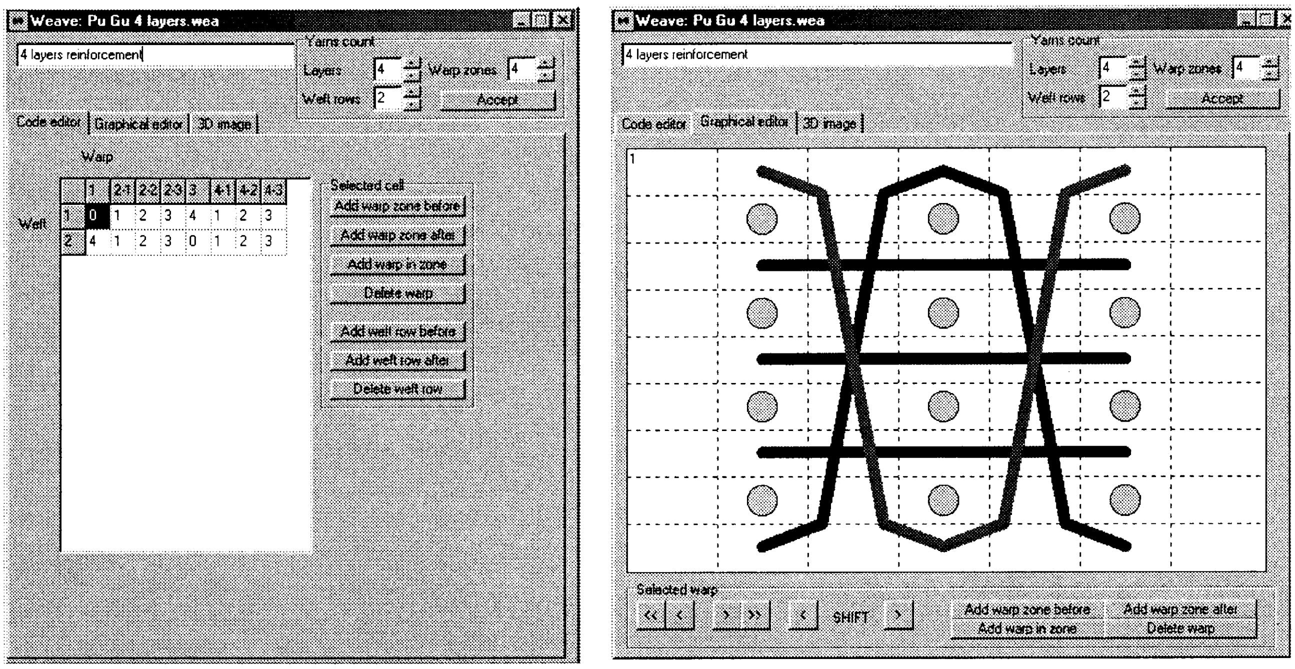
Fig. 2 *WiseTex* input data: yarn properties

- Determine the spatial placement of all the yarn heart-lines within the repeat;
- Define the yarn cross sectional shape and its dimensions normal to the yarn heart-line for each point along the yarn heart-lines.

This problem is treated in accordance with the hierarchy of a textile structure: considering the sequence of hierarchical levels "fibres – yarns – fabric", the focus is on the highest level (i.e. the "fabric"). The properties of the elements from the preceding level ("yarns") together with their interlacing pattern ("topology") enter the solution via the minimum energy principle.

The geometrical models provide the following output:

- Overall geometrical characteristics: unit cell dimensions (including thickness), mass per unit surface area, average porosity/fibrous content and yarn lengths in the unit cell.
- For any point within the unit cell: the fibrous content, the average orientation and an identification of the fibre material in the vicinity of the point.
- Yarn path geometry, position and size of the yarn cross-sections, fibre density and orientation distribution over the yarn cross-section for arbitrary points on any yarn within the fabric repeat.



Weave: Pu Gu 4 layers.wea

4 layers reinforcement

Yarns count

Layers: 4

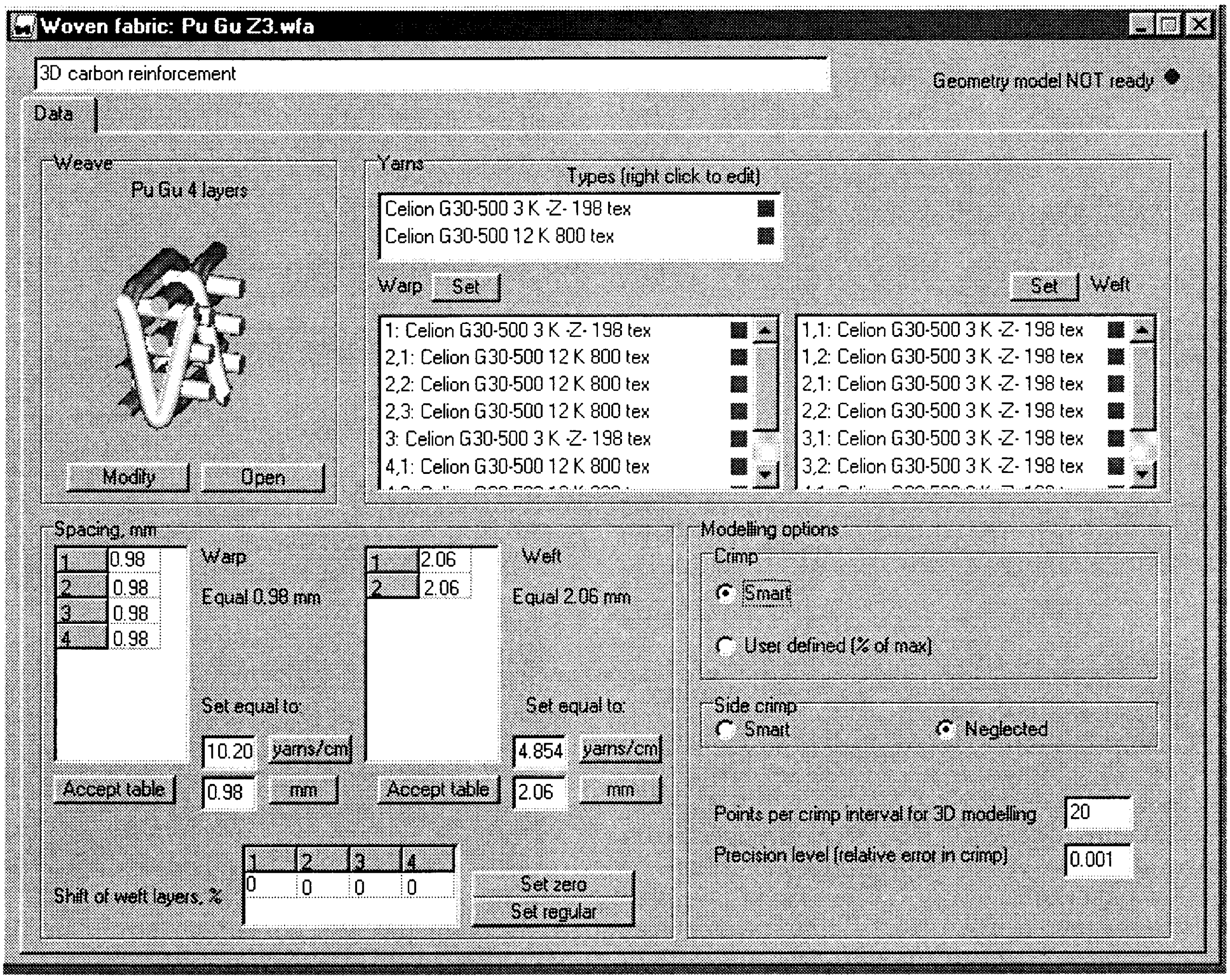
Warp zones: 4

Weft rows: 2

Warp

Weft	1	2-1	2-2	2-3	3	4-1	4-2	4-3
1	0	1	2	3	4	1	2	3
2	4	1	2	3	0	1	2	3

Fig. 3 *WiseTex* input data: code and graphical editors for weave structure



Woven fabric: Pu Gu Z3.wfa

3D carbon reinforcement

Geometry model NOT ready ●

Weave: Pu Gu 4 layers

Yarns

Types (right click to edit)

Celion G30-500 3 K -Z- 198 tex ■

Celion G30-500 12 K 800 tex ■

Warp	Weft
1: Celion G30-500 3 K -Z- 198 tex ■	1,1: Celion G30-500 3 K -Z- 198 tex ■
2,1: Celion G30-500 12 K 800 tex ■	1,2: Celion G30-500 3 K -Z- 198 tex ■
2,2: Celion G30-500 12 K 800 tex ■	2,1: Celion G30-500 3 K -Z- 198 tex ■
2,3: Celion G30-500 12 K 800 tex ■	2,2: Celion G30-500 3 K -Z- 198 tex ■
3: Celion G30-500 3 K -Z- 198 tex ■	3,1: Celion G30-500 3 K -Z- 198 tex ■
4,1: Celion G30-500 12 K 800 tex ■	3,2: Celion G30-500 3 K -Z- 198 tex ■

Spacing, mm

Warp	
1	0.98
2	0.98
3	0.98
4	0.98

Warp: Equal 0.98 mm

Set equal to: 10.20 yarns/cm; 0.98 mm

Weft	
1	2.06
2	2.06

Weft: Equal 2.06 mm

Set equal to: 4.854 yarns/cm; 2.06 mm

Shift of weft layers, %

1	2	3	4
0	0	0	0

Modelling options

Crimp

● Smart

○ User defined (% of max)

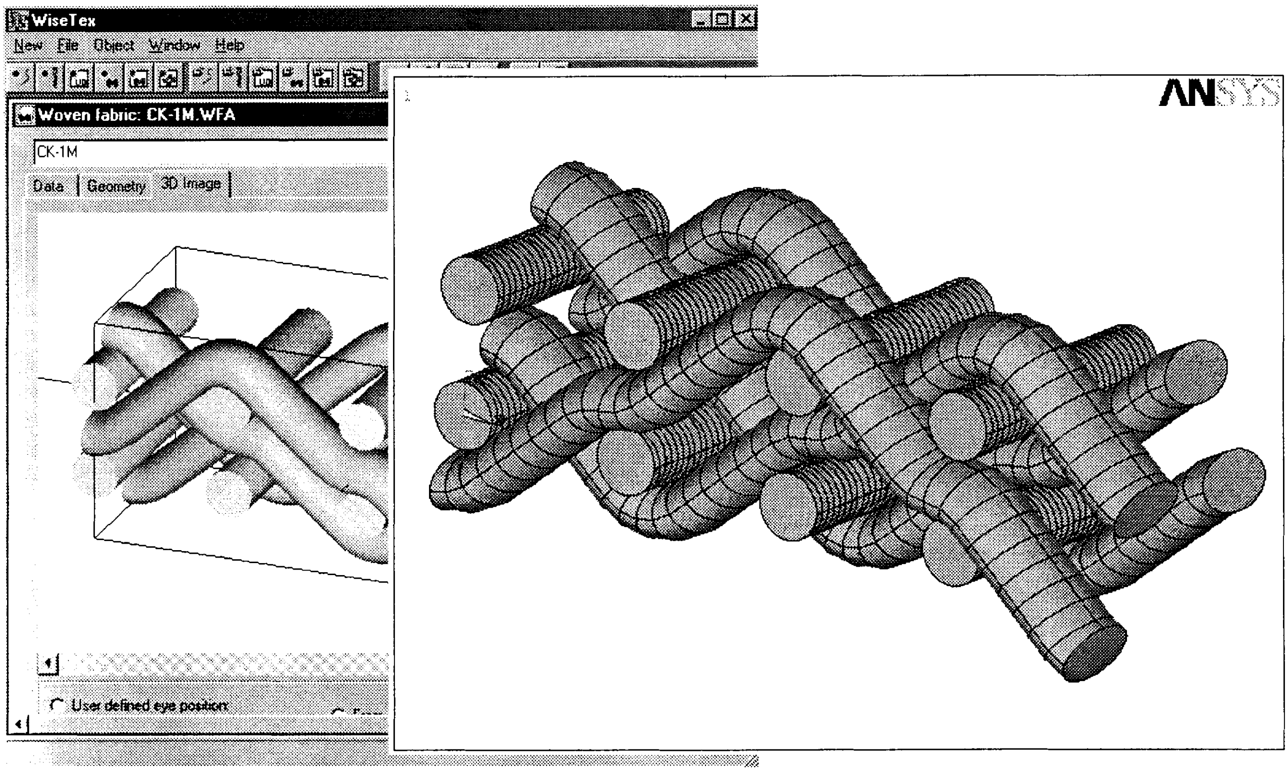
Side crimp

○ Smart ● Neglected

Points per crimp interval for 3D modelling: 20

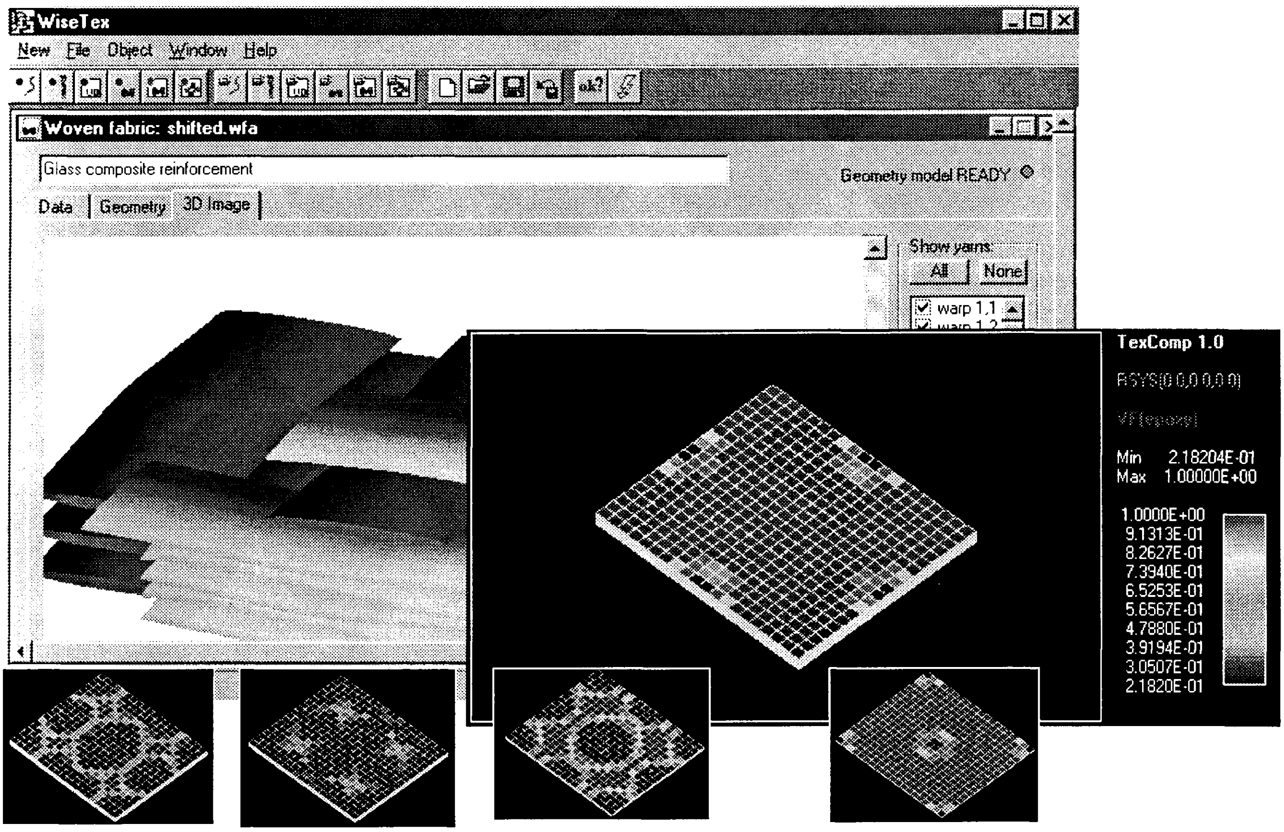
Precision level (relative error in crimp): 0.001

Fig. 4 *WiseTex* input data: full description of woven fabric



CK-1M

Fig. 5 *WiseTex* as a preprocessor for ANSYS finite element package



Glass composite reinforcement

☑ warp 1,1

Min 2.18204E-01
Max 1.00000E+00

Fig. 6 *WiseTex* as a preprocessor for TexComp – software for micro-mechanical modelling of textile composites

The description of the internal fabric geometry can be used for various purposes:

- Visualisation: creation of a 3D picture of the unit cell with rotating, zooming and sectioning capabilities;

Preprocessing for: finite element codes; hydrodynamic permeability models; textile composite micromechanics codes etc. (Fig. 5 and 6)

CONCLUSION

The *virtual textile* concept, implemented in the *WiseTex* software provides a tool for design and optimisation of textile structures in the wide range of types of technical textiles and their applications.

Acknowledgements

This work was done in the framework of the project "Development of unified models for the mechanical behaviour of textile composites" (GOA/98/05), funded by the Flemish Government through the Research Council of K.U.Leuven. S.V.Lomov's work on this project was supported by grants for Senior Fellowship by the Research Council of K.U.Leuven (F/98/108, F/99/096). Authors would also like to thank Prof.N.N.Truevtzev (St.-Petersburg State University of Technology and Design) for his constant support of international collaboration in the field of textile mechanics.

REFERENCES

1. Keefe, M., Solid modelling applied to fibrous assemblies. Part II. Woven fabrics. Journal of the Textile Institute, 1994. **85**(3): p. 350–358
2. Szosland, J., Identification of structure of inter-thread channels in models of woven fabrics. Fibres & Textiles in Eastern Europe, 1999. 7(2): p. 41–45
3. Kosek, M., Modeling of textile structures, in Spring Conference on Computer Graphics. 2001: Bumerice. p. [s.p.].
4. Chen, X. and P. Potiyaraj, CAD/CAM for complex woven fabrics. Part I. Backed cloths. Journal of the Textile Institute, 1998. **89 part I**(3): p. 532–545
5. Chen, X. and P. Potiyaraj, CAD/CAM of orthogonal and angle-interlock woven structures for industrial applications. Textile Research Journal, 1999. 69(9): p. 648–655
6. Chen, X. and P. Potiyaraj, CAD/CAM for complex woven fabrics. Part II. Multi-layer fabrics. Journal of the Textile Institute, 1999. **90 part I**(1): p. 73–90
7. Lomov, S.V. and N.N. Truevtzev, A software package for the prediction of woven fabrics geometrical and mechanical properties. Fibres & Textiles in Eastern Europe, 1995. 3(2): p. 49–52
8. Lomov, S.V. and A.V. Gusakov, Modellirung von dreidimensionalen gewebe Strukturen. Technische Textilen, 1995. **38**: p. 20–21 (in German).
9. Lomov, S.V., Computer aided design of multilayered woven structures, part 1. Technologia Tekstilnoy Promyshlennosty, 1993(1): p. 40–45 (in Russian).
10. Lomov, S.V. and A.V. Gusakov, Coding of carcasse-layered weaves. Technologia Tekstilnoy Promyshlennosty, 1993(4): p. 40–45 (in Russian).
11. Lomov, S.V., Computer aided design of multilayered woven structures, parts 2. Technologia Tekstilnoy Promyshlennosty, 1993(2): p. 47–50 (in Russian).
12. Lomov, S.V. and B.M. Primachenko, Mathematical modelling of two-layered woven fabric under tension. Technologia Tekstilnoy Promyshlennosty, 1992(1): p. 49–53 (in Russian).
13. Lomov, S.V., B.M. Primachenko, and N.N. Truevtzev, Two-component multilayered woven fabrics: weaves, properties and computer simulation. International Journal of Clothing Science & Technology, 1997. **9**: p. 98–112
14. Gusakov, A.V., S.V. Lomov, and A.N. Mogilny, Mathematical modelling of porosity of plane and 3D woven structures, in Computer Methods in Composite Materials VI, S.V. Hoa, W.P. de Wilde, and W.R. Bain, Editors. 1998, Computational Mechanics Publications: Southhampton – Boston. p. 331–340.
15. Lomov, S.V. and A.V. Gusakov, Computation of the porosity of one and multi-layered woven synthetic fabrics. Chimicheskie Volokna, 1998(5): p. 52–55 (in Russian).
16. Lomov, S.V. and A.V. Gusakov, Mathematical modelling of 3D and conventional woven fabrics. International Journal of Clothing Science & Technology, 1998. **10**(6): p. 90–91
17. Lomov, S.V., et al. Textile Geometry Preprocessor for meso-mechanical and permeability modelling of textile composites. in 9th European Conference on Composite Materials. 2000. Brighton: IOM Communications.
18. Lomov, S.V., et al., Textile composites: modelling strategies, in TexComp 5: The 5th Internatiomal Conference on Textile Composites. 2000, K.U.Leuven: Leuven. p. s.p.
19. Lomov, S.V. and I. Verpoest, Integrated model of textile composite reinforcements, in Advances in Composites Materials and Structures VII, W.P. de Wilde, W.R. Blain, and C.A. Brebbia, Editors. 2000, WIT press: Southampton, Boston. p. 367–376.
20. Lomov, S.V., et al., Textile geometry preprocessor for meso-mechanical models of woven composites. Composites Science and Technology, 2000. **60**: p. 2083–2095
21. Lomov, S. V. and Verpoest, I. Compression of woven reinforcements: a mathematical model. Journal of Reinforced Plastics and Composites, 2000. **19**(16): p. 1329–1350
22. Lomov, S. V. and Gusakov. A. V., Mathematical modelling of the structure of 3D woven fabrics. Technologia Tekstilnoy Promyshlennosty, 2000: p. N, 50–53, N3, 47–49, N4, 7–49 (in Russian).

DEVELOPMENT OF CERAMIC FIBER REINFORCED POLYMER COMPOSITES

Czigány, T.[1], Mohd Ishak, Z. A.[2]

[1]*Budapest University of Technology and Economics, Department of Polymer Engineering and Textile Technology, H-1111, Budapest, Muegyetem rkp. 3., Hungary*
e-mail: czigany@eik.bme.hu

[2]*University of Sains Malaysia, School of Industrial Technology, 11800, Penang, Malaysia*
e-mail: zarifin@usm.my

Short ceramic-fiber reinforced polypropylene composite was manufactured by different polymer- and textile technologies. It has been determined that the brittle ceramic fibers are too sensitive on different loads acting at manufacturing. Carding combined with needle-punching proved the best out of the investigated technologies, where matrix fibers as carrying fibers were applied. The reinforcing fiber-matrix adhesion has been improved by chemical curing. Characteristics of composites manufactured by different technologies have been determined by acoustic emission and fracture mechanical tests. The typical damage forms and fracture toughness of the materials were determined.

1. INTRODUCTION

The worldwide spread of polymer composites, as engineering materials makes possible to develop the product meet the best technical requirements on different fields. The ever-increasing requirements against reinforcing additives both economic and environment points inspire research fellows to develop newer and stronger reinforcing additives and more efficient structures. Owing to this inspiration an intensive research activity has begun throughout the world to work out mating technologies for both organic and inorganic reinforcing fibers in matrixes. So beside the traditional glass- and carbon fibers as reinforcing materials nowadays number of papers dealing with the use of origin filaments like flax, sisal, tropical fibers (e.g.: oil-palm, cocoa-palm, pineapple etc.) parallel to mineral origin fibers like basalt and ceramic are ever increasing [1, 2].

The aim of this paper is to present the development of ceramic fiber reinforced polypropylene composites and to investigate the fiber-matrix interface.

2. FIBERS

Basic material of matrix the PP 100 TIPFIL polypropylene mixed with 30 wt. % KERLANE 50 A type ceramic fiber was tested.

Manufacturing of this composite several difficulties should be solved as fiber were available in bale showing high scale inhomogenity both in length and in diameter of fibers. To determine fiber diameter by measurement there were used 50 samples from every material (KERLANE 50 A and PP 100 TIPFIL) in accordance with the standard (JIS R 7601). At measurements 10 mm basic length was applied. The fiber diameters were

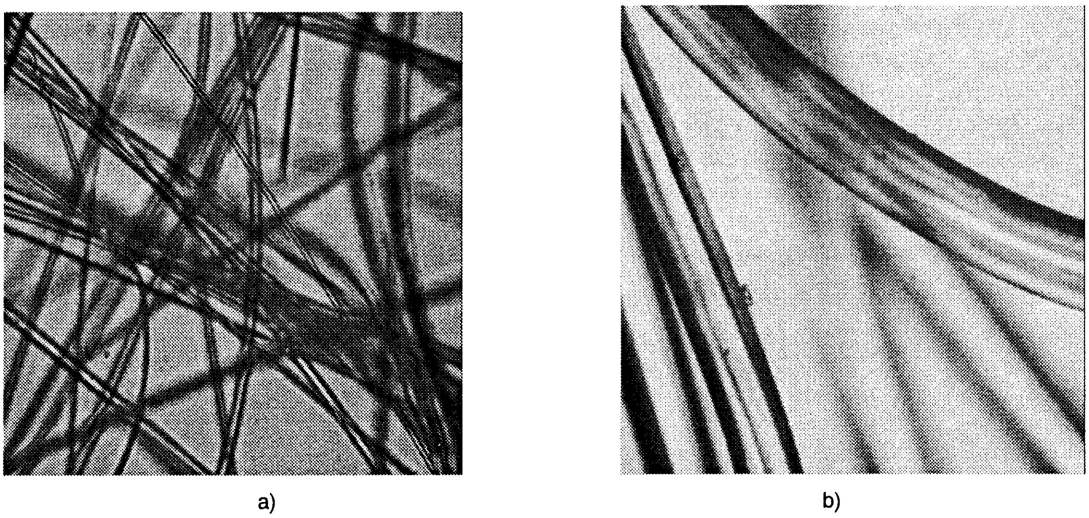

a) b)

Fig. 1 Photo of ceramic (a) and PP fiber with 500 scale

Table 1 Geometric and mechanic characteristics of the tested fibers

Fiber	Density [g/cm^3]	Length [mm]	Diameter [μm]	E modulus [GPa]	Elongation [%]	Tensile strength [MPa]
PP	0.91	100±6	34.3±4.2	4.2±0.9	44.1±16.2	331±56
Ceramic	2.55	15±5	5.9±1.1	60±13	1.5±0.6	828±306

determined by a Projectina 4014/BK-2 type projecting microscope jointed to an image processing video-camera system using 500x enlargement and cross-light. At the images seen in Fig.1 the contour width were taken as the distances measured between inflexion points of the grey-degree distribution. Values have been read with 0.1mm preciseness. The system before measurements was checked by optical net. Fiber diameter was taken at three different cross section on each fiber.

Fibers with known diameter were glued on mounting tab paper then subjected to tensile test on ZWICK 1464 type tensile machine using v = 2 and 50 mm/min testing speed. Strain was measured by high preciseness strain gauge. This method was generally used except at polypropylene samples what samples subjected tensile load showed neck generation elongating the fracture time with several minutes. Standards refering on plastic fibers assign the speed at tensile test so that the time period of the test should last within 20–30 sec. That is why the cross-head speed was increased to v = 50 mm/min. Test results are given in Table 1.

3. COMPOSITES

Composite sheets containing 30wt% ceramic fiber have been produced with COLLIN P 200 T type pressing machine though the raw materials both the poured and the fiber containing semi-products were manufactured by four different technologies [3] as follows:

1. mixing in externally heated worm mixer
2. carding in hand operated labour-mixer
3. carding-needle punching in carding machine in high scale production
4. equivalent to point 3, technology combined with the use additive improving the adhesion

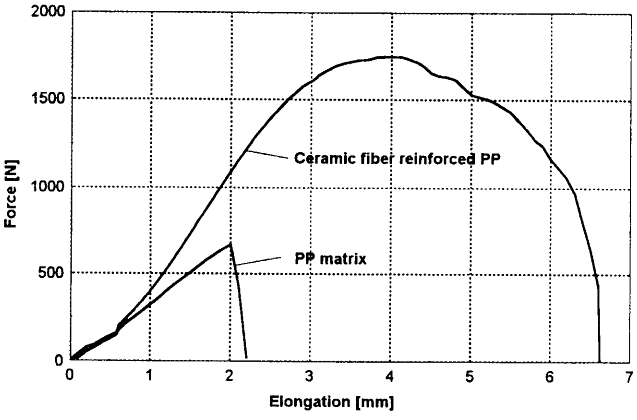


Fig. 2 Force-elongation curves for matrix and for composite

Orientation of the semi-product has been achieved in high scale manufacturing by using for carding BEFAMA 3K type multi-piston carding machine followed by needle-punching. The PP fibers, as carrying elements in the matrix, have been fed into the machine in mixed form improving the degree of homogenisation. After carding the thick mat-like material has been needle-punched help to dense further the mat leading partially to fiber length degradation but making possible mat to remain to many airbulbs in material after pressing it.

Having prepared the material according to the above written technology by pressing both matrix and composite plates (2 mm thick) were produced. Specimens to determine mechanical characteristics have been manufactured from these plates.

Based on the encouraging results gained at the tests with these needle-punched material the applied technology has been judged suitable for further investigations. To achieve even better results by improving adhesion at the interface of ceramic fiber and matrix there were tested different additives [4]. To increase the efficiency of additive PP fibers have been cured by bensol-peroxid.

4. FRACTURE MECHANICAL AND ACOUSTIC EMISSION TESTS

Fracture mechanic tests have been carried out with SEN-T (Single Edge Notched Tensile) type specimen. Before measurement perpendicular to reinforcing fibers specimens have been cut by razor blade. At the tests 5 specimens of each material group were investigated while at evaluation the highest and lowest values have been neglected. Tensile tests were carried out on ZWICK-Z020 type universal tester applying 2 mm/min testing velocity at room temperature. Characteristic tensile curves both for matrix and for composite are given in Fig. 2.

Based on diagrams it can be stated that ceramic fibers fit into matrix well manifesting in significant growing of flexibility at composite comparing to matrix. This fact can be explained that ceramic fibers ends act as stress concentrating nodes generating micro-holes in PP. Distribution of nodes is uniform but everyone can be the source of further micro-cracks. This phenomena manifests macroscopically in the observed toughness.

Fracture toughness (K_c) can be determined by calculation using equation (1).

$$K_c = [F_{max}/(B.W)].a^{1/2}.f(a/W) \qquad (1)$$

where: F_{max} is maximum force in the F-Δl trace, B is thickness of the specimen, W is width of the specimen, a is total notch length (produced by saw and razor blade) and f(a/W) is geometry correction factor.

Table 2 Values of the fracture toughness measured on PP matrix and ceramic fiber reinforced composite

Manufacturing technologies	K_c [MPa·m$^{1/2}$]	Average [MPa·m$^{1/2}$]
PP matrix	4.49	4.28±0.20
	4.09	
	4.25	
Internal mixer	3.24	3.20±0.07
	3.12	
	3.23	
Hand carding	3.90	4.39±0.68
	4.11	
	5.16	
Carding with needle punching	9.14	9.16±0.05
	9.22	
	9.12	
Carding with needle punching using adhesive	10.08	10.08±0.21
	9.87	
	10.29	

There were 5 specimens investigated for each manufacturing technology and matrix. To determine the average K_c the highest and lowest values have been neglected at calculation. Result of K_c can be seen in Table 2. (Standard deviation refers on 95% confidence).

Values of Table 2 show that mechanical characteristics of the composite sheet manufactured aftermixing are less that of the matrix and results obtained at hand carded raw material nearly equal to the values of the matrix. By other words, contrary the expected improvement ceramic fibers did not increase the strength of PP but weakened it. The reason of this seems to be contradiction is that deformation at matrix will cause breaking earlier than it can be expected on deformation of composite. Observing the numerical results one can cause to the conclusion that results of hand carded material are significant measure scattering which fact itself supports the electron microscopic photos (Fig. 3.) showing that ceramic fibers get into matrix in nodes and at pressing PP was not able to impregnate them in the required measure.

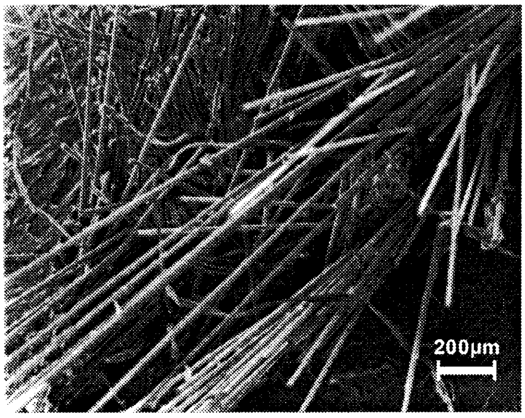


Fig. 3 Distribution of ceramic fibers

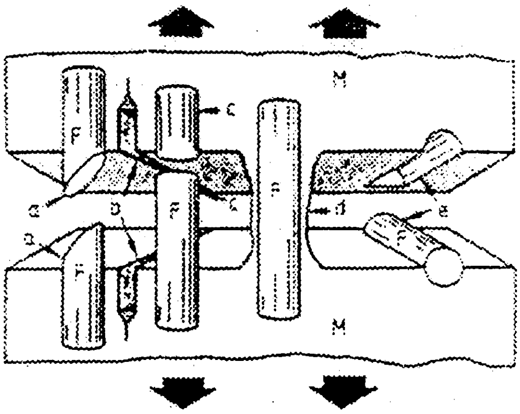


Fig. 4 Damage forms (M – matrix, F – fiber, a – fiber fracture, b – matrix fracture, c – fiber pull out, d – matrix deformation, e – debonding)

Result gained at material manufactured with high scale carding combined with needle-punching are at about double that of the matrix and the fracture toughness shows a 10 % increment in case of surface treatment.

Acoustic activity of the materials during tensile tests has been investigated by fixing sensors on specimens working in ultrasonic frequency range. The aim of acoustic emission (AE) tests was to detect the characteristic ways of composites damages presented in Fig. 4 [5].

Acoustic emission measurements supported the previous tests. Maximum amplitude of acoustic events at loading specimens manufactured by mixing and hand carding was 40 dB. This value shows matrix deformation parallel to debonding or fiber pulling out as literature correlate with it [6]. Specimens manufactured from sheets prepared by high scale carding at tensile test produce events higher than 40 dB, practically max 80 dB, what values belongs to fiber breaking.

5. CONCLUSION

Short ceramic-fiber reinforced (30 wt%) polypropylene composite was manufactured by different polymer- and textile technologies. It is managed to determine that reinforcing effect of the ceramic fibers is highly influenced by the preliminary treatment of them. Homogenisation into internal mixer shattered into pieces then fibers while carding was not efficient enough to distribute equally fibers and the adhesion was also not sufficient. Carding combined with needle-punching proved the best out of the investigated technologies, where matrix fibers as carrying fibers were applied. Fracture mechanic tests carried out on SEN-T specimens proved that the insufficient technology is responsible for the fact that reinforcing fibers function only as additives as at damages no fracture of fibers only the pulling out of them parallel to debonding can be experienced. After curing PP-fibers with benzoyl-peroxide an increase of fracture toughness can be observed proving the different forms of fiber-fractures among the different forms of damages. This latest statement was testified by AE measurements too.

ACKNOWLEDGEMENT

This work was supported by the Hungarian Scientific Research Fund (OTKA T 029034) and by the Hungarian-Malaysian Intergovernmental Research and Technology Program (TéT MAL/5).

REFERENCES

[1] I. Artinger, J. Csikós, Gy. Krállics, Á. Németh, B. Palotás: Technology of metals and ceramics, Műegyetemi Publisher, Budapest, 1999

[2] W.B. Goldsworthy: New Basalt Fiber Increases Composite Potential Composite Technology, 8 (2000), 15

[3] T. Czvikovszky, P. Nagy, J. Gaál: The base of polymer technics, Műegyetemi Publisher, Budapest, 2000

[4] I. Chodak, I. Novak: Surface modification of polypropylene by additives in Polypropylene, An A-Z Reference, J. Karger-Kocsis (Ed.), Kluwer Academic Publisher, Dordrecht/Boston/London, 1999, p.574.

[5] R. G. Kander, A. Siegmann: Mechanism of damage and failure in an orthotropic glass-polypropylene composite. Polymer Composites, 13 (1992), 154–168

[6] T. Czigány, J. Marosfalvi, J. Karger-Kocsis: An acoustic emission study on the temperature dependent fracture behavior of polypropylene composites reinforced by continuous and discontinuous fiber mats. Composite Science and Technology, 60 (2000), 1203–1212

INVESTIGATION OF GLASS KNITTED FIBER FABRIC REINFORCED POLY (ETHYLENE TEREPHTHALATE) COMPOSITES BY ACOUSTIC EMISSION

Romhány, G. , Czigány, T.

Budapest University of Technology and Economics, Department of Polymer Engineering and Textile Technology,
H-1111, Budapest, Muegyetem rkp. 3., Hungary
e-mail: czigany@eik.bme.hu

The mechanical response of weft knitted glass fiber (GF) fabric reinforced poly (ethylene terephthalate) (PET) composites with different number of reinforcing layers were investigated. For the static examinations were used standard dumbbell specimens, wide enlarged rectangle shape specimens and single edge notched (SEN-T) specimens both in wale and course direction. There were measured and calculated the elongation, force, maximum stress and fracture toughness. The effect of number of layers was demonstrated by acoustic emission (AE) techniques too.

1. INTRODUCTION

Glass fiber (GF) fabrics textile made by various techniques such as braiding, knitting and weaving being important reinforcing materials both thermoset and thermoplastic matrix composites into different markets. While the braided and woven fabrics reinforced materials have bigger mechanical properties, their drapability are smaller than knitted fabrics reinforced materials although it is very important for the new manufacturing technology to use deformable reinforcing structures. So, nowadays considerable research and development activities are devoted to develop knitted fabric-reinforced thermoplastic composites [1, 2]. Note that the non-consolidated plain knits can easily produced from commingled yarns [3]. Such non-consolidated knits exhibit excellent drapability and net shape processability. They possess outstanding deep-drawability even if consolidated knitted fabric-reinforced thermoplastic sheets are used as "raw material". The wetting out of the reinforcing fiber by the polymer melt is very good as the matrix-forming fibers, are well dispersed within the yarn or tow used for knitting.

The aim of this paper is to investigate of weft knitted glass fiber fabric reinforced poly (ethylene terephthalate) (PET) composites with different number of reinforcing layers by mechanical response.

2. MATERIALS

Composites consisting of GF and PET fibers were produced from a commingled yarn containing 70 wt. % (≈ 50 vol. %) GF and its linear density was 730 tex. This plain weft knitted textile preform had 15 and 20 ribs per 10 cm in wale (WD) and course (CD) directions. One, two, three, four and five layers were stacked on one another and consolidated by hot pressing under the following conditions: 290 °C temperature, 20 bar pressure, 20 min consolidation time [4].

3. MECHANICAL TESTS

Tensile tests were carried out on standard (DIN 53455) dumbbell specimens and wide enlarged (20 mm) rectangle shape specimens. Regarding the fact that reinforcing structure is orthotrope, tests were done into both directions using computer controlled universal tester type ZWICK Z020 with v = 1 mm/min crosshead speed in room temperature. Force-elongation curves have been evaluated automatically. Maximal forces were used to calculate stresses. There were 5 specimens investigated from each type, the inclination from average was distinguished with 95 % confidence interval. Tensile test results are given in Table 1.

As it was expected load carrying capacity in wale direction at about four times bigger to course direction

Table 1 Tensile test results

Layer	Type	Direction	Stress maximum [MPa]
1	dumbbell	wale	97.5±22.2
1	dumbbell	course	11.2±3.7
1	rectangle	wale	117.0±26.7
1	rectangle	course	14.7±2.9
2	dumbbell	wale	128.7±15.3
2	dumbbell	course	17.8±1.8
2	rectangle	wale	134.5±18.6
2	rectangle	course	23.9±2.0
3	dumbbell	wale	138,0±7.3
3	dumbbell	course	26.7±1.5
3	rectangle	wale	147.5±12.1
3	rectangle	course	32.0±2.4
4	dumbbell	wale	138.8±8.8
4	dumbbell	course	25.0±2.1
4	rectangle	wale	143.6±13.0
4	rectangle	course	28.9±1.3
5	dumbbell	wale	139.8±14.4
5	dumbbell	course	30.4±1.5
5	rectangle	wale	145.9±7.7
5	rectangle	course	36.9±1.9

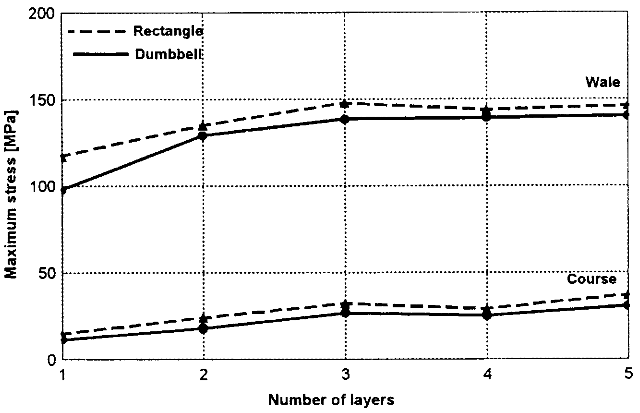


Fig. 1 Stress maximum as a function of layers

one. From tensile test curves of course direction specimens can be seen that at composite samples after reaching the maximal force behave themselves similar to matrix namely specimens did not break but show ductility with plastic elongation testifying the decreasing role of reinforcement.

In Figure 1 results of tensile tests given in Table 1 are presented both dumbbell and rectangle specimens.

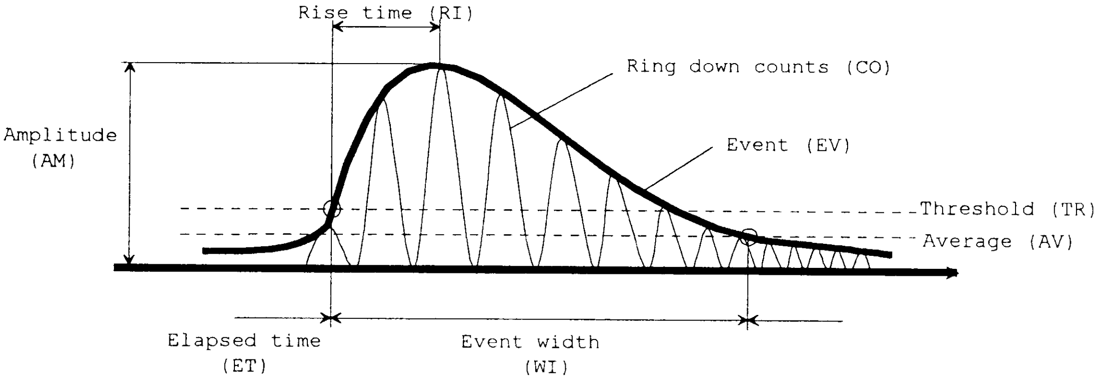


Fig. 2 Characterisation of burst-type acoustic signal parameters

It can be stated maximum stress both in wale and in course directions is higher at about 5–10% at rectangle shape specimens. The reason this fact is that at dumbbell specimens the size of damage zone is bigger than 10 mm width what according to the previous acoustic emission tests [5] at about three times bigger to one knit. It is possible to observe as well that the optimum number of layers is three as above this value mechanical characteristics are usually not improved.

4. ACOUSTIC EMISSION EXAMINATION

Table 2 Fracture toughness of examined specimens

Layer	Direction	Fracture toughness [MPam$^{1/2}$]
1	wale	15.2±3.1
1	course	5.7±0.5
2	wale	20.0±1.2
2	course	6.8±1.9
3	wale	26.7±2.3
3	course	8.1±0.8
4	wale	21.1±1.4
4	course	8.3±1.1
5	wale	23.0±2.1
5	course	9.3±1.4

Single-edge notched (SEN-T) specimens were cut and subjected to static tensile load both direction. Their notch was prepared by sawing and sharped by a razorblade. The SEN-T specimens were tested the similar conditions like tensile specimens. From the load – elongation (F-Δl) response of the SEN-T specimens the fracture toughness was determined (Tab.2.):

$$K_c = [F_{max}/(B \cdot W)] \cdot a^{1/2} \cdot f(a/W) \qquad (1)$$

where: F_{max} is maximum force in the F-Δl trace, B is thickness of the specimen, W is width of the specimen, a is total notch length (produced by saw and razor blade) and f(a/W) is geometry correction factor.

Table 2 shows clear that fracture toughness similar to tensile strength has an optimal value at three layers.

During loading of the SEN-T specimens the acoustic emission (AE) was monitored by a microprocessor controlled AE device (Defectophone NEZ-220, Atomic Energy Research Institute, Budapest, Hungary). The acoustic events were picked up by a wide bandwidth transducer in the frequency range 100 to 600 kHz (peak sensitivity –70dB/V/μbar, type Micro-30D of Dunegan Co., USA). The output signal of the transducer was amplified logarithmically.

During the tests the following primary AE signals were measured, calculated and stored: elapsed time, number of events, peak amplitude, AE energy, event width and rise time. A burst-type acoustic signal along with characteristics is depicted schematically in Figure 2.

Table 3 contains the number of acoustic events up to reach the maximal force.

Regarding the values of the Table 3 more events have been detected in wale direction to direction

Table 3 Cumulative events of examined specimens

Layer	Direction	Cum. Event/time [piece/s]
1	wale	46.2
1	course	32.1
2	wale	61.8
2	course	47.1
3	wale	72.6
3	course	59.0
4	wale	75.7
4	course	77.6
5	wale	78.0
5	course	77.7

course. This fact can be explained that into wale direction there are more knits and they take part more active in load carrying presenting that more fibers can be experienced debonding, pulling out or fiber fracture. Values given in Table 3 can be presented in Fig. 3.

As it seen the character of curves are very similar to curves of stress or curve of fracture toughness. The optimal number of layers can also be found what fact parallel to the previously mentioned similarities testify that close correlation exists between mechanical characteristics and the number of acoustic events. To examine the amplitude of detected events can be say that the number of layers can not influence them, 10–25 dB means matrix deformation, 25–40 dB means debonding, 40–60 dB means pull out and over 60 dB means fiber fracture [6].

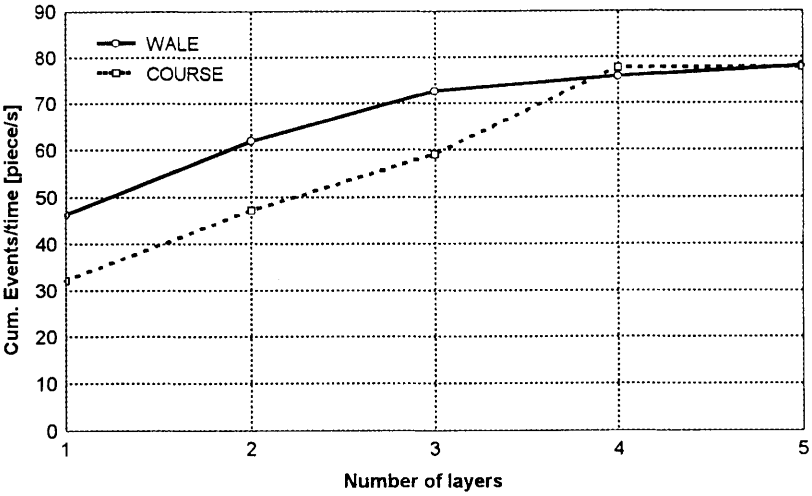


Fig. 3 Cumulative events as a function of layers

5. CONCLUSIONS

Based on this study devoted to determine the number of layer dependent mechanical response and acoustic emission (AE) behavior of weft knitted glass fiber (GF) fabric reinforced poly (ethylene terephthalate) (PET) composites with different number of reinforcing layers, the following major conclusions can be drawn:

i. the mechanical properties of composite were getting grow increasing of number of knit layers. It was found an optimum of number of layers after this tendency has stopped and the properties have stagnated.

ii. The effect of number of layers was demonstrated by acoustic emission (AE) techniques too. It was realised that acoustic parameters show similar property like mechanical characteristics, which refer to correlation.

ACKNOWLEDGEMENTS

This work was supported by the Hungarian Scientific Research Fund (OTKA F 025080) and Rubik Foundation.

REFERENCES

[1] T. Czigány, J. Karger-Kocsis, Textile fabric-reinforced thermoplastic polyester composites in "Handbook of Thermoplastic Polyesters", Ed.: S. Fakirov, Wiley-VCH, Weinheim, 2001, in press

[2] J. Mayer, E. Wintermantel, Thermoforming processes for knitted-fabric-reinforced thermoplastics: New manufacturing techniques for load-bearing, anisotropic implants in "Composite Sheet Forming", Ed.: D. Bhattacharyya, Elsevier, Amsterdam, 1997, pp. 403–440

[3] K. Friedrich, Commingled yarns and their use for composites in "Polypropylene: An A-Z Reference", Ed.: J. Karger-Kocsis, 1999, pp. 81–89

[4] I. Putnoki, E. Moos, J. Karger-Kocsis: Mechanical performance of stretched knitted fabric glas fibre reinforced PET composites produced from commingled yarn; Plastics, Rubber and Composites, 28 (1999), 40–46

[5] T. Czigány, J. Karger-Kocsis: Determination of the damage zone size in textile fabric reinforced polypropylene composites by locating the acoustic emission; Polymers & Polymer Composites, 1 (1993), 329–339

[6] T. Czigány, M. Ostgathe, J. Karger-Kocsis: Damage development in GF/PET composite sheets with different fabric architecture produced of a commingled yarn; Journal of Reinforced Plastics and Composites, 17 (1998), 250–267

3-DIMENSIONAL TEXTILE MATERIALS

Kovář, R.

Technical University of Liberec, Czech Republic, Halkova 6, 461 17Liberec, CZ,
E-mail radko.kovar@vslib.cz

INTRODUCTION

How to create spatial (3-D) textile products? The most primitive way is tailor it from flat fabrics. Nevertheless it is not the best way as it usually creates waist material. The technologies of flat textile fabrics formation enables to made even quite complicated 3-D products with little or without any lost material. Let us underline these possibilities.

Just begun millennium starts with 21st century, which is supposed to be the century of new materials. We believe that textile based composites and alike products are to play important role in new technologies. Why? They are able to use materials properties very well.

3-D textile products can be divided into next main groups:

1) Products with one major dimension.
2) Products with two major dimensions (double or multi-layered fabrics).
3) Deformed flat fabric. The principle is based on change of fabric dimensions in main directions.
4) Really spatial product with comparable all three dimensions in *x*, *y*, *z* co-ordinate system.

1. CONSTRUCTION OF PRODUCTS WITH ONE MAJOR DIMENSION

Such longitudinal textiles may be created by different ways and technologies. If they are to bear only the axial tension (not bend), simple twisted ropes and similar products can be used. More complicated profiles, aimed to bear as well **bending** moment, can be created as well by „**tailor**“ technology (cut from the flat fabric), examples see in the Fig. 1. The most usual profiles, used in machine industry etc. such as I, T, U and L cross-section, are introduced.

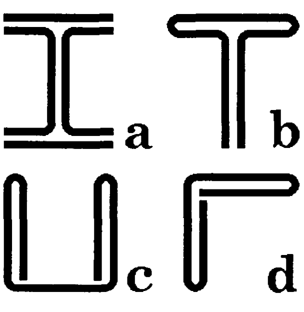


Fig. 1 „Tailored“ profiles.

From the point of view of bending load in one direction the I profile is very popular (the most of the active mass is distanced form neutral axis), for two perpendicular bending loads the square profile may be used and if the load is random the tube is the best cross-section.

2. CONSTRUCTION OF PRODUCTS WITH TWO MAJOR DIMENSIONS

The **bending load** used to be the most important in this case. To construct the product effectively, the most of the active mass should be concentrated far form the plane of symmetry. The reason is the same as why I profile is preferred – maximal profile modulus (moment of inertia) at minimal mass. Inner parts of the fabric bears little of the bending load as there is little elongation near the axis, it needs to bear only little lateral compression (the curvature of these products use to be small or radius *r* great and normal tension σ_N as a function of tangential tension σ_T is $\sigma_N = \sigma_T/r$). The examples of so-called sandwich textiles for knitted composite reinforcements are shown in the Fig. 2 a, b (weft and warp structures).

The product in a shape of **plate** can be created as well by three or several layers technology (laminate), Fig. c, d [1]. Shaped composite made of knitted fabric is used as inner very light part of the plate; outer layers can be another textile composites or non-textile product.

Some of more particular possibilities of knitting two **connected layers** on double bed warp knitting machine (raschel) are in the Fig. 3. The principle is based on **tubular** knitting – some yarns knit only on face side

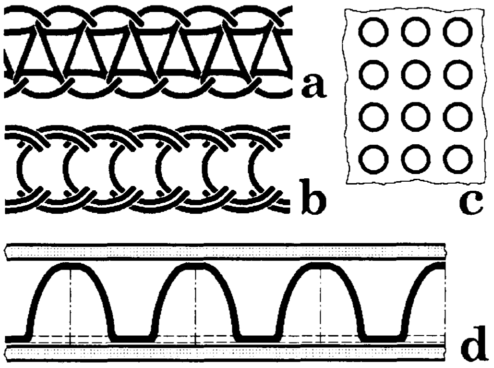


Fig. 2 The „sandwich“ textiles.

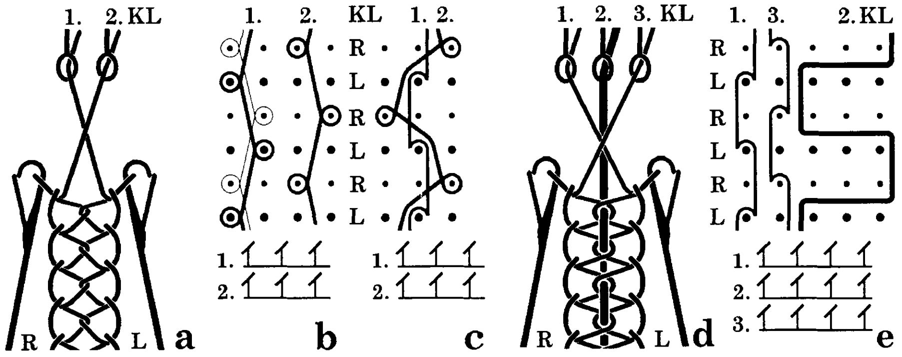


Fig. 3 Examples of the warp knitted double layered fabrics.

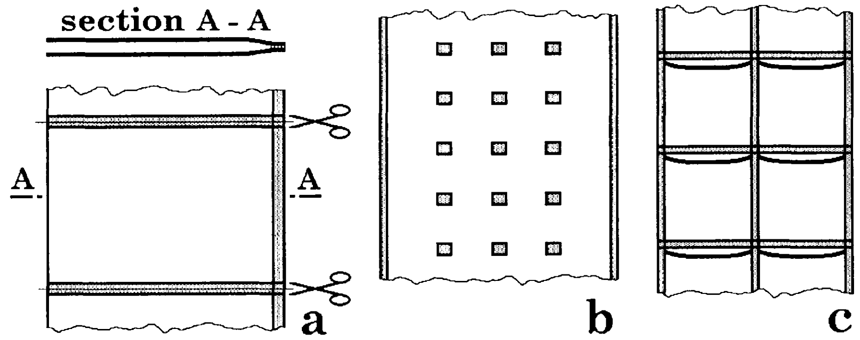


Fig. 4 Examples of using locally connected tubular knitted fabrics.

of the structure and others on the reverse side. Example (a) shows connection of the face and reverse fabric by cross lapping of the yarns (right guide bar KL to the left needle bed and on the contrary). Example (d) uses for connection third complementary yarns. Fig. b, c, e introduces some of possibly used warp knitted structures [2, 3].

Relatively simple possibilities of 3-D product imitation using local connection of tubular fabric are introduced in the Fig. 4. First (a) are seamless sacks (the space of connection is grey, white is space of tubular fabric).

Product (b) can be used for example to replace a concreting boarding. On Fig. c there are pockets that can be used for protection of plants on sheer slopes etc.

The two or multi-layered **woven** structure can be created in a very similar way. To produce several parallel fabrics on one weaving machine is not problem, example of four layers of plain weave connected by two other warps are in the Fig. 5. At least ten heald shafts are necessary.

3. SPATIAL PRODUCTS BASED ON DEFORMED FLAT FABRICS

To create such **woven fabric** is rather **difficult.** Why? The main reasons are that there is problem to change the number of both warp and weft yarns (and so the number of the binding points) in the fabric space.

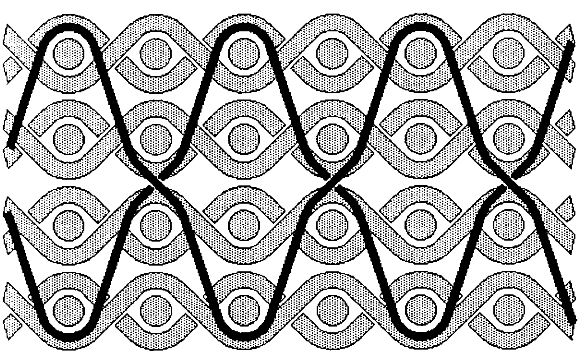


Fig. 5 Four-layered plane weave.

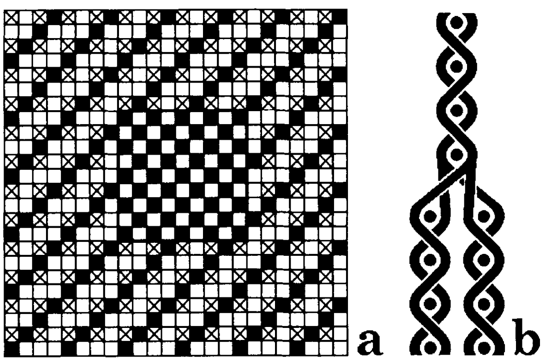


Fig. 6 Example of deformed woven structure.

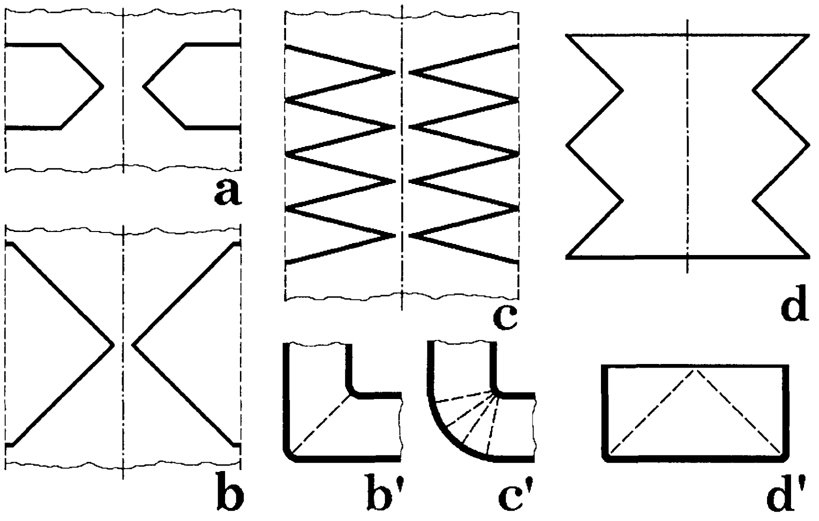


Fig. 7 Examples of 3-D deformed weft knitted fabrics.

Other problem is to change the length of the yarns put into the fabric, namely weft yarns. Warp yarns can be supplied from two or several warp beams or from bobbin creel. Example of the structure, which can partly eliminate these problems, is in the Fig. 6. It is a combination of tubular (two layered) and single (inner square) plain weave (a). By crosses (x) are marked the binding points where all upper warp yarns lays above lower wefts. Fig. b shows the scheme of the product, but without 3-D deformation of single layer space. Nevertheless we can notice that the real yarn sett is in this part doubled.

From our point of view **weft knitting** technology is in exceptional position. If the fabric can be made of one **reversibly laid** yarn the possibility to insert the courses of alternating length arises [1, 4, 5]. It is connected with large scale of change of number of the stitches both in the wales and in the courses. The basic principle in well-known form hosiery products (reversible knitted heel), the knitting scheme see in the Fig 7 a. To understand the figures: in inner parts there is fabric made of reversibly laid yarn, out of the thick lines the knitting but not the fabric is interrupted (knitting needles do not work but keep the stitches).

In the way alike the **knee-joint** on the tube can be knitted, Fig. b (b is knitting scheme, b' product). In this case the decreasing and increasing of the courses length is almost from all fabric width to almost zero.

$$x = \frac{D}{2}\cos\theta, \quad D_x = D \cdot \sin\theta = \sqrt{D^2 - D^2\cos^2\theta} = \\ = \sqrt{D^2 - D^2\frac{4}{D^2}x^2} = \sqrt{D^2 - 4x^2}$$

Example (c) is as well the knee-joint but with circular axis shape. Last example (d) presents knitted **box** (without circular knitting).

Calculation of the spatial products is easy in some special cases (in others intuition is necessary). We assume that the stitches dimensions (spacing in both main directions) are approximately the same in the product. Lets wish to knit **spherical** shape and to keep all the wales to be circular. Then we can use the Fig. 8.

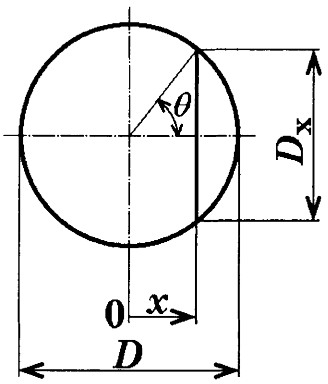


Fig. 8 Calculation of the wails length.

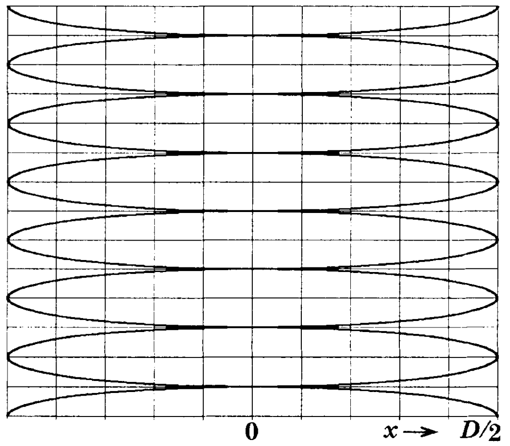


Fig. 9 The scheme of spherical knitting.

If the sphere diameter is D, the diameter of wale is D_x in distance x from the centre (point 0) it will be:

The perimeter of the circle and so the length of the investigated wale will be $L = \pi \cdot D_x = \pi \cdot (D^2 - 4x^2)^{0.5}$. Knitting need be done in sections (Fig. 9); inside one section the fabric is plane. The more of the sections the better the result (but there are limits done by the fact that we have minimal space unit – one stitch).

Some possibilities provide using of different knitted structures, as we can receive very different width of particular courses. Warp knitting technology possibilities are more limited.

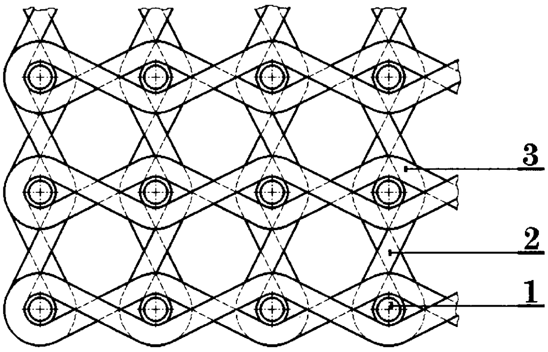


Fig. 10 Fully 3-D woven fabric.

4. FULLY SPATIAL PRODUCTS

In the Fig. 10 **fully 3-D woven fabric** [6] is introduced. The formation of such structure is not easy. Three yarn systems are used: several levels of warp yarns, horizontal and vertical weft yarns. The weaving system needs to create alternatively several horizontal and several vertical parallel sheds with simultaneous several weft yarns insertion. If we mind the problems known from multi-shed weaving systems realisation (the principles have been known for a long time) we can estimate that such machine development will not be quick matter.

Technology of **braiding** enables production of quite complicated products of different and even changeable profiles (Fig. 11 a). To remember, this technology use one or more yarn diagonal systems with interlacing by binding points such are these known from weaving (the most simple example in the Fig. b). Some of the modern computer controlled braiding machines enables very complicated movement and crossing of yarn carriers.

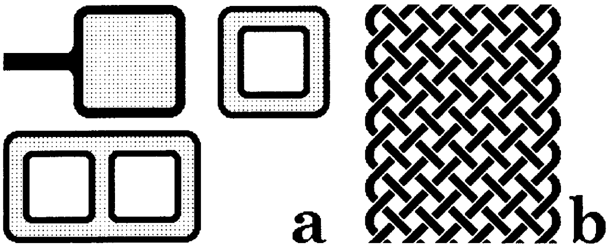


Fig. 11 Spatial braided products profile.

DISCUSSION

The presented paper brings only the brief survey of 3-D shaping of textile products possibilities. The modern machines are able, for example, to knit sweater in ready-made form, without necessity of any confection. The development in this direction is rapid.

Acknowledgement: this work was supported by the research project „Research Centre TEXTILE“ - LN00B090C.

LITERATURE

[1] Kovar, R.: Pletení (Knitting). Textbook TU of Liberec 2001 (second edition).

[2] Kovar, R.: 1D, 2D and 3D Knitted Composite Reinforcements. In: Intern. J. Polymeric Mater., 2000, Vol. 47, pp. 519–525.

[3] Kovar, R.: Double and multi-layered tubular fabric. In: Knitting Technology, 2/1999, p. 16–18.

[4] Fangueiro. R., Araujo, M., Hong, H.: Advances in Weft-knitting Technical Structures. The Nordic Textile Journal 1/99, Sweden.

[5] Dias, T., Fernando, A., Choy, A, K., Xie, P.: Knitting Seamless Three-Dimensional Shell Structures on Modern Electronic Flat Bed Knitting Machines. In: Medical Textiles, Bolton UK 1999.

[6] Khodar, N.: Noobing and 3D-Weaving Processes. The Nordic Textile Journal 1/99, Sweden.

DETERMINATION OF ESTIMATING CRITERIA FOR CLEAN ROOM TEXTILE

Vlasenko, V., Suprun, N.

Kiev State University of Technologies and Design, Ukraine

The concept "technology of cleanliness" appeared at the middle of 20th century under the influence of the rapid development of high technologies. In all advanced countries the clean technologies concern to the most progressive branches of science and engineering and have serious state support. They are widely used in electronic, nuclear, space, pharmaceutical, perfumery-cosmetic branches, in exact instrument industry, foodstuff production etc.

The constituent parts of this special kind of technologies are so-called clean rooms, equipment and facilities for them which don't eliminate particles during the work and air systems. The service staff need to wear specific garment which protects workspace and the product from contamination.

The researches show that the basic sources of contamination in the clean rooms is the personnel: on the average 70–80% of micro contamination are generated by them; 5–10% by equipment and 5–10% by an environment.

Perfectly designed, constructed and equipped clean room of a high class turns to an ordinary room in a few minutes, if the working personnel has no appropriate garment and his behaviors is not regulated. In the world practice such garment carry the name "clean room garment" and it is an equal component of high product technologies.

The basic function of the clean room garment is protection of technological environment and product from contamination generated by human being. The contamination must stay inside the garment within so-called underwear space and on the inside surface of the garment.

As a matter of fact clean room garment must play a role of a specific barrier or better - filter which finally determines cleanliness of the air at the functioning clean room.

Depending on the class of cleanliness in underwear space have to held 60–95% of the particles generated by the human being.

Holding the particles the garment has not to be the source of contamination. Besides, the garment should carry out protective function preserving the workers from harmful and dangerous industrial factors.

High requirements to the functional properties of the garment determined rigid demands to the choice of textiles, garment system, its design. (In this contribution are considered the textiles for upper garment only.)

World market offers a great variety of textiles for clean room garment – woven and knitted fabrics, non-woven and laminated materials.

At the present stage of technical textiles technology development the new textiles are creating continuously. Such textiles have their specified and regulated functional performance.

Each kind of textiles presented at the world market has its distinctive properties, however there are some obligatory requirements for all clean room textiles. First of all such characteristics as minimal own dust generation (linting), high durability, abrasive stability, also satisfactory antistatic properties and easy contamination removal during the processing are concerned to them. Another requirements are more specific.

Satisfy the main demands in full measure can only textiles from synthetic filament fibers as polyester, polyamide, polyolefin .Textiles from polyester fabric are used most often. Textiles from polyamide and polypropylene fibers are also used rather widely. In biologically clean rooms the limited use of textiles from the blend of polyester and cotton yarns is possible. By the way the issue of use of polyester fabric that contain cotton or rayon yarn is wide discuss by the scientific and user of the clean room.

Each kind of the above mentioned textiles has its distinctive field of use. Polyester and especially polypropylene textiles are resistant to chemicals including acids. Polyester textiles can be used for sterilized garment. Polyamide materials are not stable against acid but they have greatest abrasion stability among synthetic textiles and therefore minimum self linting.

Rather recently manufactures of the clean rooms garment have begun to use laminated textiles where fabric is covered with membrane polyurethane film. Their specific features consist in small pore size and ability to pass water vapor only one direction.

The fabrics from polyester and cotton blend are compatible to sterilization, have antistatic properties and are hygienic. However they can be used only in service and technical (so named "grey") zones. Using of such fabrics are strictly prohibited in the workshops by production of injection medicine.

Variety of quality parameters and wide scale of quantitative meanings make choice of textiles with optimum performance problematical. Forecasting of garment performance in functioning clean room without perfect information about technology condition is practically impossible. Especially this approach is important under condition of chemicals influence. Such a situation causes, on our opinion, necessity to discuss principle of evaluation criteria choice for clean room textiles at a modern level of knowledge.

Our work is based on generalized data presented in the scientific and technical literature. First of all, it is recommendation of the Institute of Environment Science and

Technology (IEST), USA [1,2,3]. This recommendation have no status of the normative documents but are very authoritative among the users of the clean room and manufacturers of the textiles and garment for them. For today these are practically sole source, where described in details the principles of textile choice, technique of the basic parameters estimation, approach to creation of optimum system of clean room garment. Besides we have generalized our own data of experience garment exploitation at the enterprises of a pharmaceutical industry in Ukraine and Russia [4,5,6,7,8].

In our opinion it is expedient to divide utilized parameters on some groups.

First group – obligatory parameters which characterize the properties ensuring the functioning of clean room garment as such.

Second group – parameters which describe raw composition, fabric construction, design, production mode of textiles and its mechanical properties. As a matter of fact these parameters are also obligatory, since the quantitative meanings each of them are necessary informed by manufacturer of textile of the clean room garment for each lot of goods.

Third group – parameters which importance is defined by concrete conditions of garment function.. It can be parameters of hygienic and aesthetic properties etc; in the certain cases for definite kind of garment some parameters of this group can become obligatory. For example, the parameter "compatibility to chemicals" is obligatory in conditions of chemical agents use. These parameters are claimed by users of the garment. This group can include parameters of protective properties concerning workers.

The authors of this contribution invite to discussion specialists who deals with the maintenance of clean rooms in different branches of industry.

The authors considered their pleasant duty to acknowledge their colleagues from Czech Enterprise SPOLSIN for samples and assistance with researching. We also express our thanks to the companies TORAY, KLOPMAN, FRISTADS, SATI, QUALITECH, SEIREN, SHENZHEN for samples which were used in investigations.

Table 1 Performances of Textiles (obligatory requirements of quality)

No.	Parameters of quality, units
1.	Generation of particles, number of particles
2.	Durability (surface abrasion resistance) – weight loss, %; – cycles, number
3.	Pilling, number per cm^2
4.	Chemical compatibility (stability), %
5.	Dimension stability after processing (laundry, dry-cleaning, sterilization), %
6.	Compatibility to processing (laundry, dry clean, sterilization), points
7.	Specific surface resistivity, Ohm
8.	Particle filtration efficiency, (determined by fabric producer) %

Table 2 Fabric Description

No.	Parameters of quality, units
1.	Surface density, g/m^2
2.	Thickness, mm
3.	Width, cm
4.	Type of the weave
5.	Conductive fibers (kind and pattern)
6.	Breaking strength by warp and weft, H
7.	Tear elongation by warp and weft , %
8.	Fabric density, thread per 10cm

Table 3 Hygienic requirements

No.	Parameters of quality, units
1.	Air permeability, $cm^3/cm^2 \cdot s$
2.	Hygroscopicity, %
3.	Water uptake, %
4.	Capillarity, mm
5.	Thermal conduction, $W/m \cdot K$
6.	Biological inertness
7.	Acoustic properties
8.	Equivalent pore diameter, mkm
9.	Moisture permeability, $mg/m^2 \cdot h$

Table 4 Aesthetic Requirements of Textiles

No.	Parameters of quality
1.	Weave design
2.	Transparency (optical rating, opaque)
3.	Color design, points
4.	Perfection of performance

REFERENCES

1. Institute of Environmental Sciences. Contamination Control Division. Recommended Practice "IES-PR-CC003 – Garment System Considerations for the Clean Rooms and Other Controlled Environments", Illinois, USA.
2. Institute of Environmental Sciences. Contamination Control Division. Recommended Practice "IES-PR-CC004 – Evaluating Wiping Materials Used in the Clean Rooms and Other Controlled Environments".
3. Institute of Environmental Sciences. Contamination Control Division. Recommended Practice "IES-PR-CC005 – Clean Rooms Gloves and Finger Cots".
4. V. Vlasenko, T. Demenkova, "Textiles and Garment for the Clean Rooms", "Technologia chistoty" No.2, 1993, pp. 24–28.
5. V. Vlasenko, L. Rybakova, O. Lukashevich, "New Textiles for the Clean Rooms Garment", Proceedings, 13th International Symposium on Contamination Control (ICCCS), p. 176–182, September, 16–20, 1996, The Hague, Netherlands.
6. V. Vlasenko, O. Lukashevich, "Clean Rooms Garments as the Complex Multilayer Structure", Proceedings, 14th International Symposium on Contamination Control (ICCCS), 24.04–01.05.1998, Phoenix, Arizona, USA.
7. V. Vlasenko, O. Lukashevich, V. Kovachich, M.Travnichkova, "Discussion on Air Permeability and its Significance for Estimation of the Clean Rooms Textile Quality, Vlakna a Textile, No. 1–2, pp.7–11, 1998.
8. V. Vlasenko, L. Rybakova, "Physiological Aspects of the Utilization of Garment in the Clean Rooms", Proceedings, 7th International Conference RASINKOM, 25–27.05. 1998, Moscow, Russia.

LIGHT COMPOSITES REINFORCED WITH 3-DIMENSIONAL DISTANCE TEXTILES

Schmidt, H., Kamińska, I., Lao, M.

Institute of Textile Materials Engineering,
Gdańska 118, 90-520 Łódź, Poland, e-mail: iimw@mazurek.man.lodz.pl

Light structural composites have been made up of matrices consisting of chemosetting polyester and epoxy resins, reinforced with three-dimensional woven fabric (3-DDW), comprising about 80% empty air spaces. The adhesion of the resins to polyester, polyamide and polypropylene has been assessed as well as the tensile, compression and bending strengths of the composites and their modulus of elasticity. Advantages of the obtained composites include a high strength to weight by volume ratio and very low resin and fiber consumption in making such composites.

1. INTRODUCTION

In order to reinforce polymeric composites, spatial textile structures, especially woven, and recently also braided, are more and more often used. They are most often solid composites or the ones consisting of shaped elements, made of continuous filament filled with a polymeric matrix or coated with a polymer.

In earlier studies carried out at our Institute, there were obtained light composites with relatively good mechanical properties, with chemosetting resin matrix reinforced with 3-dimentional distance knitwear [1]. The present study shows the results of tests of composites reinforced with three-dimensional woven fabric (3-DDW).

2. AIM OF THE STUDY

The aim of the present study was to examine the adhesion of chemosetting resins to fiber-forming synthetic polymers, i.e. polyethylene terephthalate (PET), polyamide (PA), polypropylene (PP), and determining the mechanical properties of the composites reinforced with 3-dimensional distance woven fabric (3-DDW) made of synthetic fibers.

3. EXPERIMENTAL

3.1. Materials

The composites in question were prepared by a laboratory process, using the following materials:

- a three-dimensional distance woven fabric (3-DDW), made of polyester yarn with a linear density of 1030 dtex f 256, a tenacity of 71 cN/tex and elongation at break of 16.5%. The surface weight of the 3-DDW was 465 g/m^2,
- Epidian E-53 epoxy resin, (a product of condensation of dihydroxydiphenylpropane and epichlorhydrine) with hardener Z-1 (3,6-diazoocta-1,8diamine),
- Polimal 109 polyester resin (orthophthalic) with an accelerating agent (cobalt naphthenate) containing 2 % of Co (Chemical Works "Organika Sarzyna") and Luperox initiator,
- polyester, polyamide and polypropylene continuous filament yarns,
- PET, PA, and PP films

3.2. Testing methods

Composites reinforced with 3-DDW were obtained by impregnating the woven fabric with Polimal 109 resin with an addition of 0.4 % cobalt accelerating agent and 1% Luperox initiator, or Epidian E-53 resin with an addition of 10 % hardener Z-1, followed by pressing off the resin excess. Figure 1 shows a cross-section of such a composite.

After 7 days, mechanical properties of the resultant composites were tested.

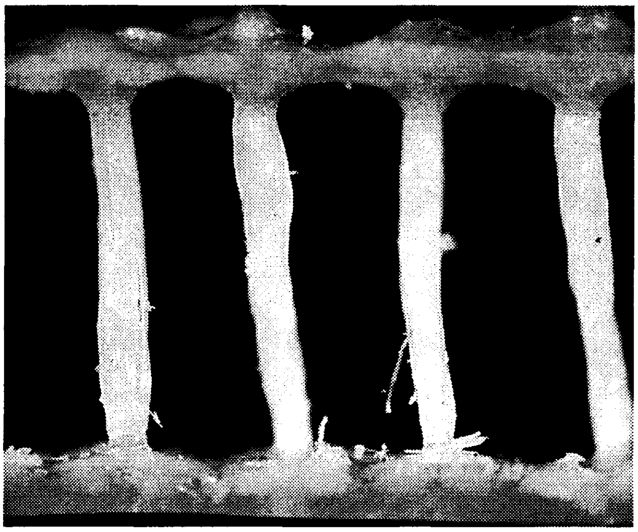


Fig. 1 Composite reinforced with 3-DDW

The tensile strength of the composite outer layers, the compression strength of composites reinforced with 3-DDW and those in the form of rods reinforced with yarn were tested by means of a Zwick GmbH universal tension tester. In compression tests with composites reinforced with 3-DDW, the travel rate of a 100 mm^2 foot was 1.35 m/min. The bending strength was tested on an Instron tester according to the Polish standard PN-82/C-89051. Three-point bending of composite beams was used at a loading rate of 100 mm/min.

The compression strength of the composite made of resin in the form of rod reinforced with continuous fibers was tested by our own method. To a polyethylene tube with an inner diameter of 1.6 mm and a length of 70 mm a bundle of yarns impregnated with resin was drawn in. Once the resin was hardened, the tube was removed in its center on the length of 11 mm. The jaw spacing was 11 mm and the jaw travel rate 1.05 mm/min. The maximum compression force F_{max} [N] was taken from the dependence of compression force on the jaw travel rate.

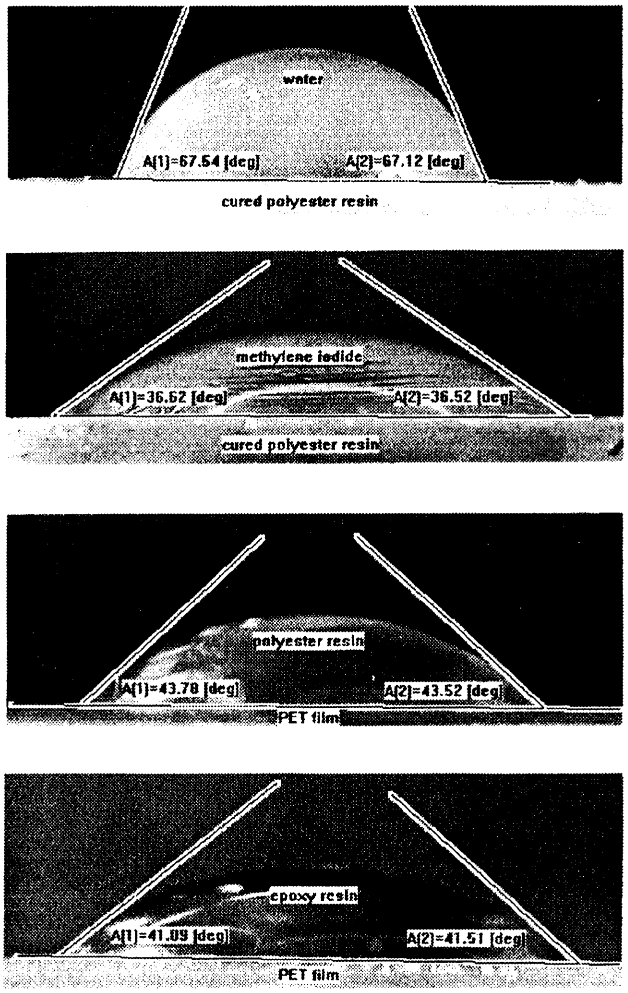


Fig. 2 Examples of determining the contact angles of water and methylene iodide on cured PET resin as well as of polyester and epoxy resins on PET film.

The static adherence of yarns to the matrix was determined according to the Polish standard PN-81/C-04267.

The contact angle of polymers was measured by means of a stereoscope microscope SZ-CTV of OLYMPUS with a photo camera coupled with a computer using the „Microscan" program for microscope image processing. The films were treated with ethanol and petroleum benzin to remove their finishing agents. A micrometric syringe was used to place a small drops of liquids on films. Fig. 2 shows examples of contact angles of water and of methylene iodide on cured PET resin end polyester and epoxy resins on PET film.

The reversible work of adhesion W_{adh} [2] at polymer interface was calculated from Dupré's relationship:

$$W_{adh} = \gamma_{s1} + \gamma_{s2} - \gamma_{s1s2} \cong 2[(\gamma^d_{s1}\cdot\gamma^d_{s2})^{1/2} + (\gamma^a_{s1}\cdot\gamma^a_{s2})^{1/2}]$$

where: W_{adh} is the work required to separate of both polymers S_1 and S_2, thereby create unit areas of S_1 and S_2 at the expense of the unit area of S_1–S_2 surface, γ_{s1} and γ_{s2} are surface tensions of S_1 and S_2 polymers, respectively, γ_{s1s2} is interfacial tension at the interface S_1–S_2, the superscripts d and a refer to the dispersion forces and the combined polar interactions.

The forces of interfacial tension at the interface of polymers which form the composite were calculated from the contact angles with two liquids of known surface tensions γ_c from the relationship [2]:

$$1 + \cos\vartheta = 2\{[(\gamma^d_s)^{1/2}\cdot(\gamma^d_c)^{1/2}]/\gamma_c + [(\gamma^a_s)^{1/2}\cdot(\gamma^a_c)^{1/2}]/\gamma_c\}$$

where: ϑ is contact angle, γ_s and γ_c are surface tensions of the polymer and liquid, respectively.

Water and methylene iodide were used to measure the surface tensions.

3.3. Results

The physical and mechanical properties of composites reinforced with filaments are determined by the reinforcing and matrix properties, the quantitative ratio of components, the forces at the component interface and the geometric arrangement of components. In the composites composed with polymeric matrix reinforced with 3-DDW, the mechanical properties are determined by:

- the properties of the hardened resin,
- fiber properties,
- resin to fiber adhesion,
- wettability of fibers during resin impregnation,
- quantitative ratio of textile material to resin and to free spaces,
- textile fabric structure.

The reversible work of adhesion is a measure of coherence of two polymers at their interface. Table 1 shows the contact angles of water and methylene jodid on polyester, polyamide and polypropylene films and cured Polimal 109 and Epidian E-53 resins as well as

Table 1 Contact angles of water, methylene iodide and liquid resins, and surface tensions of the polymers

Tested sample	Contact angle of [degrees] water	Contact angle of [degrees] CH_2J_2	Contact angle of liquid resin [degrees] Polimal 109	Contact angle of liquid resin [degrees] Epidian E-53	Surface tension [mJ/m^2] γ^d	Surface tension [mJ/m^2] γ^a	Surface tension [mJ/m^2] γ
PET film	61.6	29,9	43,6	41,3	38,3	10,8	49,2
PP film	71,9	32,1	46,9	44,9	39,0	6,8	45,8
PA film	44,1	31,4	35,0	32,3	34,7	24,1	58,8
Cured Polimal 109	67,1	36,8	–	–	35,9	10,1	45,9
Cured Epidian 53	76,4	53,0	–	–	28,4	8,0	36,4

Table 2 Reversible work of adhesion of resin/fiber-forming polymer interface and static adherence yarn to resin

Polimer	Work of adhesion W_{adh} [mJ/m^2] Polimal 109	Work of adhesion W_{adh} [mJ/m^2] Epidian E53	Yarn	Static adherence [N] Polimal 109	Static adherence [N] Epidian E53
PET film	95,02	84,59	PET	50,6	86
PP film	91,33	81,29	PP	49,8	52,7
PA film	101,70	90,57	PA	72,9	171,7

the calculated from them surface tensions γ^d, γ^a and γ. As expected, PP shows the lowest wettability having the lowest surface tension. The surface tension of Epidian E-53 is considerably lower than that of Polimal 109. Therefore, reversible work of adhesion W_{adh} for all the three polymers is higher for Polymal 109 than that for Epidian E-53. The values of W_{adh} are given in Table 2. Table 2 shows also the static adherence of yarns to the cured resins. For both resins the adherence force and the reversible work of adhesion are the lowest in the case of polypropylene and the highest in polyamide. The static adherence of Epidian E-53 is in all the cases higher than that of Polimal 109 as contrasted with W_{adh}. This indicates that the force of matrix-fiber adhesion is also affected considerably by the liquid resin-wettability of fibers. This is confirmed by lower contact angels of Epidian E-53.

The dependence of compression strength of composites in the form of rods on the PET and PA reinforcement volume fraction is shown in Fig. 3. From this dependence it follows that a good result is obtained when the PET content is about 60 %. In the case of PA fibers, it was impossible to obtain higher fiber content than 35 %. The maximum strength is observed with 20–25 % PA reinforcement volume. The drop in strength with high reinforcing fiber content is due to the worse wetting of tightly packed fibers.

Based on these results, 3-DDW of PET yarn was chosen for the first trials of composite reinforcement. Unfortunately, the impregnation of polyester woven

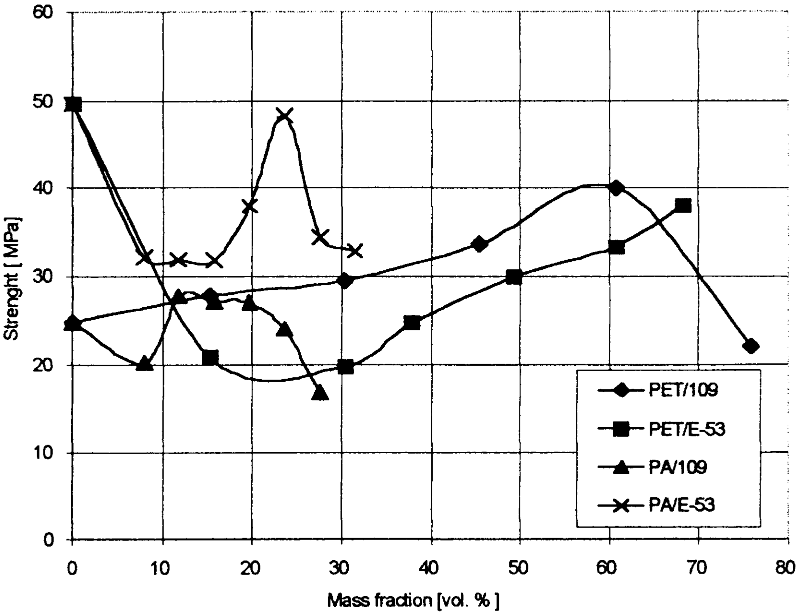


Fig. 3 Dependence of the compression strenght of tke composites with polyester matrix (PET/109 and PA/109) and epoxy resin matrix on volume fraction of the PET and PA yarn reinforcement

Table 3 Mechanical properties of 3-DDW reinforced composites

Composite with matrix of [%]	Free space volume [kg/m^3]	Resin consumption [kg/m^3]	Fiber consumption [kPa]	Tension strength [kPa]	Compression strength [kPa]	Bending strength [kPa/mm]	Tension modulus [kPa/mm]	Compression modulus [kPa/mm]	Bending modulus
Polimal 109	80	231	96	3120	2100	7460	20,9	4,33	910
Epidian E-53	84	128	72	4720	2040	8435	39,1	2,65	375

fabric with resin fails to obtain such a high ratio of reinforcement to the resin content. From the amount of the applied resin it follows that the reinforcing woven fabric constitutes 25–30 % of the total resin and fiber volume.

The mechanical properties of composites reinforced with 3-DDW including modules of elasticity and tensile, compression and bending strengths as well as fiber and resin amounts in 1 m^3 of composite are given in Table 3. The tensile strength of the composite outer layer is lower than the strength of the reinforcing woven fabric. The reinforced composites show also a very low elongation at break, about 1 %, as compared with the elongation of fibers. Thus, the strengths are determined by the forces of polymer-fiber adherence. The compression and bending strengths of composites made of both resins are at the same levels, while the composite with epoxy resin matrix shows almost twice as high tensile strength in spite of lower resin content. This is consistent with the results of liquid resin-wettability of polyester and the static adhesion of the resin to polyester yarn. Although the strengths of composites reinforced with 3-DDW are lower than those of solid composites, the preparation of the former requires 3–5 times less resin and fiber. Owing to the high content of air space and the spatial arrangement of the element linking the composite outer layers, the ratios of compression strength to the weight by volume (R_c/m_v) and the ratios of bending strength to the weight by volume (R_b/m_c) are very high. For the composite with polyester matrix these ratios are: R_c/m_v = 6.4 kPa/kg/m^3 and R_b/m_v = 22.8 kPa/kg/m^3, while for the composite with the epoxy matrix they are almost twice as high: R_c/m_v = 10.2 kPa/kg/m^3 and R_b/m_v = 42.2 kPa/kg/m^3.

CONCLUSION

The performed study made it possible to obtain very light composites with a high elasticity, a good compression and bending strengths as well as a high ratio of strength to the weight by volume. The composites reinforced with 3-DDW with matrices of polyester and epoxy resins show weights by volume amounting to 327 kg/m^3 and 200 kg/m^3, respectively. Further studies are expected to use distance textiles made of PA yarns and modified PP yarns for composite reinforcing. The effect of the textile fabric structure on the mechanical properties of composites will also be examined.

REFERENCES

1. H. Schmidt, I. Kamińska „Light Polymeric Composites Reinforced with 3-Dimensional Distance Knitwear" Fibres & Textiles in Eastern Europe 7 (1999) nr 4 (27) s. 57
2. D.W. van Krevelen „Properties of Polymers" Elsevier 1990 s. 238

These investigations were carried out within project No 7 T08E 015 17 sponsored by the Polish State Committee for Scientific Research.

MODERN TEXTILE SAILCLOTHS AND POSSIBILITIES OF EVALUATING THEM

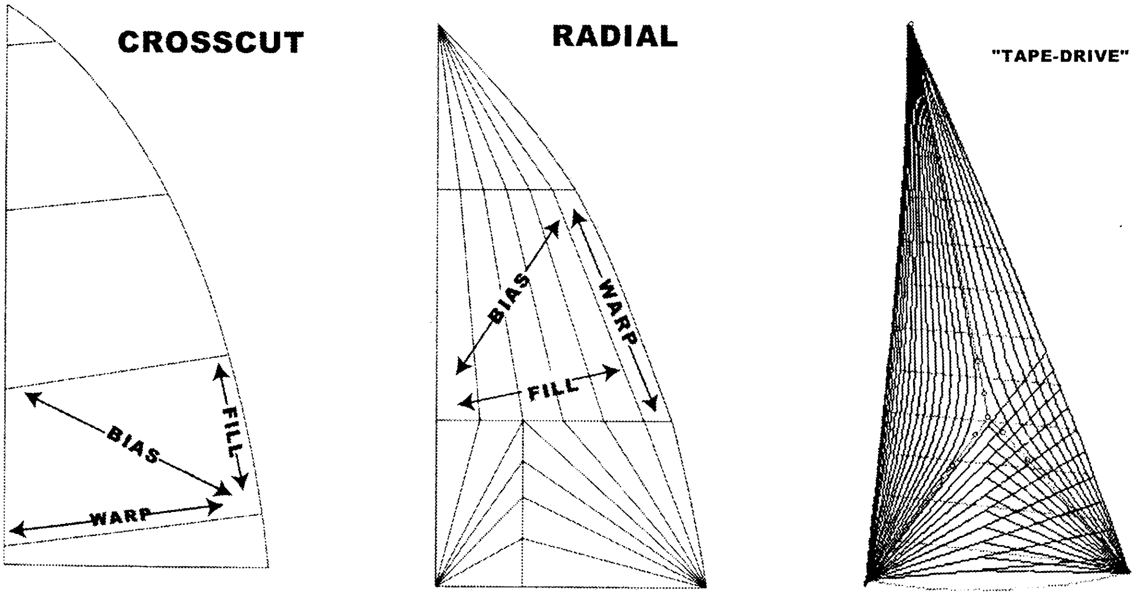
Vujasinovic, E., Cunko, R.

Department of Textile Chemistry and Material Testing, Faculty of Textile Technology, University of Zagreb,
Perottijeva 6, Zagreb, Croatia, HR-10000
E-mail: Edita.Vujasinovic@ttf.hr, rcunko@ttf.hr

Modern sailcloth materials are extremely complex, both regarding the type of fibers used and, even more so, regarding specific construction characteristics. However, there is still a kind of primitive manufacturing approach present in the production of these otherwise high performance materials. There are no clear requirements regarding quality, and experience is still the most important parameter in assessing a product. For those reasons, precise characterization and evaluation of modern sailcloth materials is a topic that asks for systematic investigation, both in view of defining relevant characteristics and parameters and in defining and adapting adequate testing methods and procedures and evaluation of results. The paper presented here is a contribution to the scientific and professional approach to the topic.

1. INTRODUCTION

Ever since sailing began, design and manufacture of sails seems to have almost more important role than the techniques of sailing itself. Maximum sail performance can be achieved through optimal aerodynamic shape of the sails, stability of the initial shape, its air impermeability and smooth surface [1, 2]. Sailmakers should shape their foils by balancing the forces of the wind with the tension in the sail, which is a difficult and ever-changing task to be solved. Manufacturing a sail is a process of constant optimization, not concerned only with sail design (Fig. 1) and construction [3–5], but also with the manufacture of suitable sailcloth materials.



a) Crosscut panel layout: all panels are parallel to each other and perpendicular to the leech; cross-cut sails use fabrics with their greatest strength in the fill direction (fill-oriented fabrics) to withstand the anticipated loading along the leech of the sail (the greatest loads in any sail are up and down the leech)

b) Radial panel layout: made with long narrow triangular panels called gores which attempt to align the warp thread of the laminate with the primary load paths of a sail; The laminated fabrics used in radial sails have much more strength in warp direction; by mixing cloth types on sail sailmakers can make a lighter but sufficiently strengthfull sail

c) "Tape-drive"® is only associated with high-tech two-parth construction process in which the structural strength of the sail is given by grid of high strength and low stretch tapes while the membrane produces aerodynamic lift. The tapes, radiate across the sail with a heavier concentration at the predicted high load areas, the corners and along the leech

Fig. 1 Present state of the art in sail design

2. MODERN SAILCLOTH MATERIALS

Sailmakers can design the best shape of sail based on experience, but the permanence of the shape under different wind conditions depends upon the fabric used, e.g. its construction, geometry (warp, weft and bias) and properties like stretch resistance, strength, flexibility etc.

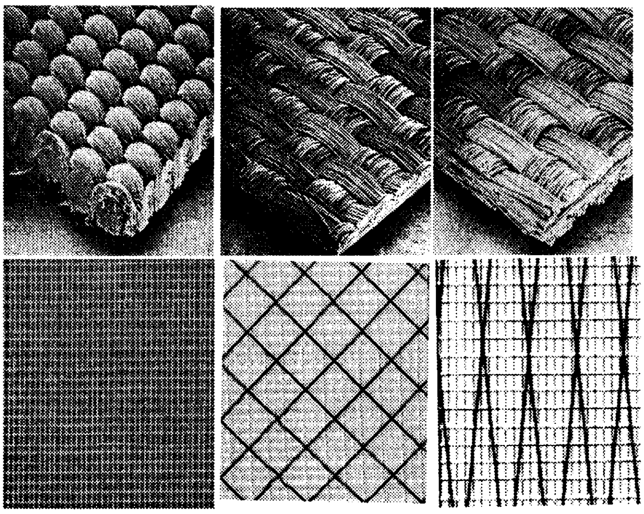


Fig. 2 Present state of the art in sailcloths design

The last 50 years have seen a virtual explosion in the development of new sailcloth materials (Fig. 2), largely as a result of the evolution in the field of fibers [6, 7]. Today's sailcloth fabrics are not made only of the familiar woven Dacrons® and Nylons® in various weights and finishes, but also from all kinds of laminates. Most laminates include one or two layers of transparent Mylar® film, the main purpose of which is to form a base to hold the structural fibers in place and to stop air slipping through something that would otherwise be rather more like a net than a cloth. On or between the Mylar® layers there are one or more layers of scrim – thin ribbons of yarn arranged in a lattice pattern (Fig. 3). These make up the load-bearing structure of the film. To fulfil different requirements for variety of applications, the arrangement of the layer's may be varied, and a number of different fibers (Tab. 1), each with different properties, may be used [8–13].

3. TESTING SAILCLOTH MATERIALS

Testing sailcloth materials can be enormously complex and, of course, in the final analysis, the best pos-

Table 1 New fibres used in modern sailcloth materials

Trade name	Produced by	Generic name	Tenacity [cNdtex^{-1}]	Modulus [cNdtex^{-1}]	Breaking elongation [%]	Density [gcm^{-3}]	Moisture regain [%]
Dacron	Du Pont (USA)	Polyester	5–8	100	10–20	1,39	0,4
Terylene	Imperial Chemical Industries (GB)						
Trevira	Hoechst Celanese Co. (USA)						
Dyneema	Dutch State Mines (NL)	Polyethylene	35	1100	3,8	0,97	0,0
Spectra 900	Allied Signal Co. (USA)		34	1250	3,5		
Spectra 1000	Allied Signal Co. (USA)		35	2200	2,7		
Kevlar 29	Du Pont (USA)	Aramid	23	545	3,6	1,45	4,5
Kevlar 49	Du Pont (USA)		24	895			
Kevlar Edge	Du Pont (USA)		29	940			
Twaron	Akzo (D)		23	545			
HM Twaron	Akzo (D)		24	880			
Technora	Teijin (J)		28	540			
Vectran	Hoechst Celanese Co. (USA)	Modified Polyester	23	510	1,2–5,5	1,78	–
Zylon	Toyobo (J)	Polybenzoxazole	44	1850	2,5	1,56	0,6

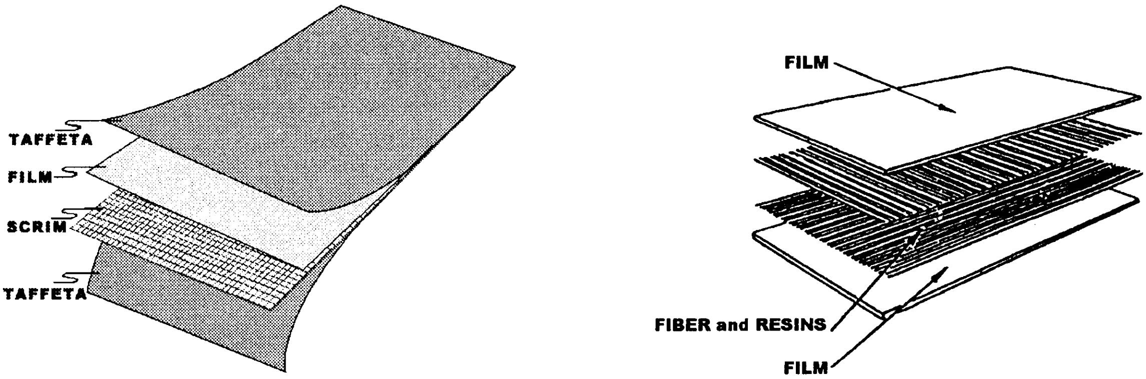


Fig. 3 Possible constructions of laminated sailcloth

Table 2 Sailmaker testing methods

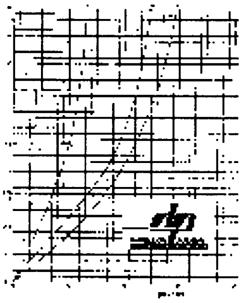
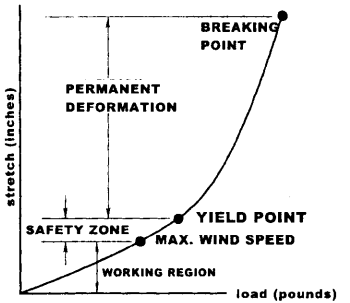
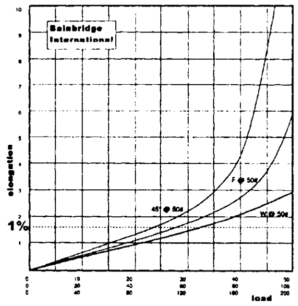
Mass per unit area	Tenacity	Flex strength
⇒ Is important factor from the standpoint of sail-handling as well as weight aloft. It is defined like: **SM [oz/36in x28,5in] (42,83gm^{-2})** SAILMAKERS WEIGHT e.g. the weight in ounces (28,35g) for a piece of fabric 36 inch x 28,5 inch (0,9144m x 0,7239m).	⇒ Is, beside breaking strength, more often represented with yield strength. **Yield strength**: dividing line between recoverable and non-recoverable strain. Stripes of fabrics that are 2 in (5cm) wide and 16 in (app. 40cm) long are stretched with constant pull speed (0,3–0,4 or 2 in/min) to 40–50–100–200–225 lb (453,59g) of load. ⇒ Combing the yield-strength number with the predicted sail-load number allows the sailmaker to determine the"maximum wind-speed capability" of a given sail.	⇒ Is commonly expressed as loss in breaking strength after flutter testing. **Flutter testing**: set of strips has been fluttered (whirled around at 30 mph or app. 48,4 kmh^{-1} for 30 min) which simulates some of abuse cloth is subject to in sails e.g. sail luffing when not being trimmed. ⇒ The flutter test determines the fabric ability to resist degradation giving a reasonable indication of how the cloth will last in use.
		

Table 3 Proposed testing methods and procedures

Parameter	Methods	and procedures
Qualitative analysis	FT-IR spectroscopy	ASTM D 276-87^{E} Standard Test Methods for Identification of Fibers in Textile, also comparison with FT-IR spectrograms according to [17]; Perkin-Elmer Spectrometer, Model 2000/KBr matrix; IRDM software package
Construction characteristics	Fabric count	HRN F.S2.013 Defining yarn density in a woven fabric
	Fabric thickness	ASTM D 1777-64 Measuring Thickness of Textile Materials (respectively in DIN 53855/1,2,3; HRN F.S2.021); Kawabata evaluation System [18] for KES-FB-3
	Mass per unit area	HRN F.S2.016 Defining mass per unit length and unit area
Mechanical properties	Tensile properties	ASTM D1682 Test Method for Breaking Load and Elongation of Textile Fabric (respectively in DIN 53837; HRN F.S2.017); dynamometer ZWICK backed by a computer (PC software Z7005); Kawabata evaluation System [18] for KES-FB-1
	Tear resistance	ASTM D 1424 Test Method for Tear Resistance of Woven Fabrics by Falling Pendulum (Elmendorf) Apparatus (respectively in DIN 53862)
Flex resistance	Flex strength	DIN 53362 Bestimmung der Biegesteifigkeit
	Crease resistance	DIN 53890 & DIN 53891/1,2 Bestimmung des Knittererholungswinkels
Water absorption	Wetting angle	NRL.C.A. Goniometer Model No A-100, Rame-hard

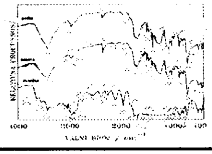
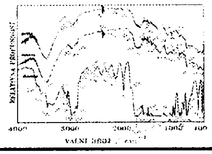
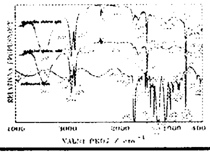
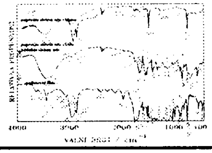
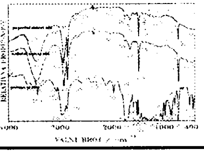
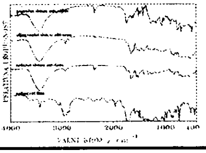
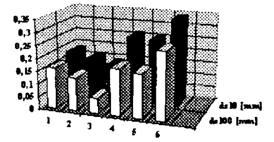
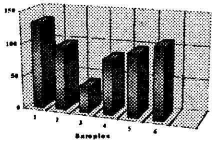
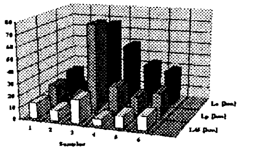
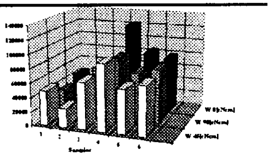
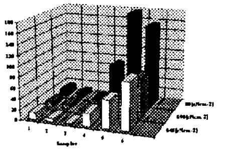
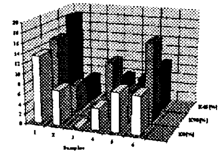
sible testing ground is in a sailboat on water, preferable on a race course. However, many manufacturer of sailcloth materials and sails have developed a series of their own routine tests, to be performed on the cloth they manufacture (Tab. 2) [4, 5, 14–16]. This allows them to monitor the quality and uniformity of their sailcloth materials. It also helps sailmakers to adjust their design to account for the detailed stretch properties of a particular style of cloth and to ensure that a new lot of cloth is as closely matched as possible to previous delivered lots used in successful sails.

Although sailcloth materials belong to the group of high-performance materials, a kind of primitive manufacturing approach is still present in their production, there are no clear requirements regarding the quality, and experience is still the most important parameter in assessing a product. The above statement is also confirmed by the fact that only a few research papers have been published on the topic of testing and characterization of sailcloth materials, although it is an extremely complex and scientifically interesting problem. The paper presented here is a contribution to the scientific and professional approach to the topic.

4. POSSIBILITIES OF SAILCLOTH EVALUATION

Theoretical knowledge, as well the practical experi-

Table 4 Some results of comparative sailcloth analysis

Samples	1	2	3	4	5	6	1–6
Qualitative analysis							1. PES – Dacron 2. PES – Dacron 3. PE-Spectra //PE+PES 4. PE-Spectra //PE+PES 5. AR-Kevlar/PE//PE+PES 6. AR-Twaron/PE//PE+PES
Fabric count g_0/g_{90} [threds/10cm]	440/326	558/456	53/46	47,8/30,2	24/20	30,8/15,4	–
Fabric thickness D [mm]	D_{10}=0,18 D_{100}=0,16	D_{10}=0,16 D_{100}=0,13	D_{10}=0,14 D_{100}=0,06	D_{10}=0,26 D_{100}=0,18	D_{10}=0,25 D_{100}=0,17	D_{10}=0,34 D_{100}=0,26	
Mass per unit area PM_{ku}[gm^{-2}]	131,59	98,06	39,37	84,74	96,67	109,19	
Tensile properties $\sigma_{1\%}$ [Nmm^{-2}] L [km]	$\sigma_{1\%?0}$=18,60 $\sigma_{1\%90}$=11,40 $\sigma_{1\%45}$=6,40 L_0=22,08 L_{90}=18,31 L_{45}=13,24	$\sigma_{1\%?0}$=20,14 $\sigma_{1\%90}$=12,86 $\sigma_{1\%45}$=12,86 L_0=14,65 L_{90}=10,71 L_{45}=8,92	$\sigma_{1\%?0}$=40,00 $\sigma_{1\%90}$=54,29 $\sigma_{1\%45}$=2,50 L_0=67,57 L_{90}=73,70 L_{45}=19,95	$\sigma_{1\%?0}$=39,29 $\sigma_{1\%90}$=14,29 $\sigma_{1\%45}$=4,29 L_0=48,93 L_{90}=22,01 L_{45}=5,48	$\sigma_{1\%?0}$=42,86 $\sigma_{1\%90}$=35,71 $\sigma_{1\%45}$=5,71 L_0=33,55 L_{90}=15,33 L_{45}=9,77	$\sigma_{1\%?0}$=37,14 $\sigma_{1\%90}$=12,86 $\sigma_{1\%45}$=7,14 L_0=29,10 L_{90}=19,92 L_{45}=11,49	
Tear resistance W [cNcm]	W_0=42510 W_{90}=33354 W_{45}=43818	W_0=29757 W_{90}=29103 W_{45}=26487	W_0=61476 W_{90}=71286 W_{45}=66708	W_0=123279 W_{90}=87963 W_{45}=94503	W_0=84366 W_{90}=68997 W_{45}=62457	W_0=77826 W_{90}=76518 W_{45}=69978	
Flex σtrength S [cNcm^2]	S_0=14,84 S_{90}=9,80 S_{45}=13,01	S_0=7,84 S_{90}=7,62 S_{45}=5,44	S_0=1,57 S_{90}=1,52 S_{45}=1,28	S_0=72,82 S_{90}=16,17 S_{45}=24,27	S_0=178,52 S_{90}=35,32 S_{45}=52,15	S_0=156,20 S_{90}=75,14 S_{45}=89,44	
Crease resistance K [%]	K_0=13,46 K_{90}=15,04 K_{45}=18,33	K_0=6,97 K_{90}=5,69 K_{45}=4,82	K_0=0,00 K_{90}=0,00 K_{45}=0,01	K_0=4,31 K_{90}=11,13 K_{45}=5,84	K_0=7,86 K_{90}=5,62 K_{45}=6,08	K_0=7,46 K_{90}=15,73 K_{45}=9,24	

ence on the part of sailcloth manufacturers and sail producers, indicate that the following fabric properties should be well known in order to design and manufacture top-quality sailcloth and sails: cloth geometry, stretch resistance, strength, mass per unit area, flexibility, tear resistance, porosity, water adsorption and UV stability. No precise specification of individual testing procedures was found either in literature [2, 3, 6, 7, 12] or technical data provided by some manufacturers [4, 5, 15, 16]. No regulations and procedures are generally accepted in testing, and considerable degree of chaos is present in sailcloth characterization, partly due to the implementation of different systems of measures (SI; UK etc.), and partly due to utter lack of definition in assessing individual fabric properties (different instruments, different testing conditions, different testing samples etc.).

Having above in mind, but also respecting adequate rules in objective evaluation of individual properties of the materials tested, standard and partially modified tests were performed for the purposes described here (Tab. 3) on sailclothes, with the aim of describing them, as well as to be able to compare various testing samples (Tab. 4).

Investigations described here indicate that contemporary sailcloth materials include a wide variety of products – both regarding the type of fiber used they are made of and (even more) the characteristics of their construction.

Since most revolutionary advances in sail design and manufacture resulted from the implementation of new fibers in sailcloth manufacture, their qualitative analysis should be the first element to be analyzed in order to characterize the samples to be tested. A reliable qualitative analysis proved to be impossible without sophisticated instrumental analytical techniques, such as, for example, FTIR spectroscopy.

Various types of cloth constructions are used in sailcloth manufacture – from simplest woven constructions to a variety of complex composites, laminated ones being most often the manufacturer's choice. The strength, as well as specific mechanical and aerodynamic properties of these constructions can be attributed to the high-performance fibers mentioned, coated by a polymer film. Specific construction characteristics of the textile component of the sailcloth materials dictate the degree of optimal end-use characteristics of the sailcloth to be attained. This is why their definition and evaluation constitute a quality parameter of extreme importance. In new (laminated) sails, the polymer film exhibits, as compared to the fibers used, most often poorer properties. Investigations described here indicate a need for better adjustment of the film and fiber characteristics, meaning optimization in the content, construction and strength of the bond between the components used, with the aim to exploit maximally exquisite properties of the high-tech fibers used in their manufacture. Success in this will determine the possibility of attaining all the other properties important in the end-use of sailcloth products.

4. CONCLUSION

The results of comparative testing of sailcloth materials of various raw material content and various constructions, as presented and analyzed above, are a sound basis for objective assessing some crucial and specific characteristics of these materials. Still, to give a reliably estimation regarding the quality, it is necessary to be familiar with the requirements on sails for various purposes. In this context only it is possible to assess correctly the usability of a particular cloth, possibility of it being used for a particular purpose, or, simply saying, the quality of a sailcloth material. The results presented here are a sound basis for making the above assessment.

REFERENCES

[1] Maritime Encyclopedia, Leksikografski Zavod Zagreb, Vol. 3, HR 1953

[2] Wallace R: Sail Power, Alfred Knopf Pub. Inc., USA 1984

[3] Whidden T, Levitt M: The Art and Science of Sails, St. Martin's Press, USA 1990

[4] URL:http://www.uksailmakers.com/otherconstruction.html

[5] URL:http://www.cubenfiber.com

[6] Doyle B. E.: Strong Fabrics for Fast Sails, Scientific American 277(1997)1:60+, 46–53

[7] Bartlett T: Crusing Sails, Yachtting World (1999)1, 104–105

[8] Mukhopadhyay S. K.: High-performance Fibres, Textile Progress **25** (1993) 3/4, 1

[9] Pilato L. A., M. J. Michno: Advanced Composite Materials, Springer-Verlag, New York 1994

[10] Hongu T., G. O. Phillips: New Fibres, Woodhead Pub. Ltd., UK 1997

[11] Kroschwitz J.: High Performance Polymers and Composites, John Wiley & Sons, USA 1991

[12] Vujasinovic E., Cunko, R.: Spectra, one of the latest sailcloth wonder fibres, Proceedings of The 1st AUTEX Conference, 26–29 July 2001, Portugal 2001

[13] Lindemalder J. L. at all: DMS High Performance Materials, Proceedings of The 11th, International Techtextile Symposium, 23–26 April 2001, Frankfurt 2001

[14] URL:http://www.sailcloth.com

[15] URL:http://www.bainbridgeint.com

[16] Testing of Sailcloth – Dimension Polyant, Private communications

[17] Hummel D. O., F. Scholl: Atlas of Polymer and Plastic Analysis, Vol. 2, Verlag Chemie International, D 1984

[18] Operating Instruction for KES-FB, Kato Tech Co. Ltd., Japan 1997.

ACKNOWLEDGEMENT

Investigations presented here are a part of broader research project organized at the Department of Textile Chemistry and Material Testing, Faculty of Textile Technology, University of Zagreb, in collaboration with a well-known sailmaker company (Victory – Intervela d.o.o., SI) through usage of new sailcloth materials produced by Bainbridge, North Sail, Dimension Polyant and others.

50 years of activity of the VÚCHV,a .s. Svit in the field of chemical fibre development

Budzák, D., Varga, T., Brejka, O.

(Výskumný ústav chemických vlákien, a.s. Svit)
Research Institute for Man-Made Fibres, a.s. Svit, Slovak Republic

Nowadays, when we evaluate this period of activity of the Research Institute for Man-Made Fibres in Svit (hereinafter referred to as VUCHV), we assess its contribution to national development of fibres as significant, indeed. Since the end of fifties, the Institute has conditioned the development of cellulose and synthetic fibres with respect to quantitative increase not only by its activity but, particularly, also by the development of new types and new assortment of fibres. The implementation of development achievements of the VUCHV affected production growth even by 70 % in some periods. The Institute has contributed to the development of fibre production by implementation of its achievements not only at home but also abroad.

The research activity in the first period after establishment of the Institute was focused on rationalization tasks of chemical fibre production at home. After 1955, the Institute was charged to solve the preparation of viscose cord yarns that were imported from abroad. The Institute resolved and implemented this task in Czechoslovakia: the production of 1,100 t/y in Rudník in 1959 and the plant with total capacity of 10,000 t/y of "Super 1" and later "Super 2" type in Lovosice in 1960.

The Institute implemented the production of this cord yarns also in Pirna/GDR in 1965 and in Tomaszov in Poland in 1967. The economic effect, in effective prices of that period, recorded the income of our production of amount about 70 mil. Kčs/y (Czechoslovak crowns) and about the same amount per sales of machinery and know-how. Establishing the production of cords of Super 2 grade the former Czechoslovak Republic was ranked to advanced industrialized countries, possessing this technology.

Other great task of the Institute was solving of POP fibre production development. Informative works started in the VUCHV and in Chemical-Technological Faculty of the Slovak Technical University in 1958 and first patent was already granted in 1959 for preparation of polyolefine and POP fibres. First production of POP staple fibres with capacity of 1,000 t/y was established in Chemosvit in 1965 followed by other implementations of production in the Chemical Factory of Jurij Dimitrov in 1970 with 4,400 t/y of staple fibres, in 1975 with 4,000 t/y of textured filament yarn, in 1980 with 15,000 t/y of staple fibres and 12,600 t/y of textured filament yarn.

Even in 1973, the pilot-plant production of POP filament yarns with the output of 120 t/y and in 1980 the production of capacity 4,000 t/y were implemented, both in Chemosvit.

The implementation of non-woven textiles and fibres, films and other special types of POP fibre materials was also accomplished. All these productions represent the capacity about 68,000 t/y. To assess the total economic effect of production implementation of all these materials is complicated. However, the income only from production of POP fibres represents the amount of more than 1 ths. mil. Kčs. The main effect was manifested in textile products, especially in their export. At present, some export problems occur resulting from the loss of eastern markets as well as the requirement of a change of POP fibre assortment. But definitely, the Institute give respective attention to these perspective fibres.

The technology and machinery for drawing and twisting of cord filament yarn was successfully solved in the field of PAD fibres and the production was implemented in Chemlon. Equally, the solution of PAD filament yarn preparation was successful, including mass-dyeing of fibres, what was implemented in Chemosvit Svit and Chemlon Humenné.

What is the area of PES fibres concerning, the production of staple fibres for bulked yarns of Velana, Tesil-31 type with reduced pilling and increased affinity to colouring agents was implemented in Silon Planá, national enterprise. The mass-dyeing was introduced. These modification were applied in filament yarn production. We affected the engineering production of Slovakia, as well, by our achievements in building of considerable fibre production capacities.

Comparatively good instrumentation of the Institute along with staff capability have enabled to achieve many new knowledge of theory of polymer structure modifications, fibre preparation processes, technology development, process regulation and the like, in the process of complex solution of tasks.

Information achieved in the mentioned areas was of high level. The staff of the Institute presented this knowledge in national or international periodicals, in lectures of professional conferences and seminars at home and abroad. Moreover, the Institute became recognized by the worldwide professional community thanks the periodic organization of Tatras´ conferences and the issue of own magazine "Chemical Fibres".

The activity of the Institute was again re-evaluated in the period after 1989. This was induced by fibre capacities in Slovakia, which have been sufficient till that time, and further by changed economic conditions in our economy that resulted in reduction of implementation possibilities of many fibre companies. Naturally, this impacted also the activity and work of our Institute.

Therefore, the first-rate task was to stabilize the Institute activity, to establish a program that would stop staff drain, mainly specialists and, at the same time, to redirect the activity. First of all, it meant proper utilization of all facilities built in the Institute till that time as well as patient and steady persuasion of customers that we have still been able to support them in solving their problems.

The results have gradually occurred. We have discovered such solutions during 1993 that started a stabilization of the Institute.

Different approach of fibre companies resulted in different approach of the Institute to research-development tasks. From their financial background through solving of short-term tasks up to preparation of new ones that will help to keep continuity of solutions in near future.

The research of synthetic fibres was characterized mainly by solving of fully aromatic polyesters with immediate impact on automotive industry, but from the aspect of monomer preparation, the application of this project was extended to other branches.

When dealing with new types of fibres, let us mention high-tenacity polyethylene and/or polyurethane fibres that were a scope of our research, too. Moreover, the research of PES industrial yarn and/or inflammable treatment of PES textile filament yarn has continued.

A considerable research capacity of the Institute is spending for polypropylene fibres that were a domain in the past. As a specific sample, the research of POP micro-fibres was done, where the POP micro-filament yarn was solved in the 1-th step. Now, let me mention that this research task was a typical example of co-operation between a solver, i.e. our Institute, the foreign partner that participated in supply of needed machinery, i.e. the Barmag and/or Inventa company, the implementation party, i.e. Chemosvit and the user, i.e. Tatrasvit, a.s.. The co-operation with Istrochem, a.s., Bratislava continues in the field of POP staple fibres. Other research tasks, or ideas for the moment, are prepared for solving, whether it is a case of colour masterbatches, POP industrial filament yarn or others. In the field of viscose fibres, the Institute put the most effort into revival of the research-development activity. The attention was focused on modernization of machines of KVH family for continuous production of viscose filament yarns but also on solving of the technology itself towards higher speeds.

As it was mentioned before, a redirection of the activity was vital for keeping of the Institute operation. It was a case of generation of a manufacturing segment as one of critical activity in the transition period. This philosophy was built on utilization of all facilities built in the Institute. We took advantages of long-term knowledge of our Institute in the field of colour masterbatches, POP fibres and others, too. Naturally, the segment of this activity needed investments for upgrading of small-lot productions to meet a character of production process. This production, along with the engineering one, covers about 75 % of performance, at present. We believe this is the right trend for a specific period.

Another important point for revival of the Institute activity and utilization of its facilities was the initiation of establishment of testing activities. The Institute was granted the accreditation of laboratories in the beginning of 1993 and the statute of the State Testing Room SKTC-118 at the end of 1993. Thereby, technical and legislative conditions were originated for operation in this field. At present, laboratories equipped with highly-specialized instrumentation and professional personnel offer their activities to companies involved not only in the field of fibres but also in the environment, polymer chemistry and mainly in textiles.

Rather wide range of laboratory activities resulted in formation of the team with 15 members that prove the professional capability by following basic documents:

- Certificate of accreditation of testing laboratory,
- Certificate of accreditation of certification body certifying products
- Decision of authorization issued by ÚNMS of the Slovak Republic. The Authorized Body SKTC-118 in the VUCHV, a.s. Svit acts in the field of testing and conformity assessment,
  - textile fibres, yarns, threads
  - textile products.

The Authorized Body SKTC-118 offers its services to entrepreneurs in the field of textiles in meeting legal obligations as well as services in the field of consultant and advisory activities.

The implementation capability of the Institute after 1989 can be characterized as follows:

We implemented the production of filtering candles for filtration of dyes and varnishes in the SLZ, a.s. Hnúšťa and intensified the production of non-woven textiles in the Tatraľan, a.s. Kežmarok in the period from 1992 to 1993. In 1995, we provided for a complete delivery of injection colouring of PA textured filament yarn in the Chemlon, a.s. Humenné and similar device for granulating line, one year later. In 1998, we implemented a separation of lines IWKA and RS-9 for production of PA textile yarn in the same company that have been renamed to NYLSTAR Slovakia. The aim was to create pilot plants with self-contained heating and driving aggregates from 1/3 of these machines. In 1999, we delivered to the Silon, a.s. Planá the device for injection colouring of PES fibres and we participated in implementation of the production of 3,500 t/y of the PA-FOY filament yarn for the company NYLSTAR Slovakia, where we delivered dinyl circuits, finishing agent system, controlled drives of pumps, godets and winding machines including electrical panels. In 2000, we developed and implemented the filtering device intended for filtering tests of masterbatch melts in the SH, a.s. Senica. From the aspect of our implementation capabilities, this year was really eventful as we implemented following projects.

- colouring device for 10,000 t/y of PET staple fibres for the Silon, a.s. Planá (Czech Republic)
- heat-air canals for production of PE staple fibres for the Istrochem, a.s. Bratislava
- 1-station compact spinning line for PP POY for the Fibrochem, a.s. Svit
- device for finishing agent application in the line for PA POY for the Zoltek RT (Hungary)
- completion and modification of a station for block polymerisation for the Kaučuk Kralupy (Czech Republic).

The important milestone of our company development was the acquirement of the certificate that certifies conformity of the quality system to the standard ISO 9001:1994. Representatives of the Norwegian certifying company Det Norske Veritas presented this certificate to the Chairman of the Board of Directors and the General Manager of the VUCHV RNDr. Dušan Budzák in the beginning of July 1998, as to the first company of the branch in Slovakia. One year later, in November 1999, our company successfully sustained the Environmental Management System to ISO 14001 in the certification audit again by the company Det Norske Veritas. Our company was the first organization with research character that actively express its relation to the environment by its activity in the Environmental Management System. The VUCHV, a.s. controls all activities in the systems of quality management and environmental management, assures the quality of its production and research-development activity in relation to the environment with liability for sustainable quality improvement. This fact was proved by re-certifying audit of the Quality Management System in compliance with revised requirement of the standard ISO 9001:2000 and 2-nd Periodical SEM Audit 14001:1996 that were successfully passed in June of this year.

Let us proudly state that our Institute has lately originated good prerequisites for active co-operation not only with national but also with foreign customers. As a result, we solve and/or have solved 13 research-development tasks of projects for national and foreign companies, such as ISTROCHEM, a.s. Bratislava, SLOVENSKÝ HODVÁB, a.s. Senica, CHEMOSVIT, a.s. Svit, MATADOR, a.s. Púchov, RHODIA INDUSTRIAL YARN Humenné, NYLSTAR SLOVAKIA Humenné. To mention foreign companies, they are PRECOLOR, a.s. Přerov, SILON, a.s. Planá,, KAUČUK, a.s. Kralupy, DEGUSSA AG Germany, CIBA SC Switzerland, ZOLTEK RT Hungary. Moreover, our commercial activity is successfully developing with the companies in Russia, Hungary, Czech Republic, Poland, Germany and Switzerland, where we have exported about 40 % of our performance.

Dear Ladies and Gentlemen,

I tried briefly mention activities of the VUCHV, a.s. Svit during its 50 years lasting existence in this lecture. Naturally, not everything can be mentioned and not all our customers and co-operating companies can be listed. Finally, let me thank to all our co-operating companies and customers for present co-operation and express a hope of further good relations on behalf of the general Manager RNDR. D. Budzák and the Board of Directors of our company.

THE MAN-MADE FIBRES INDUSTRY IN EASTERN EUROPE

Urbanowski, A.

Institute of Chemical Fibres,
Łódź, Poland

1. The Past and the Present

Table 1 The ten biggest man-made fibres producing countries (x 1000 tonnes)

1.	USA	2250
2.	Japan	1517
3.	Germany (West)	707
4.	USSR	623
5.	Great Britain	592
6.	Italy	412
7.	France	306
8.	Germany East	215
9.	Poland	139
10.	India	135

Source: Textile Organon, June 1971.

Cannot be true. It, however is true, the list goes for 1970. In the 70ties the Comecon region was in the forefront of the development in production and consumption of man-made (m-m) fibres. At the end of the decade the expansion in other regions begun. In 1980 following countries with considerable production drove some countries back from the 1970 list: Taiwan – 557, Korea South – 536 and P.R.China – 248 (x 1000 tonnes).

The dramatic changes in the production of the man-made fibres which took place in the period 1980–1999 (data for 2000 still not available) in Eastern Europe are presented in Table 2.

Table 2 Production of man-made fibres except olefin in Eastern Europe – 1980 and 1999 (× 1 000 t)

Country	1980 synthetic	 cellulosic	 total	1999 synthetic	 cellulosic	 total
Bulgaria	54	36	90	27	4	31
USSR (CIS)	550	650	1 200	260	88	348
Czechoslovakia	76	55	131	–	–	–
Czech Rep.	–	–	–	17	18	35
Slovakia	–	–	–	48	4	52
Hungary	21	9	30	17	–	17
Lithuania	–	–	–	17	11	11
Latvia	–	–	–	16	–	16
Poland	163	86	249	75	2	77
Romania	136	64	200	35	6	41
Yugoslavia	63	75	136	46	6	52
Eastern Europe	1 202	1 142	2 334	541	139	680
Western Europe	2 163	744	2 907	2 203	453	2 656
Turkey	98	6	105	636	9	645

Source: Textile Organon, June 1981 (1). Fibres Organon, June 2000 (2)

In 1980 the Eastern Europe production of m-m fibres constituted nearly 40% of the entire European output, it dropped to only 21% in 1999. In the same time the Western European synthetic fibres output stagnated with a distinct down-trend in the cellulosics. The quantity of 541 synthetics comprised 237 polyester, 185 polyamide, 113 acrylics and 6 tonnes of other fibres (all figures in tonnes x 1000). The figure below gives a summary of the changes which occurred in the three regions.

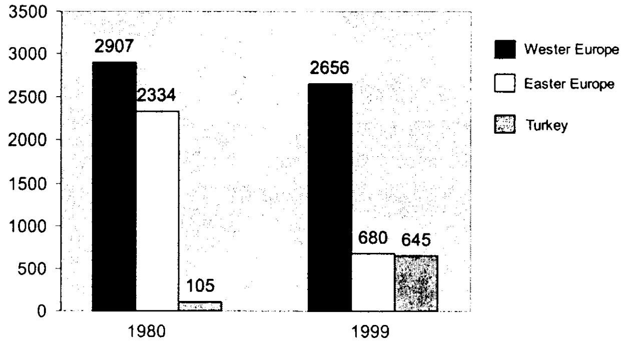


Fig. 1 The summary of the m-m fibres production for three regions in 1980 and 1999 (except olefins)

Olefin fibres (mainly polypropylene) expanded very quickly in nearly all regions of the world to become the second fibre raw material after polyesters amongst the m-m fibres.

Table 3 gives information about the olefin fibres production in some regions.

Table 3 Production of olefin fibres in some regions – 1999 (x 1000 tonnes)

Country	Staple + filament	staple – film
Western Europe	926	367
Eastern Europe	75	73
Turkey	191	112
USA	1009	334

Source: Fibres Organon, June 2000 (2)

Once again, in olefin fibres Eastern Europe lags behind other regions.

The overall regional pattern of the European m-m fibres production is presented below.

The most turbulent changes in production had occurred in the 80ties however continued in the 90ties. This is shown below for some of the countries in Figures 3, 4, 5.

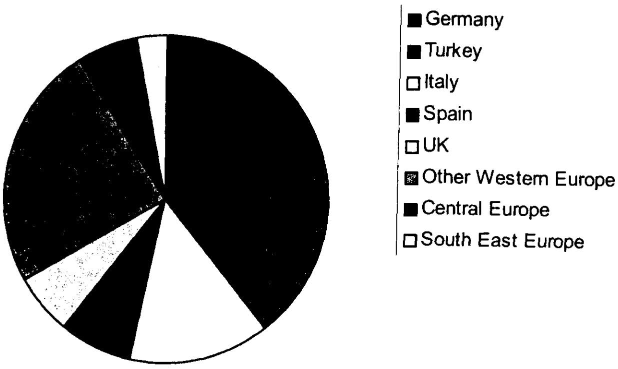


Fig. 2 The regional pattern of European man-made fibres production; European production 1999: 4.8 million tonnes (Source: C. Purvis presentation at Dornbirn 2000 (2))

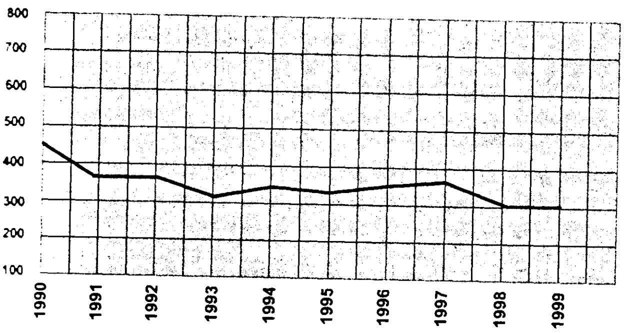


Fig. 3 Man-made fibres production in Central Europe, '000 tonnes; Czech Republic, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia

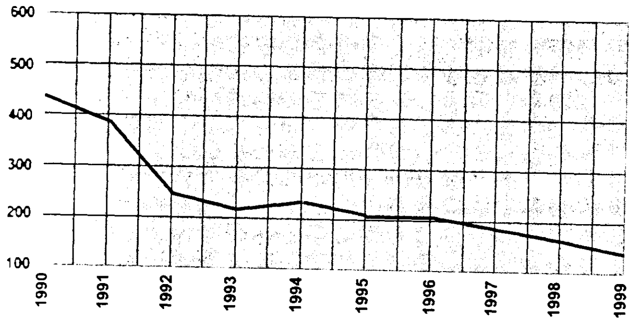


Fig. 4 Man-made fibres production in South East Europe '000 tonnes; Bosnia, Bulgaria, Croatia, Macedonia, Romania, Yugoslavia

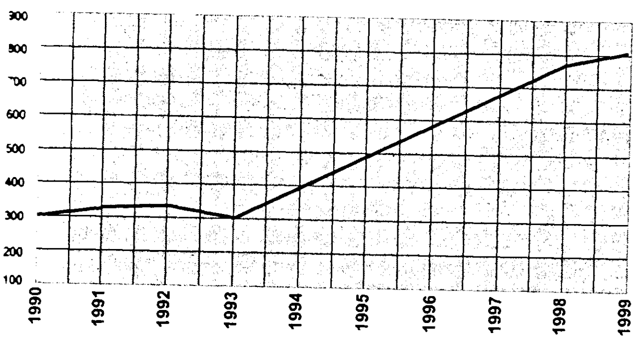


Fig. 5 Man-made fibres production in Turkey '000 tonnes (Source: C. Purvis presentation Dornbirn 2000 (2))

The reasons of the catastrophic down fall by nearly 70% in production of the m-m– fibres in the former socialist countries were as follows:

Firstly – the radical changes in politics and economy in the region caused a recession in the overall industry. The recession in the light industry and the related m-m fibres industry occurred quicker and was deeper than in other industry branches.

Secondly – the formerly organised and centralized market in the Comecon world suddenly disappeared.

Thirdly – many countries in Eastern Europe were flooded with cheap garments and textile products from the Far East. This in turn caused closures of spinning and weaving mills that is the main consumers of m-m fibres.

Fourthly – many of the m-m fibres production facilities were outdated in comparison to West European and Far East counterparts and producers in the region confronted with competitive prices could not compete due to high running costs.

The main cost problem was in the over-employer in the Eastern m-m fibres factories.

2. Integration with the European Market

The m-m fibres are part of a global market both directly as indirectly through the entire textile chain down the stream to apparels.

Many countries from East Europe are now closely integrated with the EU in the exchange of textile goods. An illustration for this is Table 4.

Table 4 The EU trade in textiles and clothing with East European partners, 1999 (mln. EURO)

Country	Import value	Export value
Poland	1 020	1 061
Romania	956	772
Hungary	564	540
Czech Rep.	517	485
Slovenia	261	271
Croatia	230	213
Slovakia	248.5	201
Bulgaria	291	217
Macedonia	114	85
Total	**4 290**	**3 919**
Former USSR Countries	825	762

Source: Textile Outlook, March 2000 (4)

The EU is the prevailing partner for the countries listed in Table 4 in textile and clothing goods.

Also the exchange of chemical fibres for many of the East European countries is concentrated on the EU. Let only take Poland as an example.

Some of the renowned West European producer took over m-m fibre plants in the Eastern region.

It is interesting to note that four out of the six takeovers are in polyamide fibres. Particularly Rhodia and

Table 5 Poland's production and foreign exchange of m-m fibres, 1999 (x 1000 tonnes)

Production in Poland	96
exports of which:	38
to EU	28
to Central and East European Countries	4
imports of which:	88
from EU	46
from East and Central Europe	14

Table 6 Take-overs of m-m – fibre plants in Eastern and Central Europe

	Country	Plant taken over	Acquiring company
1.	Slovakia	Chumene – PA 6 filament plant	Rhodia, France, Italy
2.	Poland	Stilon Plant in Gorzów Wlkp. PA 6 filament and granulate	Rhodia, France, Italy
3.	Latvia	Tolaram Fibres PA 6 filament	Rhodia, France, Italy
4.	Romania	Fibrex Savinesti PA 6 staple and filament	Radici, Italy
5.	Czech Rep.	Lovosice Glanzstoff Bohemia	Glanzstoff (Acordis) Germany
6.	Hungary	Magyar Viscosa Zoltec Magyar Acrylic PA 6 filament	Zoltec, USA

its JV with Snia – the Nylstar company are following a strategy to capture the nylon markets in Eastern Europe.

Most of the m-m – fibre producers in Central and Eastern Europe save the CIS countries are closely integrated with the EU. The vivid foreign exchange in textiles and m-m fibres between the regions extorted the adoption of unified nomenclature, standards analytical methods and legislature for example the rules on public aid which may be granted to producers of m-m fibres.

The integration is particularly advanced in the field of polyamide fibres where multinational companies are controlling a substantial part of the production and market. Some companies, producers of m-m fibres are members of CIRFS (Comite International de la Rayonne et des Fibres Synthetiques) in Brussels.

3. Prospects for the future

It is very difficult to forecast the further development in the m-m fibres sector in Central and Eastern Europe due to still lasting unstability in the economy of some of the countries. In some countries (Hungary, Czech Rep., Slovakia, Poland) composure seems to be ahead. In the entire region still some down- tendency in production can be expected. The pressure of fibres and textiles deliveries from abroad particularly the Far East is mounting. Imported fibres are easy available for consumers at attractive prices.

The cellulosics (viscose fibres) producers were most afflicted with the recession. Viscose factories once stopped never resume operation, hence there is no chance to return to the once substantial capacities. In this sector even some further still-stands can be expected. The synthetics are much better off, particularly the polyamides in some countries of the region. Polyesters as in other regions, constitute the major part of the m-m fibres production. Their producers in the region remain as single players without strategic alliances. This poses a mounting danger from the integrated polyester makers for whom the Eastern European market is an attractive bite.

Presently, there is little chance for the m-m fibres industry in Central and Eastern Europe to develop and to regain markets. It seems that in the future the demands will, to an even larger extend, be covered by imports from Turkey and the Far East.

Note. This article was published in Fibres and Textiles in Eastern Europe, Vol. 9, No 3, p.12–14.

References

1. Textile Organon, June 1971
2. Fibres Organon, June 2000
3. Dornbirn 2000 – Proceedings – Plenary Lectures C. Purvis: Meeting the Challenge
4. Textile Outlook Intern. March 2000 p.31

TECHNICAL FIBRES AND YARNS – PRODUCTION, PROPERTIES, APPLICATION*

Matchalaba, N. N.

Joint-Stock Company "Tverchimvolokno". Tver city, 170000 Russia

Introduction

The high performance fibers (yarns) based on aramides have super-high mechanical properties and improved thermal properties. The capacity and production of para-aramides are the highest among all high performance fibres – in 1999 were produced 31000 ton [1].

The most important high performance aramide yarns, which will be discussed in this paper, are following:

- Super-high mechanical properties and thermal resistant yarns based on polyamidobenzimidazole (PABI) – SVM and co-polyamidobenzimidazole (co-PABI) – Armos (Russia).
- High mechanical properties and thermal resistant yarns based on polyparaphenyleneterephtalamide (PPTA) – Twaron (The Nederland), Kevlar (USA) and similar copolymers (co-PPTA) – Terlon (Russia).

There are two main types of para aramide yarns – high modulus (dynamic deformation modulus 130–160 GPa; static deformation modulus 100–120 GPa); high strength (dynamic deformation modulus 80–100 GPa; static deformation modulus 60–90 GPa) [2–5];.

The properties of first type yarns – high modulus ones (with maximal mechanical properties) are shown in table 1.

The main thermal resistant fibres, which will be discussed in this paper are following:

- Thermal resistant fibres based on co-poly-meta-para-amidobenzimidazole (co-PMABI) – Tverlana (Russia)
- Thermal resistant fibres based on polymeta-phenileneisophtalamide (PMIA) – Fenilon (Russia) and Nomex (USA).

These thermal resistant meta- and meta-para-links containing aramides have common textile properties, which will be shown below (see table 4).

This paper present new aramide fibres and yarns Armos and Tverlana that have the highest properties in aramide group. Traditional – PPTA, SVM and PMIA fibres are in examination for comparison to more new aramide fibres

Short history of aramides

Thermal resistant fibres based on meta-aramides were elaborated in USA in seventieth years of 20-th century. Approximately at the same time these fibres were created in Russia. Creation and production of meta-aramide fibres was a new step in application of fully aromatic polymers, which have opened the direction of thermal resistant fibres and textiles. At the same time these fibres were a stimulus for series of researches in the field of different thermal stable fibreforming polymers and copolymers. For the last three ten years a number of high developed countries (including Russia) have developed and have begun producing new fibres and fibrous materials with ultra high mechanical and improved thermal characteristics for technical application on the base of different aromatic linear polymers, including different aromatic polyamides and a number of related co-polymers. These fibres are necessary for the development of the modern technical spheres.

The next step was in area of para-aramides, which were elaborated in beginning of eightieth years by two independent ways in two countries – in USA, based on aromatic carbocyclic para-polyamides (PPTA) and in

Table 1 Main properties of yarns with high mechanical characteristics

Fibres (yarns)	Fibres density, g/cm^3	Deformation modulus, Gpa		Tenacity, GPa*)	Elongation at break, %	Moisture content, % **)
		Dynamic	Static			
Terlon, Twaron, Kevlar	1,45–1,47	140–150	95–120	2,7–3,5	2,5–3	2–3
SVM	1,45–1,46	130–160	95-115	4–4.5	3–3,5	3,5–4,5
Armos	1,45–1,46	140–160	100–120	4,5–5,5	3,5–4	3–3,5

* The presented data are the results of testing – trenacity by single fibers or microplastics, deformation modulus – dynamic by impulse acoustic method, static based on mechanical tests.

** Moisture content of fibres is at relative air humidity 65 %.

---

* This paper contain new data of super-high tenacity para-aramide yarn Armos and first published data of new thermoresistant fibre and yarn Tverlana

Russia based on aromatic co-poly-para-polyamides (co-PPTA) and especially hetero-cyclic para-polyamides (PABI) [2, 6 – 8].

These new fibres (often called "the fibres of the third generation") were created in Russia by All-Russia Scientific and Research Institute of Polymer Fibres (former NPO "Khimvolokno" – Scientific and Research Organisation) on the base of the fundamental and technological researches with the close collaboration of other organisations. The main achievement in this area was super-strength yarns SVM and later Armos. The excellent scientific leader of these researches was Prof. Georgy I. Kudryavtsev. The great role in researches and Armos yarn development was of Prof. Vladimir S. Matveev, Prof. Gennady A. Budnitsky, Prof. Alexandra V. Volokhina, Dr. Anatoly V. Tokarev, Dr. Vladimir B. Glazunov, Dr. Alexander M. Stchetinin, Dr. Viktor M. Stchetinin, Dr. Igor V. Tikhonov and many other specialists. St-Petersburg Research Institute of Chemical Fibres and Composites (SVM fibre) and J-S Co. "Tverchimvolokno" (Armos fibre) have taken an active part in this work for many years improving the technology and producing para-aramide fibres. The main researches of these fibres structure, properties and application in textiles and composites were done in St-Petersburg Research Institute of Chemical Fibres and Composites and St-Petersburg State University of Technology and Design by direction of Prof. Kirill E. Perepelkin.

The production of SVM and later Armos, these ones technology improving were organised by J-S Co. "Tverchimvoloko" and later J.-S. Co "Kamenskvolokno" with the output volume and assortment necessary for country needs. Russian researchers and technologists having chosen their own original way; have created the world strongest reinforcing para-aramide Armos yarns having high thermal and flame resistance. The creation of Armos was the next step after the creation and production of SVM yarns.

The logical development of these high performance fibres was possibility to create thermal resistant fibres based on co-PMABI polymers. The fibre named Tverlana was created due to initiative of this paper author and developed by his collaborators in J.-S. Co "Tverchimvolokno" and All-Russia Research Institute of Polymer Fibres. It was the fibre of more high thermal properties and open fire resistance in comparison with PMIA fibres.

Requirements for polymers and fibres structure of high mechanical properties and thermal resistant fibres

There are some requirements to baseos polymers and fibres on three main structural levels – molecular, sub-molecular and micro-levels [9, 10], which are necessary for achievement of optimal structure fibres with high performancde characteristics. These main peculiarities are following.

For high mechanical properties fibres:

- maximal chemical bonds energy in polymeric chains or / and maximal number of these chains in cross-section. Absence of large side substitutes and weak chemical bonds. There are preferable to have only aromatic links in chain structure;
- extended polymer links configuration and polymeric chain conformations;
- super-high orientation of molecular chains in fibre axis direction;
- homogenous fibers micro-structure

For high thermal resistant fibers:

- maximal chemical bonds energy in polymeric chains. Aromatic structure of polymeric chains. There are preferable to have hetero-aromatic links in chain structure;
- there aren't any "super-special" requirements in comparison with common fibre-forming polymers and fibres.

Technological requirements:

- fibre-forming aromatic polymers should be soluble in accessible solvent (non-degradable and recycled);
- solution concentration and their reological properties, absence of impurities etc. should be optimal from point of view technology (filtration, degassing, fibre-spinning);
- structure building – as spun fibre formation and further fibre treatments shoud lead to mentioned above optimal structure peculiarities.

All discussed in this paper aramide polymers, copolymers and fibres have mentioned above structural characteristics in high degree.

Aramide fibres production and properties regulation principles

The para-aramide fibre formation and high mechanical properties achievement are based on possibility of rigid-chain linear polymers to transform in liquid-crystalline state. This fact lead to self-ordering effects even at small preliminary orientation both on the stage of fibre spinning and thermal treatment [2, 4, 8].

All heterocyclic para-polyamides are non-fusible, therefore these polymers are dissolved in nucleophilic solvents – amide compounds with addition of lyophilic salts (in particular dimethylacetamide with addition of lithium chloride).

Homo-polymer (PABI) or copolymer (co-PABI) are produced by one-step or two-step polycondensation of terephtaloilchloride and para-aromatic diamines (carbocyclic or hetero-cyclic) in organic solvent. Spinning solution will be able made based on previously prepared polymer (secondary solution scheme) or directly after polymer synthesis (primary solution scheme – direct solution).

The fibres are spun by wet-spinning method (often through air-gap). The as-spun fibres are washed of solvent rests and dried. All these mentioned above operations are led as step-by-step uninterrupted process. Next stage is thermal treatment, which lead to fibres spontaneous orientation. The small stretching is applied for deformation modulus arising.

Exactly this way was the base of highest mechanical property indexes of Armos fibres (yarns). The heterocyclic copolymer solution is in non-isotropic state; there is an opinion that transformation to liquid-crystalline state is by fibre-forming process.

The fibres properties are determined of raw polymer or copolymer composition in many respects. There were taken in attention, that transition from poly-para-phenyleneterephtalamide to less regular polymer and copolymer decrease structuring of spinning solution and is promoting to fibre high-oriented structure-building at spinning and thermal treatment and therefore arising of mechanical properties.

Meta-containing links copolymers are produced by the same method as para-aramides by direct spinning solution preparing. Aromatic meta-polyamides and meta-links containing co-polyamides are more soluble in polar organic solvents and therefore their solutions are more concentrated. The same conventional process is suitable for wet spinning and post-treatments of fibres based on these polymers and copolymers.

Peculiarities of Armos and Tverlana fibres technology

The technology principles of aramide fibres and yarns Armos production (the same as SVM) are presented in previous papers [2, 7, 12 – 16].

Armos yarns are produced on the base of co-polyamides with ≥ 35% hetero-links. The main stages of technology:

- copolymer synthesis with direct spinning solution production;
- spinning solution preparing for fibre-forming process – mixing, filtration, degassing;
- wet-spinning, drawing, washing, drying – uninterrupted process;
- thermal treatment and additional thermal drawing (not more than a few percents)
- textile operations – for yarns winding to final bobbin; for roving – slubbing and winding to final bobbin.

Fibres and yarns Tverlana are produced on the base of co-polyamides of following constitution:

- staple fibres – copolyamide with meta-links 15–35% and hetero-links 15–35%;
- yarns – copolyamide with meta-links ≥ 5% and hetero-links ≥ 35%;

Tverlana yarns production is based on the same technological scheme, but technological regimes on separate stages should be corrected. As-spun staple fibres production has any differences:

- thermal treatment both without tension or at tension in dependence of final fibres requirements, especially deformation characteristics (modulus and deformation ar break);
- additional operations – surfactants treatment, crimpling, cutting etc.

Assortment and technical data of Armos and related para-aramide yarns and roving

All produced by J.-S. Co "Tverchimvolokno" yarns are divided to following types [2, 4, 5, 7, 8, 13, 16 – 19]:

- high-modulus reinforcing yarns and roving – Armos – HMR
- high-modulus yarns for technical textiles – Armos – HMY
- thermal resistant yarns for technical textiles термостойкие технические нити для текстильных изделий - Armos – TRY, Tverlana – TRY (Tverlana yarns are produced as marketing batch).

The main Armos assortment include complex yarns with linear density from 29.4 till 167 tex. On their basis the company produces also a roving with linear density of 600 tex. that are produced by slubbing of yarns 100 tex [16–19].

Technical requirements for yarns and roving meet the guaranteed data given in Table 2.

The main data of the produced roving are the following:

- breaking strength not less than 1 373 N;
- dynamic elasticity modules of yarns in the roving not less than 142 GPa;
- average destruction stress of filaments under microplastic stretching not less than 5 100 MPa.

All data given in tables on mechanical properties are obtained in testing of yarns according to the Russian standards:

- yarn data according to GOST 6611 at testing length of 250 (500) mm;
- microplastic data according to GOST 28007 at testing length of 100 mm;
- dynamic (acoustic) modules of elasticity is determined with the impulse method according to GOST 28007;
- yarn humidity in the samples conditioned in the standard conditions is 3,5%.

It should be noted that the actual data of mechanical properties of the produced yarns are higher than it is guaranteed according to the technical requirements.

Table 2 Para-aramide yarns properties

Parameter	Armos (guaranteed indexes)			Tverlana	Terlon, Kevlar,
	HMR yarn	HMR roving	TRY yarn	TRY yarn	Twaron
Yarn specific tenacity, cN / tex	185–206 240–280*	196–240 260–280*	150–180	180–230	165–260
Elongation at break, %	4,0–6,0 2,8–3,5*	4,0–6,0 2,8–3,5*	4,5–5,0	3,5–4,2	1,4–3,5
Dynamic elasticity modules, GPa	137–142 157*	142–157*	70–120	68–98	130–160
Breaking stress of yarn in microplastic, MPa,	4120–4412	4414–4905 5100–5435*	3800–4100	–	3500–4000
Humidity at standard conditions, %		3,0–3,5		5–6	2,0–2,5

* Real achieved values

Assortment and Technical Data of Tverlana fibres

There are elaborated two main kinds of Tverlana fibers and yarns [16]:

- Thermal resistant technical yarns 28.4 tex and 58.8 tex – Tverlana TRY;
- Thermal resistant staple fibres Tverlana TRF: staple length 38 – 40 mm and linear density 0.17 tex and; staple length 60 – 70 mm and linear density 0.3 tex.

There is possibility to produce also another assortment. The main characteristics of Tverlana fibres in comparison with PMIA fibres are shown in table 3.

Armos and related yarns thermal troperties and Flame Effect

Armos and related para-aramides are characterised of high glass transition temperatures, high thermal and thermal-oxidative resistance. [2, 4, 17–21]. The main data of their thermal characteristics are given in Table 4.

Armos yarns (as well as SVM) have high thermal characteristics and can be related as high thermal resistant fibres. The strength of these yarns at high temperature changes slightly:

- in the temperature range till 100 °C by 10–12%
- till 200 °C by 25–30%.

The strength preservation in air exposition for 10 hours is:

- 95–96% at temperature of 250 °C,
- 88–90% at temperature of 275 °C,
- 60–70% at temperature of 300 °C.

The temperature of long exploitation of Armos (SVM) is 250–300 °C.

These fibres have high ignition and self-ignition temperatures, рщпр дшьшеув oxigen indexes. Armos yarns and fibres do not ignite in open flame up to 500–550 °C and they stop burning after removal of fire source. It is determined by the high values of oxygen index (38–43%). The oxygen index is 40–45% for SVM. Limited oxygen index of Tverlana yarns is 38–39% (the values for staple will be shown below)

The principal peculiarity of para-aramides in comparison with other fibres is shrinkage absence or low shrinkage till very high temperatures. It is due to their tendency to spontaneous elongation. PABI and co-PABI fibres (Armos and) haven't dimension change till 300 °C and only at 400–450 °C a slight shrinkage can be observed that is not more than 2–3%. PPTA fibres have the same shrinkage approximately at 350 °C.

Para-areamide fibres resistance to active media and their hydroscopic properties

Armos, SVM and Tverlana yarns and fibres have high resistance in many kinds of active media – moisture, many kinds of chemicals, petrochemicals, micro-organ-

Table 3 Main characteristics of Tverlana and traditional thermal resistant fibres

Indexes	Tverlana	Fenilon, Nomex
Fibres density, g / cm^3	1,40–1,41	1,37–1,38
Tenacity, cN / tex	40–45	30–45
Elongation at break, %	12–17	20–40
Deformation modulus, GPa	10–14	7–12
Shrinkage in boiling water, %	2,0–2,5	< 3
Shrinkage in hot air, % (Temperature, °C)	Shrinkage beginning 320–370 °C 0,5–1 (400–420 °C)	3–10 (300 °C) 12–15 (450 °C)
Moisture content at standard conditions, %	4,0–6,0; 11–12	4,5–5,0
Limited oxygen index, %	35–36	28–29

Table 4 Thermal characteristics of para-aramide fibres indexes

Indexes	Fibres (yarns) types PABI (SVM), co-PABI (Armos)	 PPTA (Twaron, Kevlar, Terlon)
Glass transition temperature, °C	270–280	345–360
Melting point, °C	no melt	no melt
Exploitation temperature (long time), °C	250–300	220–250
Exploitation temperature (limited), °C	300–330	250–270
Destruction temperature, °C	550–600	450–550
Ignition temperature, °C	500–600	450–500
Self-ignition temperature, °C	550–650	500–600
Oxigen index, %	40–45	27–29

isms [2, 4, 5, 17–20]. They unlimitedly swell in polar solvents.

Armos yarns belong to the fibres with limited hygroscopicity, which is slightly lower than SVM and considerably less than other polar fibres (e.g cellulose). Moisture sorption in the atmosphere in normal conditions (relative air humidity 65% and temperature 20 °C) is for discussed yarns: Armos 3,5% for SVM 4–4,5%, Tverlana 5–6%.

Armos swelling in water is not high and is 15–16%. Its strength properties change slightly in water. These changes are mostly reversible after drying. Armos yarns and fibres in wet state slightly change mechanical properties which are close to the initial data after drying.

Comparison of Armos with other para-aramide fibres and yarns

Armos in many characteristics has substantial advantages in comparison with the fibres and yarns on the base of PPTA and co PPTA Terlon, Twaron, Kevlar.

As it has been shown above, Armos reinforcing yarns and roving have higher strength among all types of para-aramide yarns at the equal values of deformation modules. The values of their strength are in average higher by 30% than of SVM yarns and are higher by 50% than of Terlon and other PPTA yarns. Armos technical yarns also exceed the existing values of other para-aramide yarns, that can be seen in the above mentioned values (Tab. 6).

Thermal characteristics of Armos yarns considerably exceed the values of PPTA yarns and at the same time they are close to those of SVM. Their thermal resistance in air is higher, and their oxygen index is 38-43% that is higher by 10–15 units than of the values of PPTA yarns.

Tverlana yarns and fibres are characterised by more high thermal resistance in comparison with PMIA.

Application of Armos yarns in textiles

The main application of Armos yarns are high loaded textile manufactured goods [4, 5, 16, 21]. Textile processing of Armos yarns does not cause any considerable problems. The usual typical textile equipment is used in the most cases to Armos textiles production. Armos yarns are processed into bends, fabrics and other textile structures without any difficulties but their processing has some peculiarities. It is necessary to use pre-prepared yarns by specially chosen lubricants for successful conducting of this process and to use a high quality size for weaving.

Braided and twisted ropes are characterised with high strength and low deformation replacing in many cases steel cables due to the high specific mechanical characteristics. It gives advantages especially at high length of cables when their own weight limits the possibility of their application. Application of such cables for deep-water operations (lifting of deep-water apparatuses or sunk ships from extra-high depth) can be used as an example. Application of ropes and braided straps in load-bearing goods, rescue devices for sea-ships and aircraft, insurance kits for steel erectors, mountaineers and in many other cases is also very important.

Textile materials Armos yarns based are widely used in some types of individual protection. Nowadays fabric structures are widely applied in ballistic protection - particularly in constructions of "soft" bullet-proof vests. Cut resistant gloves and garment parts for workers of different specialisation turned to be highly effective.

Application Armos yarns and roving in composites and composite Goods REA

Armos yarns and roving application in construction composites is based not only on high values of their mechanical properties but also on the other specific peculiarities [4, 5, 7, 13, 16, 21}. Processing on yarns and roving into composite materials is possible with standard equipment, which is traditionally used for processing of analogous assortment of glass yarns, but it have some differences in comparison with glass reinforced plastics production. This difference is caused by the fact that components of many of thermo-reactive binders diffuse into para-aramide fibres that can lead to reduction of the obtained properties. Therefore it is required to correct binder resin compositions and conditions of their hardening.

High adhesion of Armos to majority of reactoplasts (epoxide, phenolic acetalic, polyurethane and others) allows to obtain composites with high monolithity and an excellent complex of properties for drawing loading.

Due to high mechanical properties of para-aramide fibres in the axial direction and rather lower values in cross-section direction, composites on their base have also high values for drawing and moderate values for pressing, bending and shear. There is exfoliation with destruction of not only at the inter-phase fibre surface (matrix), but a cracks can be in the fibres at these mechanical influences. That is why hybrid structures from para-aramide and carbon or glass fibres are often used to increase considerably the values of pressing and shear.

The main types of composite materials and goods in which application of Armos is the most effective, are composites and goods obtained with the winding method and used under drawing loading are especially effective. They include large-sized parts of aircraft, high-pressured vessels and others. Construction composites on the base of fabrics from para-aramide fibres are especially effective where high specific mechanical characteristics are required and where application of metal and ceramic materials becomes less effective. For example: different types of armour are created on the base of textiles from Armos yarns. Bullet-proof vests based on combined structures o of ceramic plates together with textile composite structures ("hard" bullet-proof vests) are especially effective. Reinforced helmets different sport goods is also very important

Original application is additional reinforcement with winding of different metal hard-pressured vessels to decrease their weight. Gas-pressured vessels, oxygen-pressured vessels for mountaineers and skin-divers are produced in accordance with this method.

Application of Armos reinforced composites is effective in creation of high-speed rotors for different application particularly for mechanical energy accumulators and centrifuges. These goods have high specific characteristics of mechanical properties and accordingly - reliability.

Application of Armos yarns and roving reinforced composites has high effectiveness in comparison with traditional kinds of materials in all cases for composite materials and goods used under stretching where minimal weight at high loading is required.

It should be note that Armos can replace asbestos in friction materials. At present brake shoes made on the base of para-aramides for automobiles, other vehicles, high-speed powerful presses and other devices have taken a position in the modern technique having solved the very important ecological problem.

Para-aramide yarns and textile structures from them are considerably seldom used for reinforcement of reactoplasts as high mechanical and thermal properties of these fibres are used not in full value. Moderate adhesion of para-aramide fibres to thermo-plasts limits the application sphere for these fibres in such materials.

Possibility of Tverlana yarns and fibres application

Tverlana yarn and fibres have preferable possibility for application in sphere of professional safety and for rescues means in many cases – protective thermal resistant garment and gloves for workers of different specialisation – fire-mans, rescuers, special transport drivers, workers of chemical and metallurgical industry etc [16]. Tverlana is more economic kind of fibres in comparison with SVM or Armos due to more low cost of raw materials and partly – technology. The processing of Tverlana yarn and fibres haven't any difficulties in comparison with common fibres.

Conclusion

There were discussed requirements to fibres-forming polymers and fibres with high mechanical properties and thermal resistance. In paper are presented information about aramide new elaborated fibres and yarns, which are produced by J.-S. Co "Tverchimvolokno" Armos (co-PABI) and Tverlana (co-PMABI). Comparative data about mentioned above aramide fibres and other aramide fibres based on PPTA (Twaron, Kevlar), related copolymers (Terlon), PABI (SVM), PMIA (Fenilon, Nomex) are shown. This information is useful for selection of these fibres, based on them textiles and manufactured goods in comparison of functional properties and prices.

The functional advantages of hetero-cyclic aramide fibres Armos and Tverlana) are shown in mechanical properties and thermal resistance, especially open fire action in comparison with fibres based on aromatic carbo-cyclic aramides (PPTA and PMIA - fibres).

There are the planes of Armos and Tverlana fibres production increasing based on reconstruction and widening of workshops J-S Co "Tverchimvolokno". There are planes to increase Armos fibres production and Tverlana fibres to organize in amounts, which will be necessary for different consumers.

The ways of development para-aramide fibres will be in joint cooperation of J-S Co "Tverchimvolokno" with All-Russian Research Institute of Polymer Fibres, Sankt-Petersburg State University of Technology AND design and other institutions in Russia and abroad. The specialists of mentioned above organizations lead a great work in area of technology improving, assortment widening, properties increasing and also economical indexes improving.

Acknowledgemetn

My thanks to colleagues, especially to Prof. Kirill E. Perepelkin, for discussions in area of high performance fibres, which were useful for this paper writing.

References

1. Chemical Fibers International. 2000, v. 50, No 3, May, p. 202. Man-Made Fiber Year Book, 2000, p. 30.
2. Kudryavtsev G. I., Varshavki V. Ya., Stchetinin A. M., Kazakov M. E. Reinforced Chemical Fibres for Composites. Moscow, Chimia Publ., 1992, 236 p.
3. Volokhina A. V. High-tenacity synthetic yarns for reinforcing of construction organoplastics. Chemical Fibers. 1997, No 3, p. 44–53.
4. Perepelkin K.E., Matchalaba N.N., Budnitskii G.A., Kurileva N.N. Para-aramides in taxtile and composites – high-modulus fibrous materials for reliability and safety guarantie. Bulletin of St-Pb State University of Technology and Design. St-Petersburg. 2000, No 4, p. 64–83.
5. Mac B. Para-aramid Fibers in Poland. Import and Special Applications in the textile Industry. Fibers and Textiles in Eastern Europe. 2000, v. 8, No 2 (29), p. 12–17.
6. Volokhina A. V., Stchetinin A. M. Memory of academician Georgy I. Kudryavtsev. Chemical Fibers. 1998, No 2, p. 3–7.
7. Matchalaba N. N. Today para-aramide fibers. The rule of J.-S. Co, "Tverchimvolokno" in production of Armos fibers". Chemical Fibers. 1999, No 3, p. 3–10.
8. Perepelkin K. E., Matchalaba N. N., Budnitski G. A. Armos – the Russian High-Performance Fiber: comparison of other p-aramid fibber types. Chemical Fibers International. 1999, v. 49, No 3, p. 211–214.
9. Perepelkin K. E. Structure and properties of fibres. Chimia Publ., Moscow (1985). 208 p. (China Ed. Beijing. (1991). 230 p.).
10. Fibres and fibrous materials for the reinforcement of composites with extremal characteristics. Mechanics of Composite Materials. 1992, No 3, p. 291–306. (Reprinted in USA. MCM. 1992, v. 28, No 3, p. 195–208).
11. Sokolov L. B. Fundamentals of polymers synthesis by polycondensation method. Moscow, Chimia Publ., 1979, 264 p.
12. Perepelkin K. E., Matveev V. S., Volokhina A. V. Special Features of the Man Made Fibres Preparation from Polymers with Various Stiffness of Macromolecules Chains. Chemical Fibres. 1984, No 3, p. 17–24; No 4, p. 14–19 (Reprinted in USA. Fibre Chemistry 1984, No 3, p. 147–158; No 4, 221–228.
13. Kurilyova N. N., Stolberg S. Z., Andriyuk, Matytsyn P. A.. Some aspects of enterprise "Tverchimvolokno" JSC development. Chemical Fibers. 2000, No. 2, p. 64–68
14. Tichonov I.V. New organic materials with improved consumer properties and articles based on them. Chemical Fibers. 1998, No 5, p. 27–33
15. Koroteeva L.I., Ozerskii O.N., Yaskin A.P. Technological equipment of chemical yarn and fiber works. Moscow, Legprombitizdat, 1987, 400 p.
16. Matchalaba N.N., Andriyk I.A., Perepelkin K.E., Budnitsky G.A., Volokhina A.V. Aramide fibres and yarns of J-S Company "Tverchimvolokno" (Russia(: production, properties, ways of development. International Conference "Tecnique for Chemical Fibres". Tchernigov (Ukraine). 21–25 May, 2001. Proceedings. Tchernigov, J-S Co "Chimtextilmach", 2001, p. 214–224.
17. Perepelkin K.E., Matcalaba N.N., Kvarachelia V.A. Para-aramid yarns: Armos properties at under conditions of use. Comparison with other para-aramids. Chemical Fibers. 2001, No 2. p. 22–29.
18. Perepelkin K.E., Matchalaba N.N. Recent achievements in structural ordering and control of properties of para-aramid fibers. (Lecture of 5th International Conference on Frontiers of Polymers and Advanced Materials). Molecular Crystals and Liquid Crystals. 2000, v. 354, p. 331–346.
19. Matchalaba N.N., Perepelkin K.E. Aramid fibre development – today and future. 1st Central European Conference "Fiber-Grade Polymers, Chemical Fibers and Special Textiles. Lodz, 3–4.10.2000. Proceedings. Lodz, Institute of Chemical Fibres. Chapter 14. 2001. P. 204–223.
20. Perepelkin K. E., Gurova E. Yu., Baranova S. A., Kynin A. T. Complex examination of thermoresistance of aromatic yarns. Chemical Fibers. 1993, No 6, p. 43–47. (Reprinted in USA . Fiber chemistry. 1993, v. 25, No 6, p. 490–497.).
21. Perepelkin K.E., Matchalaba N.N., Angreev A.S. Para-aramide fibers, yarns and based on them materials application perspectives. J-S Co "Tverchimvolokno" International Conference of Chemical Fibers "Chemfibers-2000". Tver city, 2000. Papers. Section 5. Paper 16, p. 1–10.

BIOACTIVE SYNTHETIC FIBRES

Struszczyk, H., Niekraszewicz, A., Lebioda, J., Brzoza, K.

Institute of Chemical Fibres, M.C. Skłodowskiej 19/27, 90-570 Lodz, Poland
e-mail: iwch@mazurek.man.lodz.pl

INTRODUCTION

The allergic diseases, especially in the breath system like allergic rhinitis and astma bronchiales, are becoming more and more dangerous for human health. 100 mln people suffer from allergic diseases caused by house-dust mites. The house-dust mites of *Pyroglyphidae strain*, playing the most important role in the allergy threat, themself are harmless for human whereas their excrements in lump form with diameter of 10-40μm contain a lot of antigens. These antigens are transfered into human breath system causing the allergic reaction.

The house-mite dust problem in private and public houses in Europe shows also a growing tendency. The concentration of dust mites, especially in carpets, floor coverings and bed clothes, shows a dramatically increasing tendency in spite of the use of well-know cleaning techniques or membrane covers for bed pillows and quilts. Medical, technical and household textile producers express the requirment for the new "high tech" bioactive chemical fibres useful for protection against above diseases.

The aim of this work is to present some aspect of bioactive chemical fibres containing selected additives predisposed for reduction/elimination of dust-mites hazard.

Table 1 Selected bioactive additives for PP, PET and PA-6 fibres

Symbol/name of additive	Producer
M-20	Esel Techtra Inc., South Korea
Triclosan (Irgasan DP300)	Ciba, Switzerland
Tolnaftate	Aarti Drugs Ltd., India
Permatrine (Coopex)	AgrEvo Environmental Health Ltd, Great Britain
Stearic acid	SIGMA ALDRICH, Germany
Tanine	Silesia University of Technology, Poland
Benzyl benzoate	SIGMA ALDRICH, Germany
Actigard 87-12	Sanitized, Switzerland
Palmitic acid	SIGMA ALDRICH, Germany
K	–
C	–
CA	–

EXPERIMENTAL PART

Several additives for polyamide and polypropylene fibres selected according to their bioactivity were used (Table 1) for modification of polypropylene, polyamide-6 and polyester fibres. The additives were introduced into polymeric chips before melt spinning.

Bioactivity of additives as well as modified fibres were tested in vitro for inhibition of growth of fungi of *Aspergillus repens* ATCC 10079, being a nutrition bridge for dusty mites, at the Microbiological Laboratory of Institute of Chemical Fibres, Lodz, Poland according to international Standard of SN 195921.

RESULTS

Some bioactive additives were tested according to their activity for inhibition of the growth of *Aspergillus repens* (Table 2).

Based on the results presented in Table 2 some selected bioactive additives coded K, C and CA were used for modification of polyamide, polypropylene and polyester fibres. The results of bioactivity test are presented in Tables 3–5.

Table 2 Inhibition of *Aspergillus repens* growth by selected additives

Symbol/name of additive	Growth	Description	Result
M-20	middle	no inhibition zone, growth reduced	negative
Triclosan	no	inhibitiom zone higher than 1 mm	positive
Tolnaftate	full	no inhibition zone	negative
Permetrine	no	inhibition zone from 0 to 3 mm	positive
Stearic acid	full	no inhibition zone	negative
Tanine	no	inhibition zone from 0 to 3 mm	positive
Benzyl benzoate	middle	inhibition zone from 5 to 10 mm	limited action
Actigard 87-12	no	inhibition zone from 85 to 100 mm	positive
Palmitic acid	full	no inhibition zone	negative
K	no	inhibition zone from 30 to 35 mm	positive
C	no	inhibition zone from 20 to 30 mm	positive
CA	no	inhibition zone from 25 to 35 mm	positive

Table 3 Inhibition of *Aspergillus repens* growth by modified polyamide fibres and knitted fabrics.

Sample type	Additive type	Additive content, %	Bioactivity test result
Standard PA-6 (40/9)	–	–	negative
PA-6 (40/9)	K	0.5	positive
	C	0.5	positive
Knitted fabric (90% modified PA-6, 10% Elastil)	K	0.4	positive
Knitted fabric (100% modified filament)	C	0.5	positive

CONCLUSIONS

1. Selected bioactive additives were used for modification of polyamide, polypropylene and polyester fibres prepared by standard melt spinning technique.
2. Modified polyamide, polypropylene and polyester fibres were distinguished by inhibition of the growth of *Aspergillus repens* fungi, being a nutritious bridge for dusty mites.
3. Modified chemical fibres seems to be suitable for reduction or elimination of dusty mites.

Table 4 Inhibition of *Aspergillus repens* growth by modified polypropylene fibres.

Sample type	Additive type	Additive content, %	Bioactivity test result
Standard PP (56/17)	–	–	negative
Modified staple fibres	C	0.5	positive
Modified (57/17)	CA	0.5	positive
Modified (57/17)	CA	1.0	positive
Modified (56/17)	K	0.35	positive
Modified (56/17)	K	0.5	positive
Modified (56/17)	K	0.75	positive
Modified (56/17)	K	1.0	positive

Table 5 Inhibition of *Aspergillus repens* growth by modified polyester fibres.

Sample type	Additive type	Additive content, %	Bioactivity test result
Standard PET (52/16)	–	–	negative
Modified (52/16)	CA	1.0	limited action

Acknowledgment

This work was carried out within the research project No 7T09B 006 20 supported by National Committee for Science and Development.

THE INFLUENCE OF VISCOELASTIC PROPERTIES OF FIBERS ON THE COURSE OF THEIR MECHANICAL PROCESSING

Nosek, S.

Technical University Liberec.

The influence of viscoelastic and dynamic properties (dynamic compliability) of textile fibers, yarns and other LTB's (linear textile bodies) on the dynamics and resulting quality of mechanic textile processes is described in the paper. Relevant properties of the participants of the textile working process, i.e the viscoelastic properties of textile materials on one side and the dynamic characteristics of active parts of textile machines on the other side, are described in terms of rheologic and dynamic models.

1. Preface

Processing of textile materials represents a bilateral exchange of energies between the working machine and the object of processing. Yet the energy flow and the resulting effect on the material depend on the resistance of material against processing on one side, and of course on the ability of the machine to overcome this resistance on the other side.

As an illustration of that fact let us first observe a simple working process – stirring of some loose viscose material in a mixer (Fig. 1.).

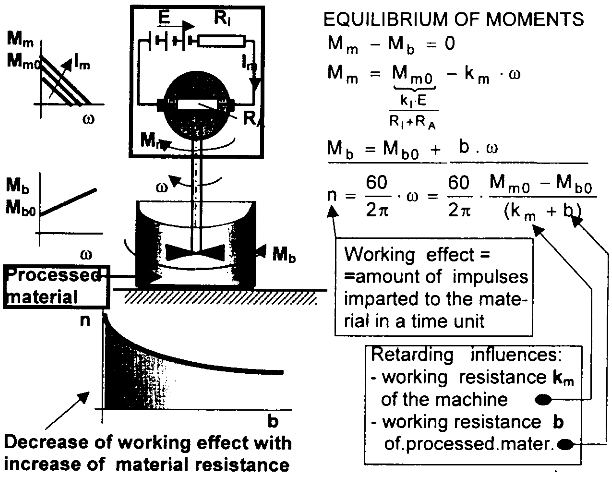


Fig. 1 The influences acting on the working effect of a producing system a) viscoelastic properties of the processed material (= of the object) b) inner machine properties (of the working characteristics). (Simple stirring of materials taken here as an example of the process.)

The mixer consists usually of a rotating propeller and of a motor which transforms the energy gained from an electric supply to the energy of rotation. The rotation energy is then imparted to the material against its resistance to stirring. *This resistance depends on the velocity of rotation ω and on the viscoelastic properties E(jω) of the material.* The working effect of stirring is determined by the properties of both participants of the process – by the s.c. moment characteristics depending on the working speed of the working device ($M = f(j\omega)$) and by the viscoelastic resistance ($R = g(v_{rel})$) of the processed material.

It is evident, that the working device (mixer) influences the processed object the more, the higher frequency and intensity of impulses can be imparted to the object in a time unit. Yet the processed material influences the machine backwards, too, so that the mixer rotates more slowly and yields lower useful output if the material shows higher viscosity. *The viscoelastic properties of material play here the basic role.* They affect not only *the ability of the material to be processed* but also *the productivity and quality* of the whole process.

Similar effect of feedback from the processed material back to the working machine occurs of course also in more complex devices than in a simple mixing machine. The above mentioned statements on simple mixing of materials hold therefore commonly for all processing systems, especially for textile machines and textile fibers and materials.

The feedback effect between any working machine and processed material shows the Fig. 2. Today's textile machines must be designed as relatively light (with low masses) due to the necessity to highten the machine working frequencies and productivity. In result of that their *mechanisms are more and more compliable.* With similarly *compliable processed materials* as e.g. man-made fibers, the tandem „machine – textile material" functions as a single closed feedback circuit where both members interferre with each other. *The textile material becomes thus an integral part of the whole producing system.*

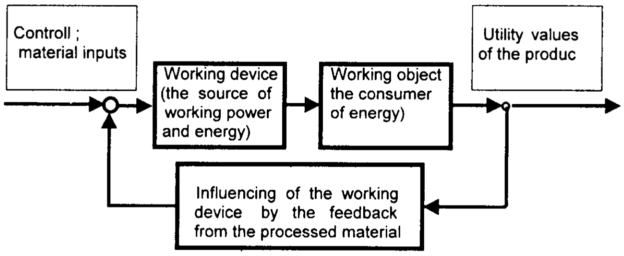


Fig. 2 Influencing of the working machine by the feedback from the processed material and vice versa.

2. The textile material as a part of the working unit „textile machine + material“

Drawing of linear textile products.

Drawing of linear textile products represents an omnipresent process in textile materials treatment. In any mechanic textile process an accompanying effect of material treatment is usually *the drawing or stretching or other result of straining of textile materials between the working mechanisms of textile machines*: elongation of individual fibers, drawing of slivers, rowings, straining of yarns, warps, fabrics, knitted fabrics etc.There always act together the mechanism and the textile material as a unit.

For the reason of shortness let us call the textile products underlying the straining or drawing generally as *linear textile bodies (LTB).*

Let us study the relevant dynamic properties of both the processed textile material and the working machines as well.

Drawing of LTB´s is followed by

- reversible *elastic elongation* (with maintaining the molecular structure of the material), or
- irreversible *stretching* (with certain rearranging of molecular structure), or with
- irreversible *material extension* (caused e.g. by sliding of fibers on each other at drawing).

Processes illustrating these deformations (stretching, drawing, weaving...) are shown on Fig. 3.

The deformations of textile materials rise not only with steady velocities but often also with *alternating or wavering or impulse-type courses of motion velocity*, which depend on the principles of the feeding and delivering devices in the given technological system. *Steady velocities correspond usually to the area of spinning processes whereas the impulse-type unsteady motions correspond mainly to knitting and weaving.*

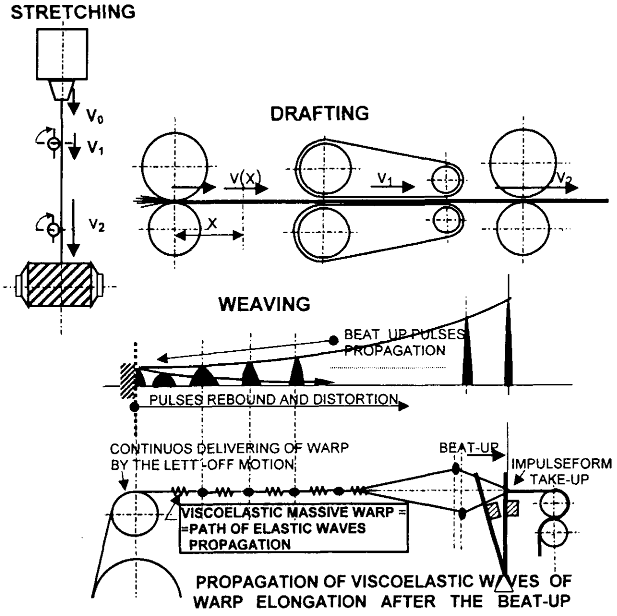


Fig. 3 Typical textile technologies where the textile materials (fibers) are *stretched without shifting* of any particles along each other or *elongated under shifting* of fibers with friction (in slivers, rovings), *or strained by short deformation pulses* followed by propagation of elastic tension waves along the LTB's (warp ends) practically without sliding of fibers inside of yarns. In all cases the deformations are both elastic and plastic.

Generalized drawing field.

After a certain abstraction, *any textile technologic system* with some input and output delivering velocities can be *modelled as an generalized drawing device* as on Fig. 4.

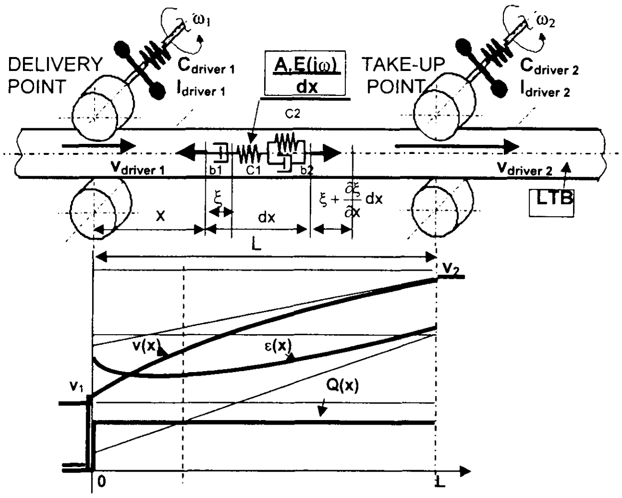


Fig. 4 Practically every mechanical textile process represents a sort of stretching of the processed textile material. An idealized stretching device of some textile process is shown on the figure. An arbitrary LTB (fiber, yarn, warp...) is stretched between the fictitive delivery and take-up points on the textile machine (here represented by two pairs of rollers). The courses of the local speed (flow) v(x) of the material particle and the immediate local elongation $\varepsilon(x)$ as well the resulting drawing force Q (which is constant in the whole drawing field length) depend on the input and output velocities v_1, v_2 and on the type and value of the viscoelastic parameters of the stretched material. Both the processed material as well as the driving mechanism are less or more compliable and deform themselves due to acting outer and inertia forces.

The idealized (generalized) drawing device consists of two fictitive driving mechanisms acting on the LTB – a feeding (delivering) driver and a drawing-off one. On the figure the drivers are equipped with two pairs of driving rollers, yet ofcourse the feeding and drawing-off mechanisms on varios real machines can be realized also in very different forms. Due to inner inertia of the drivers (illustrated here by two flywheels with inertia moments $I_{driver\ 1,2}$), and due to elastic transmission $C_{driver\ 1,2}$ of revolutions from the motors to active elements (to the rollers), the drivers may possibly react dynamically (= with delay) on outer signals as well as on the varying tension of the LTB between the rollers. (The LTB represents the loading of drivers).

In result of the elongation of material in the drawing field, in the strained LTB arises a drawing force Q. Whereas Q is naturally constant along the whole length of material in the drawing field, *the material elongation $\varepsilon(x)$ increases along the drawing field in various courses depending on viscoelastic properties of material.*

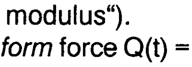
Viscoelastic properties of the LTB´s

Viscoelastic properties of a LTB with the real length ℓ, total elasticity **C**, and some inner energy dispersion (damping) **B** can be modelled by a chain of continuously distributed differential models with lengths **dx** which consist of springs with the rigidity **c = C(ℓ/dx)** inverse-proportional to that of the original, of dampers **b = B(ℓ/dx)** and of distributed differential masses **dm = m.dx/ℓ**. Capitals **C**, **B** represent the elasticity and damping of the whole length ℓ of the original LTB, whereas **c**, **b** belong to short sections **dx** of the model.

To express the different types of elasticity of the given material, *rheologic models* [2] presented on the Fig. 5 can be used. If any of these models *begins with a spring in series*, the model may represent *elastic behaviour of the material* without sliding of fibers or other particles on each other inside of the LTB (e.g. it may represent some retarded propaga-tion of elastic waves in the body). On the contrary the models beginning with *dampers in series* represent processes with *sliding of particles* in the LTB or with irreversible deformations.

Description of a stationary model of viscoelasticity of textile (mainly man-made) materials

The parameters of the model of some viscoelastic material must respond to the course of the force/deformation curve of material at the proportional increase of elongation or at other types of straining.

To find the *time course* of elongation of one differential section dx of the LTB let us observe e.g. the 4-element elasticity model in the form as in the Fig. 4.: (damper-spring-(spring//damper)) =  .

In each element of the model the longitudinal force Q causes a deformation described by the equations

$$
\begin{aligned}
Q(t) &= b_1 \frac{d[\xi_1(t)-\xi(t)]}{dt} &&\cong Q(p) = b_1 p[\xi_1(p)-\xi(p)] \\
Q(t) &= c_1[\xi_2(p)-\xi_1(p)] &&\cong Q(p) = c_1[\xi_2(p)-\xi_1(p)] \\
Q(t) &= \left(c_2 + b_2\frac{d}{dt}\right)\left\{\left[\xi(t)+\frac{\partial\xi(t)}{\partial x}dx\right]-\xi_2(t)\right\} \cong \\
&\cong Q(p) = (c_2+b_2 p)\left\{\left[\xi(p)+\frac{\partial\xi(p)}{\partial x}dx\right]-\xi_2(p)\right\}
\end{aligned}
\tag{1}
$$

Here ξ, ξ_1, ξ_2, $[\xi + (\partial\xi/\partial x)dx]$ are the deformations of function points between individual elements of the model.

Notice: It is of advantage to write these equations in the Laplace operator form where a function of time *t* is transformed to a function of the s.c. Laplace operator **p**, e.g. $\xi(t) \to \xi(p)$. The operator p represents a symbol of 1.st derivative: $p.\xi(p) - \xi(0) \cong (d/dt)\xi(t)$. Operator methods bring a simplification into the calculations: the set of operator equations can be solved as plain *algebraic equations.*Their results Q = Q(p), $\xi = \xi(p)$ can be then simply transferred back into the *time domain* Q(t), $\xi(t)$, when using ready solutions content in tables of two-sided Laplace transforms [3] prepared already before by a row of authors.

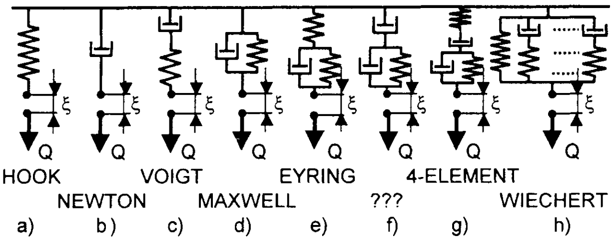


Fig. 5 Rheologic models of viscoelastic behaviour of textile fibers or of other LTB's (= linear textile bodies). Models which start with a spring represent elastic deformation of fibers accompanied with some time delay of the deformation. Models which start with a damper represent sliding of fibers on each other, accompanied with some viscoelastic deformation.

If some *section* **dx** of material is loaded by the force Q(t) it starts to elongate by values $[\partial\xi(x,t)/\partial x].dx \equiv \varepsilon(x).dx$ yielding from the equation (1) (which represents in fact the generalized Hook´s law in the operator form):

$$
\begin{aligned}
Q(p) &= c_1 \frac{p\tau_1(1+p\tau_2)}{1+\alpha.p+\beta.p^2}\cdot\frac{\partial\xi(x,p)}{\partial x}\cdot dx = \\
&= \frac{E(p).A}{dx}\cdot\underbrace{\frac{\partial\xi(x,p)}{\partial x}}_{\varepsilon(x,p)}\cdot dx
\end{aligned}
\tag{2}
$$

Here $\tau_1 = b_1/c_1$; $\tau_2 = b_2/c_2$; $\alpha = [(c_1 + c_2)/c_2].\tau_1 + \tau_2$; $\beta = \tau_1\tau_2$ are the time constants of the elongation $\varepsilon(x,t)$ reacting on the force Q(t).The coefficient [E(p)A]/dx between the force Q and elongation ε.dx of the section dx represents the dynamic elasticity of the section dx of the strained material. A/dx is the material cross section divided by the length dx of the differential model, and E(p) is the operator modulus of elasticity (the generalized „complex modulus").

For the *step-form* force $Q(t) = Q.1(t) \cong Q.(1/p)$ the corresponding elongation $d\xi(x,t) \equiv [\partial\xi(x,t)/\partial x]dx \equiv \varepsilon(x,t).dx$ of the 4-element model in the section dx is from (2)

$$
d\xi(x,t) \equiv \varepsilon(x,t)dx = \frac{Q}{c_1}\left[1+\frac{t}{\tau_1}+\frac{c_1}{c_2}\left(1-\exp\left(-\frac{t}{\tau_2}\right)\right)\right] \tag{3}
$$

here $t = x/v_1$, $c_1 = C_1(\ell/dx)$ (C_1 = elasticity of the real material length, c_1= elasticity of the differential model).

After certain transition process at the start, the elongation of the 4-elem. model increases proportionally to time.

Similarly *all other types of rheologic models* can be described. Their behaviour may be but very different to (3) according to different organisations of various models.

Process of elongation of *moving* (yielding) viscoelastic material in the drawing field.

Textile materials practically newer work stationary like the rheologic models described in the literature: being fixed between two steady points without motion and strained by some given constant or varying force or deformation.

The textile material practically allways *passes through* some working process, the parts of the material successively entering the working line and leaving it on the other end. During the passage the material particles are exposed to forces so that at the given time instant the parts which entered sooner are exposed to acting forces allready for a longer time than those which entered later. Therefore the transformation processes (deformations, form transformations, chemical reactions etc.) with the longer influenced parts of material are accomplished with a greater extent than with the parts just arriving into the line.

The process of continuous material straining in any textile machine can be illustrated as the passage of a series of differential sections dx of textile material (LTB) through an *idealized drawing field with feeding and drawing-off devices* with different input and output velocities v_1, v_2., not necessary steady. During passing through the drawing field the material is loaded by the drawing force Q. In result of it and of the material viscosity the material „creeps“ in the course of time. Individual sections dx of the material can be modelled by using the known rheologic models of elasticity.

During a period *t* of time the feeding device *inserts into the drawing field a length X(t)* of (unstretched) material. In this time period individual sections **dx** of the inserted reach successively the positions **x, x+dx, x+2dx..., X** in the times $\mathbf{t_x = x/v_1}$, $\mathbf{t_{x+dx} = t_x + dt = (x + dx)/v_1 \ldots}$, $\mathbf{t = X/v_1}$. During these individual times the sections *dx* dilate by the increments $d\xi(x,t_x)$ according to eq. (3). The total elongation $\xi(t)$ of the inserted length **X(t)** is then given by the integral of the increments $\mathbf{d\xi(x,t_x)}$ in all sections of **X**. When addying to the total elongation $\boldsymbol{\xi}$**(t)** the originally inserted unstrained length $\mathbf{X_{tot}(t)}$ we obtain *the total path X(t) of the material* which has been covered in the given time **t**:

$$X_{tot}(t) = X(t) + \xi(t) = v_1 t + \int_0^t d\xi(x,t)dt = \\ = v_1 t + \frac{Q}{C_1}\frac{v_1\tau_1}{\ell} \times \\ \times\left[\left(1+\frac{c_1}{c_2}\right)\frac{t}{\tau_1} + \frac{1}{2}\frac{t^2}{\tau_1^2} - \frac{c_1}{c_2}\frac{\tau_2}{\tau_1}(1-\exp[-t/\tau_2])\right] \tag{4}$$

If the properties of the strained material are those of the 4-element model, the covered path of any material section dx in the drawing field increases *progressively* with the time t^2 or with corresponding inserted length $x^2=(v_1.t)^2$. It does not increase linearly as it is usually suposed e.g.in the theory of spinning as if the material would be purely elastic.

Now from the eq. (4) it is possible to derive further important equations discribing the process of material straining in an idealized drawing field:
The motion velocity of a section dx of material (by differentiation of the eq. (4)):

$$v_{tot}(t) = v_1\left\{1+\frac{Q}{C_1\ell}\left[\left(1+\frac{c_1}{c_2}\right)+\frac{t}{\tau_1}-\frac{c_1}{c_2}\exp(-t/\tau_2)\right]\right\} \tag{5}$$

The drawing force Q follows from the eqs (4) and (5) when considering that the total strained length of inserted material $X_{tot} = X + \xi$ covers the length L of the drawing field:

$$L = X_{tot}(T) \tag{6}$$

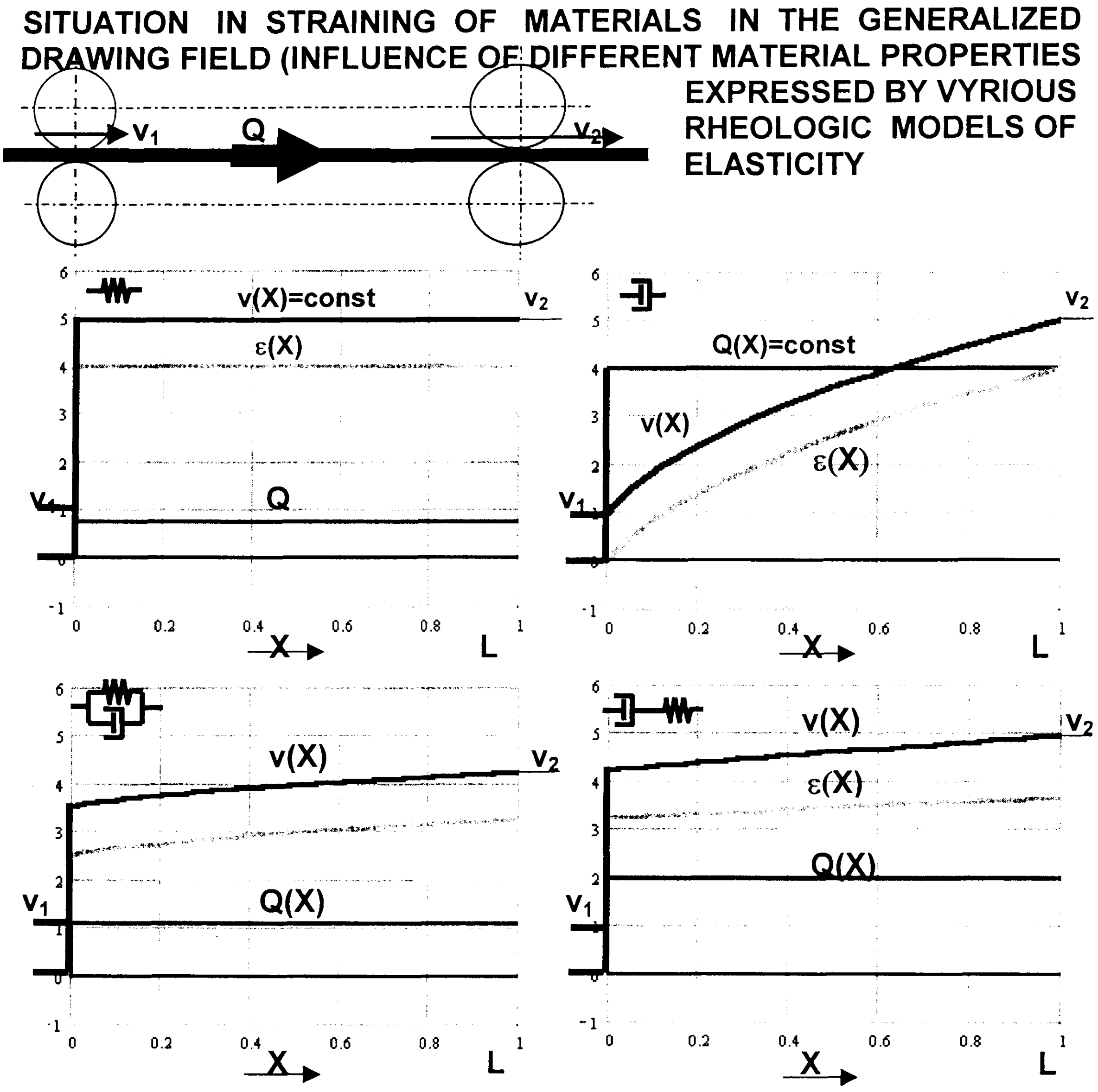
The transcendent equations have to be solved together by numeric methods, yet with some simplifications (supposed e.g. long drawing fields where the exponential functions fade off) we can obtain coarsely the expression

$$Q \cong \frac{C}{4}\frac{v_2 - v_1}{v_1}\left[\frac{L}{1+c_1/c_2}v_1\tau_1\right] / \left[\left[\frac{L}{1+c_1/c_2}+v_1\tau_1\right]\right] \tag{7}$$

The courses of *relative elongation of material* $\varepsilon(x) = \varepsilon(v_1.t)$ (according the eq.(3)), *of local velocity* $v_1 < v(x) < v_2$ (eq. (5)), and of the *drawing force* Q(t) = Q (eq. (7)) are plotted on Fig. 4.

As it can be seen from the expression (3) and on the Fig. 4 bellow, the course of elongation $\varepsilon(x).dx=d\xi$ is unsteady. It starts immediatelly with a jump, yet then decreases a bit and at the end of the drawing field it grows again practically proportionally to time *t* or distance x. *The exact form of elongation depends ofcourse on the type (on the rheologic model) of the material viscoelasticity and on the elasticity and time constants of the material.*

Yet the textile materials – natural as well as man made – can show up different viscoelastic properties expressed e.g. by various more or less complex types of rheologic models. Also the time- and proportionality constants τ_i, C_i of the models may differ significantly what influences the resulting courses of material deformation and strain. On the Fig. 6 courses of $\varepsilon(x)$, v(x), and Q are plotted for main known types of viscoelasticity models. For possi bility to compare the influences of the model types on the deformation courses the time and proportionality constants have been kept the same for every model types.



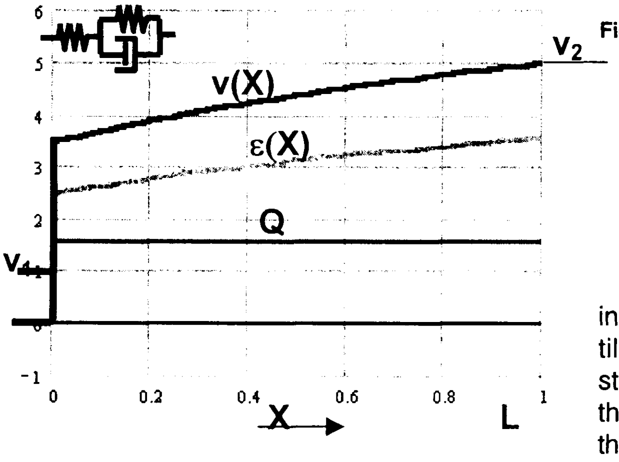


Fig. 6 The influence of various viscoelastic behaviours of different textile materials (represented by various rheologic models) on the generalized process of drawing of LTB's occuring in various forms practically during any textile technology. Different relations between viscose and elastic resistances change significantly the courses of material elongation $\varepsilon(X)$ in the drawing field as well as the values of drawing forces Q.

Similarly to a LTB in the above mentioned fictitive models with the textile material strained between two simple and steadily working drivers, in real dynamically moving textile machines work also the real textile materials – in a drafting machine, spinning and winding machine, warping machine, weaving loom etc.

On the base of dynamic analyses like that one shown in this paper the influences of various properties of textile materials on various working processes can be studied. The problems can be certainly wider than just the described steady drawing of a fictitive LTB. E.g. in the weaving process the deformations of the processed material obtain a impulse form, what certainly brings further complications into the solution. The working mechanisms of the machines are not rigid enough and therefore they yield under the resisting forces of the material, as it was mentioned with the simple model of a mixer loaded by the stirred viscoelastic material on the beginning of this paper. With very fast dynamic processes as it is especially weaving of today even the masses of the processed material (warp and wefts) play a significant role. There arise effects like propagation and rebound of tension waves in the material – warp as well as weft. The dynamic characteristics of elasticity of these materials become then still more complicated than those shown here. During high dynamic loading of that type the material can change its properties in the course of time, what needs to be studied, too.

Literature

[1] – Nosek Stanislav: Straining of various linear textile bodies in generalized drawing fields, mainly in warps on looms. Book of proceedings, Conf. Textile Science, TU Liberec 1998.

[2] – Dillon J. H., Rezinovskij M. M., Priss L. S. Ustalosť vysokopolimerov. Gos.Nauč.Issled.Izdat. Moskva 1957
- Ferry J.D. Viscoelastic Properties of Polymers.John Wiley, N.Y.1960.
- Freudenthal A.M. Inelastisches Verhalten von Werkstoffen. VEB Verlag Technik, Berlin 1955.
- Holodniok M, Klíč A., Kubíček M., Marek M. Metody analýzy nelineárních dynamic. modelů. Academia Praha 1986.
- Holzmüller W., Altenburg K. Physik der Kunstoffe. Ak.Verlag Berlin 1961.
- Jambrich M., Pikler A., Diačik J. Fyzika vlákien. Alfa Bratislava 1987.
- Leadermann H. Elastic and Creep Properties of Filament Materials. The Textile Found., Washington 1943
- Plander T.,Tomáš J. Dynamické vlastnosti viskoelastických materiálov. SAV Bratislava 1964.
- and other publications on viscoelasticity.....

[3] – Pírko Z., Veit J.: Laplaceova transformace (The Laplace Transform). SNTL/Alfa, Praha – Bratislava 1970
- Nixon J. Principy soustav automatického řízení (Principles of Systems of Automatic Control)–Appendix: The Laplace Transform (incl. list of Laplace transforms)

[4] – Nosek Stanislav : Teorie tkaní I–III. (Theory of Weaving I – III.). Dům Techniky Pardubice 1988–9.
- Nosek Stanislav: The dynamics of fabric forming on the loom at high weaving rates. Indian Journal of Fibre and Textile Research Vol.19, September 1994, pp.125–138.
- and other publications on these topics.

STRUCTURE AND PROPERTIES OF SUPERCRITICAL FLUID, WATER AND HOT AIR TREATED PET FIBRES

Smole, M. S., Zemanova, E.*

Laboratory for Characterisation and Processing of Polymers, Institute of Textile Chemistry, University of Maribor,
Smetanova 17, SI 2000 Maribor, Slovenia; majda.sfiligoj@uni-mb.si

**Department of Fibre and Textile Chemistry, Faculty of Chemical Technology,*
Slovak University of Technology Bratislava, Radliského 9, SK-812 37 Bratislava, Slovakia

The influence of different treatment media, e.g. supercritical CO_2 fluid, water and hot air, respectively at the same thermal conditions on poly(ethylene terephthalate) (PET) fibre properties was investigated. Different treatment media caused some structural changes in polymer but were not pronounced enough to influence significantly the fibre properties.

INTRODUCTION

The fine structure of poly(ethylene terephthalate) (PET) fibres varies with processing history and due to these differences fibre properties are influenced [1–4]. In general, the higher orientation introduced at drawing, the higher will be tenacity and the lower its extensibility. An increase in crystallinity due to heat setting of PET fibres completes the effect of high orientation [1]. For commercial PET fibres a highly oriented and developed crystalline structure is characteristic. Any additional high temperature treatment of fibres can cause some structural changes which can influence the fibre properties.

Recently supercritical CO_2 fluid (critical conditions of CO_2: $Tc = 304.2$ K, $p_c = 7.38$ MPa), an environmentally friendly medium for transportation for hydrophobic dyes, was introduced in the textile fibres dyeing processes. The energy saving and no waste water are the main advantages of this dyeing process [5-6]. Structural changes in poly(ethylene terephthalate) multifilament yarn caused by supercritical CO_2 fluid blind dyeing were intensively studied by means of different analytical methods. e.g. x-ray scattering, density measurements, calorimetry and SEM analyses [6–10]. The determined effect of the supercritical fluid treatment on the structural changes was additionally compared to the changes in PET fibres observed after conventional dyeing in hot water and after heating the fibres in dry air, respectively [10].

It was found that supercritical CO_2 fluid increases the crystallinity parameter of the polymer fibre due to formation of new smaller or less perfect crystallites or due to an increase of imperfection of the previously formed crystallites [8]. Different treatment conditions show little difference with respect to the observed changes in crystalline structure [10]. The crystalline orientation remains nearly unchanged after treating PET fibres in different media at the same temperature conditions [9].

The microvoid system of the fibres is slightly influenced by different thermal treatment. Some oligomers from the inner part of the fibres are pushed by the elevated pressure to the fibre surface and at their previous place new microvoids are formed. SCF causes a dispersion of a void in a few smaller voids and additionally new voids are formed [7].

EXPERIMENTAL

Preparation of the samples

The analyses were carried out on a PET multifilament yarn (dtex 143 f 48) from Hoechst (Bobingen). The SCF blind yeing was performed in an apparatus Andreas Hofer. The SCF treatment condition were: T = 130 °C, p= 40 MPa, t = 60 min. The dyeing in water medium and CO_2 fluid was similar to conditions employed in conventional textile processing. The blind-dyeing in the water medium was performed in the laboratory dyeing apparatus Ahiba. Dyeing was started at 70 °C, afterwards the temperature was raised to 130 °C at a heating rate of 2 °C/min. Dyeing was carried out at this temperature for 60 min. The cooling rate of the dyeing bath was the same, 2 °C/min. The fibres were hot air treated in a forced draft oven at the same temperature conditions as the blind water dyeing of the fibres. All thermal treatments were performed with the yarn wound up on perforated cylinders.

Analytical methods

Thermomechanical Analysis TMA, a method for the determination of mechanical properties under tensile load in a thermally controlled environment was performed by means of a Shimadzu TMA-50 detector. The measurements were carried out under different experimental conditions. The heating rate was 10 °C/min and 5 °C/min, respectively and maximal temperature between 150 and 230 °C. The measurements were performed without the initial load and with it, i.e. 0.5 N and 1 N load, respectively.

Table 1 Fine structure changes of PET fibres treated under different conditions [7–10]

Sample	Untreated	SCF treated	Water treated	Hot air treated
Density (g/cm^3)	1.3881	1.4001	1.3961	1.3976
Crystallinity index (from density)	0.464	0.564	0.531	0.531
Long spacing (nm)	16,3	15.7	16.0	15.8
Dimension of crystallites $D_{(100)}$, (nm)	8.1	6.3	5.9	6.4
Dimension of crystallites $D_{(010)}$, (nm)	6.2	4.7	4.4	4.7
Dimension of crystallites $D_{(110)}$, (nm)	5.6	5.1	5.0	5.0
Orientation of crystallites	0.9714	0.9763	0.9758	0.9755
Volume fraction of voids (%)	1.38	2.07	2.58	2.21

Additionally stress-strain curves were measured on the dynamometer Statigraph S Textechno (Herbert Stein) with the length between the clamps of 500 mm according to ISO 2062 [11]. Average data were calculated from 10 experiments.

RESULTS

Fine structure changes observed after the SCF, water and hot air treatment of PET samples treated at 130 °C are given in Table 1 [7–10].

The deformation of PET samples under load was measured while the samples were heated linearly (Fig.1).

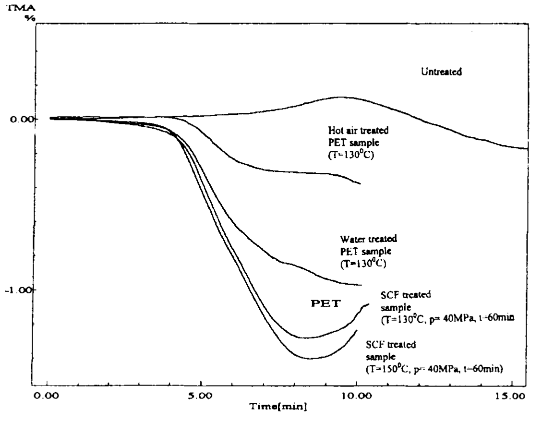


Fig. 1 TMA relaxation curves of PET fibres treated under different conditions

The thermal history of the samples influences the thermomechanical properties of PET fibres to some extent (cf. Fig.1). Some slight changes in thermal expansion characteristics of the PET polymer due to the increased crystallinity index and increased crystalline orientation are observed with all treated fibres, especially after treating PET fibres in SCF. Very slight differences between the expansion coefficients of the treated samples can be observed when comparing the slope of the TMA curves of treated fibres, but the curves are significantly different in comparison to the TMA curve of the untreated fibre.

Elongation ε and stress at break σ for some of the analysed samples are presented in Table 2. Any treatment increases the strength of the filaments, but taking into account the variation coefficient (CV) between 3 to 9 %, the differences between the various treated samples are not significant. σ/ε results do not point to any change of mechanical properties. Probably the structural changes are not pronounced enough to be reflected in changed mechanical properties.

CONCLUSIONS

PET fibres with a highly developed microfibrillar structure were supercrical fluid dyed, conventional water dyed and hot dry air treated in accordance with the conventional conditions used in practice. Different treatment conditions change the fibre structure to some extent and some changes in fibre thermomechanical properties were detected as well, but the observed structural changes are not pronounced enough to influence much the mechanical properties of the fibres.

REFERENCES

[1] M. Lewin, E. M. Pearce: Handbook of Fiber Chemistry; Marcel Decker, New York (1998)

[2] Y. Fu, B. Annis, A. Boller, Y. Jin, B. Wunderlich: Analysis of

Table 2 Mechanical properties of SCF, hot water and hot air treated samples

Sample	σ (N)	CV (%)	σ/tex (cN/tex)	ε (%)	CV (%)
Untreated PET sample	6.15	6.04	43.00	29.31	4.93
SCF treated sample T =150 °C, p = 40 MPa, t = 60 min	6.50	3.77	45.45	27.39	1.91
water treated sample T =130 °C, t = 60 min	6.19	4.23	43.29	28.41	3.28
hot air treated sample T =130 °C, t = 60 min	6.49	2.64	45.38	28.68	3.03

Structure and Properties of Poly(ethylene Terephthalate) Fibers, Journal of Polymer Science; Part B: Polymer Physics, Vol 32, (1994) 2289–2306

[3] M. Žiberna Šujica, M. Sfiligoj Smole: Structural Parameters and Mechanical Properties of Poly/ethylene Terephthalate) Fibres; in preparation

[4] M. Sfiligoj Smole, P. Zipper, M. Žiberna Šujica, S. Jeler: Supramolecular strucure of PET fibres, The 7th World conference of The Textile Institute, May 22–24 Tampere, Finland, (1997) p 372–373

[5] W. Saus, D. Knittel, E Schollmeyer: Dyeing of Textiles in Supercritical Carbon Dioxide ; Text.Res J. 63 (3) (1993) 135–142

[6] M J: Drews, C. Jordan; AATC Book of Papers USA (1994) 261

[7] M. Sfiligoj Smole, P. Zipper, S. Jeler: Small angle x-ray diffraction studies of PET fibres, Prog. colloid & polym. sci., Vol. 105, (1997) p. 85–90

[8] M. Sfiligoj Smole, P. Zipper: WAXS analysis of structural changes of poly(ethylene terephalate) fibers induced by supercritical-fluid dyeing. Colloid polym. sci., 276 (1998), p. 144–151

[9] M Sfiligoj Smole, P. Zipper. Determination of the orientation of crystallites in PET fibres. Int. j. polym. mater., Vol. 47, (2000) p. 681–691

[10] M. Sfiligoj Smole, P. Zipper: The Influence of Different Treatment Media on the Structure of PET Fibres, in preparation

[11] ISO 2062 (1972): Textiles-Yarn from packages-Method for determination of breaking load and elongation at the breaking load of single strands (1972)