FORMATION OF THE TEXTILE STRUCTURES FOR A SPECIFIED PURPOSE

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Abstract: *Woven fabrics are the most common example of flat textile materials used in the manufacturing of clothing, decorative, technical, and special purpose products. Increasing expectations regarding the variety of fabric uses have prompted researchers to seek the optimal applied properties of fabrics as well as their internal structure. Woven fabric as a complex textile product, with advantages and disadvantages of the fibres and yarns on one side as well as of the way of manufacturing and finishing on the other, is an interesting, however not thoroughly acquainted, study case. The article presents the possibility of modelling mechanical properties of a dedicated woven product, shaping the bending stiffness of technical woven structures intended for pipe conveyor belts, structures as sound-absorbing barriers and multi-axis woven structures used to reinforce composites. These are a few examples of developed, dedicated woven structures of specific purpose.*

Keywords: *Textile structures, pipe conveyor belts, sound-absorbing barriers, multi-axis woven structures.*

1 INTRODUCTION

Woven fabrics are the most common example of flat textile materials used in the manufacturing of clothing and decorative, technical and special purposes products. Increasing expectations of the variety of fabrics' uses incline to the search of optimal applied properties of fabrics and, following, their internal structure. Woven fabric as a complex textile product consisting of advantages and disadvantages of fibres and yarns on one side, as well as of the way of manufacturing and finishing on the other one, is an interesting, however not thoroughly acquainted, study case.

Parameters of fabric structure are used for its identification, that is, to characterize it so that it can be accurately and precisely reproduced at any time. The more accurate the characteristics of structural parameters of the reference fabric, the more fabric being reproduced is similar to the original. In addition, almost all fabric properties can be shaped as functions of many factors.

In the case of textile design, the endeavour is to make the finished product as similar as possible to the designed one. The designer must be careful in choice of parameters of the fibre, yarn and fabric structure so that the functional properties of the finished product are consistent with the earlier assumptions.

The construction of models of textile products aims at setting the basis for discussion on mechanical and applied properties of these products as well as providing the technologists with the information on the extreme parameters of the products possible to manufacturing from certain materials and on machines available.

2 MODELING OF THE FABRICS

Large number of solutions when it comes to construction of fabrics differing in the raw material used, thickness, structure and filing, weave and finishing, makes it difficult to empirically find the dependence between the product structure parameters and the mechanical properties of its finished form. There are many parameters of the fabric structure, which the designer should choose optimally when modelling the characteristics of the product. This is core for giving fabrics the basic functions that a product should achieve for given needs. Thorough knowledge of rule and structural and utilitarian relations in fabrics is the basis needed in their conscious analysis. For many years, scientists have been introducing mechanical and geometric models for structural analysis of fabrics to characterize their internal geometry.

The textile structure changes under small deforming strengths. There are two consequences of these changes: the first is a significant difference in the barrier of deformed products, and the second – a difference in mechanical properties such as resistance and stiffness.

When considering the properties of fabrics, certain models of their construction can be used [1, 2]. There are two basic types of these models:

- mechanical models (e.g. according to Olofsson, Nosek), based on the analysis of the conditions of fabric creation and the properties of its threads,
- geometrical models (e.g. Peirce, Kemp), not concentrating on tension of threads, or not taking into account the external forces, but, relatively, most precisely reflecting the actual structure of the fabric.

In the literature on the fabric structure various descriptions are always based on simplified models.

Peirce's geometric model is widely used to describe the structure of fabrics. However, structural changes of fabrics during stretching are characterized using Painter's nomogram.

In order to specify and more accurately describe the structure of fabric subjected to static load, it seems important to look for new methods in this field of research so that they could describe the fabric architecture as precisely as possible, with the possibility of predicting its mechanical properties.

There are many parameters of the fabric structure that the designer should choose optimally when modelling the product features. This is the basis in providing fabrics with the most important functions needed during the use of the finished product. Thorough knowledge of laws and relations between structural and utilitarian features of fabrics makes up the basis for conscious analysis of many aspects of fabrics. This knowledge also serves as an indispensable tool for fabric design.

Experimental and scientific research, as well as fabrics modelling enables determining the principles of changes in the fabric structure subjected to static forces. By modelling changes in the fabric structure subjected to static forces with the use of new modified nomograms, it is possible to more accurately describe the structure of real fabrics subjected to static strengths, eliminating generalizations of analysis while using Painter's nomogram [9].

All real fabrics can be specified by the deformation of circular cross section of warp and weft threads. The scale of the deformation depends on the kind of thread, material used, the way of weaving, the weave, the weaving strengths and the susceptibility of thread to cross deformation. The shape of cross section of threads in fabric can only be approached by different plane geometric figures, such as: a circle (Peirce) [3-6], an ellipse, a hippodrome shape (Kemp) [3], a convex lens (Milasius) [7]. The shape of cross -section in real fabrics is diverse, which is the result of pressing and bending strengths effecting in the areas of contact of crossing warp and weft threads.

Fabric modelling using Painter's nomogram was compared with three new nomograms created as a result of research carried out at the Institute of Textile Architecture, Lodz University of Technology [8]. The experiment showed that depending on the designer's approach and expectations, various forms of the internal structure of fabrics may be created. In addition, changes in the internal geometry of the fabric, subjected to static loads, can also be modelled in a different way. Thus, using these nomograms, each designer has the opportunity to achieve whatever they expect as far as the fabric structure is concerned.

Taking the elliptical cross-section of the yarn into account, it is possible to more accurately model the internal structure of fabrics and go through different stages of their changes when subjected to deforming strengths.

3 CONVEYOR BELTS DESIGN

The knowledge about structure and modelling of woven fabrics was used to shape technical woven products intended for pipe conveyor belts. Conveyor belts are designed for the technological transport of all kinds of bulk materials and damp which do not cause permanent adherence to the belt and conveyor construction elements. These conveyors are applicable wherever it is necessary to quickly and accurately transport materials on the distance specified by the range of one or more coupled conveyors.

The textile conveyor belt is made of fabric-rubber carcass and rubber covers. The carcass may consist of 2 to 6 spacers made of synthetic polyamide-polyester fabrics impregnated with a solution of latex which provides an intermediate layer preventing from delamination of fabric and rubber. Conveyor belt at the point of contact with the drive and reverse drums is flat. Pipe conveyor belt is closed in the work field or return and maintained by a set of four or six rollers on its circuit.

The main problem occurs when the conveyor closes, as previous construction of the pipe conveyor system makes the edges collapse inwards and the conveyor spin, causing unsealing of the belt, which may result in a loss of material transported. In addition, the unsealing causes that the material transported is not sufficiently protected against weather conditions such as rain and wind.

One of the most important elements before designing a new product is to identify and clarify the purpose of the textile product as well as to determine the problem to solve. Precise determination of the characteristics to be fulfilled by a textile product determines the properties of the product through the refinement of the structure of the product.

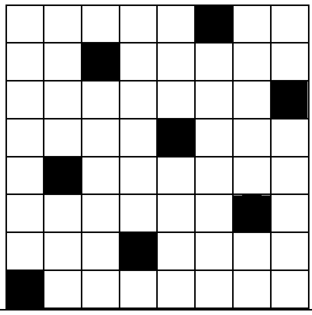
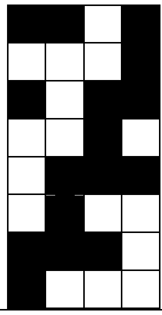
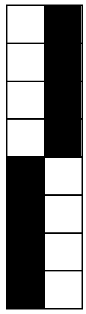
Formation of bending stiffness of technical woven structures differing in weave and internal geometry allowed designing the innovative pipe conveyor belt that is able to close while eliminating the tendency of collapsing its edges inward and minimizing the stresses generated in the structure during the return of the conveyor belt. Based on the first test summaries, it was stated that depending on the weave, belts differently press against the rollers, have different stiffness and that the layer of rubber did not largely eliminate the differences in fabric properties [9-11].

The preliminary research opened the way for further research on the optimization of the production process of conveyor belts so that the mechanical properties of the fabric as reinforcement could be used in a controlled manner and as far as possible. The action was taken to optimize bending stiffness of fabric used in pipe conveyor belt.

The analysis of measurement results enabled designing a new woven structure, symmetric to its longitudinal axis but different in bending stiffness on its width. These differences were possible by using three different weaves paired with each other on the fabric width (Table 1).

In order to verify the validity of the application of the selected three weaves, a new woven structure was produced and then covered with latex and vulcanized (Figure 1). The measurements were done of structure parameters of the new fabric, as well as of mechanical properties of the belt and its pressure on the set of rollers [9, 10].

Table 1 Weaves applied in a new woven structure [10]

Satin weave	Back weft weave	Warp rep weave
$\frac{1}{7}(3)$	On the basis of twill weaves 1/3 and 3/1	$\frac{1}{1}(0,0,0,1,0,0,0)$
		

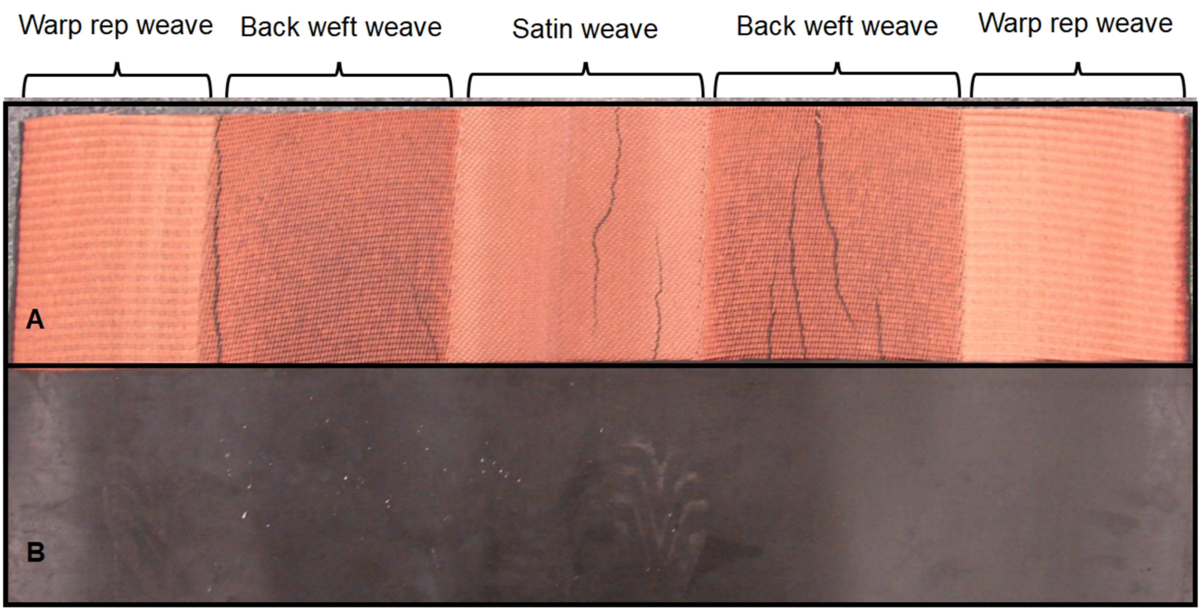


Figure 1 New woven structure with zones of different weaves symmetrically arranged along the longitudinal axis of the belt. A) covered with latex, B) vulcanized [10]

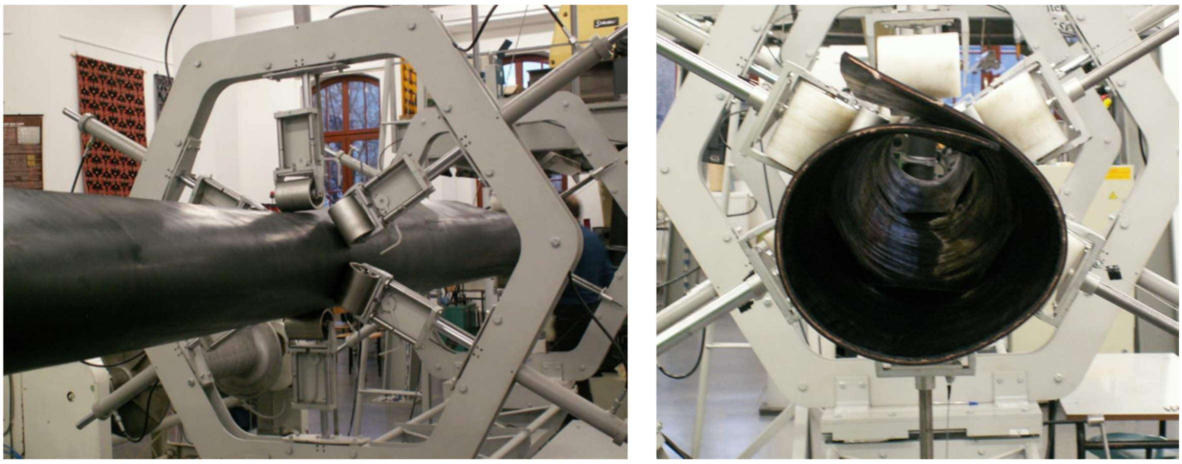


Figure 2 Pipe conveyor belt with the new fabric carcass of different weaves [10]

In line with the project assumptions the fabrics were made as reinforcement of one-spacer conveyor belts. The conveyor belt was made with the possibility of piping and closing but without a tendency of its edges to collapse inward (Figure 2). The construction of the belt made it possible to minimize the stresses generated in the structure at the stage of the belt return eliminating multiple layers of spacers and gaining high transverse flexibility. One-spacer belt has minimized thickness, which reduces its weight, which in turn minimizes the resistance movement during rewinding the belt through the drums [12].

This original solution puts a step forward in the conveyor belt industry. The new woven structure will also better protect the carried material from weather conditions such as rain and wind. Implementation of the project allowed the introduction of innovative solutions for the production of conveyor belts produced, inter alia, in the FTT Wolbrom SA.

4 THE TEXTILE SOUND ABSORPTION BARRIERS

Other dedicated textile structures may be used as acoustic absorption barriers. The problem of noise is one of the fundamental issues that have a very significant impact on the comfort and safety of people [13]. Currently, noise is a common occurrence in the human environment. It is presented in all types of human environment and has adverse effects on human health, including hindering rest and regeneration. It reduces the efficiency of human work and also increases the likelihood of accidents at work. Long-term exposure to noise on the human body is also accompanied by deterioration of hearing or, in extreme cases, total deafness [14].

Fibrous materials have been widely used in noise reduction due to their porous structures [15]. Researchers are still developing new materials that can absorb sound energy. They comprise experimental studies on acoustic properties improvements of rigid polyurethane closed-cell foams, by incorporating various quantities of textile wastes into the matrix [16]. Various fibrous materials including inorganic and metallic fibres, synthetic fibres, natural fibres, and nanofibrous membranes for noise reduction are reviewed. The tailored cross-sections of synthetic fibres such as circle, hollow and triangle are beneficial to improve acoustic absorption properties. The use of material wastes, coming from the fibres of fluffs, when manufacturing the sound absorber products, can help to combat two different kinds of problems: the disposal of this kind of waste and the noise control [17].

The main aim of research work was to present the acoustic transmission losses of 10 different structures of woven fabrics and to investigate the influence of weaving on the acoustic attenuation of the fabrics under the presented tests. The patterns of weaves and their structures influence mechanical properties. The internal structures give different effects, for example of abrasion resistance and air permeability, deformability and complex shape forming including shearing properties. It is interesting how the structures of fabrics influence acoustic attenuation.

10 specimens of 150 x 150 cm fabrics of different structures and patterns were used for the study. The raw material for the weaving was the textured Polyester 167 dtex x 2 as the warp material. In eight samples, as the weft, the acrylic yarn 64 tex was used. Cotton and Trevira weft of similar linear density were used in other samples. The fabrics were made on the Picanol Gamma loom with Jacquard machine in the Institute of Architecture of Textiles, Lodz University of Technology. The textiles were especially prepared to specific purposes as acoustic absorption barrier. All fabrics were made on the same loom with constant

densities 30 warp/cm but the internal stresses changed it during 24-hour relaxations. The individual fabrics were subjected to sound absorption tests in the aeroacoustic anechoic chamber in the Laboratory of Aeroacoustics of the Institute of Turbomachinery (Lodz University of Technology) to achieve free-field anechoic environment.

As it was expected, all tested fabrics have low sound absorbing properties at low frequencies. The presented studies also showed that all fabrics with honeycomb weaves have much less attenuation than other fabrics. Low attenuation of these fabrics is likely due to their similarity to fabrics with lower number of threads per centimeter, resulting in less dense structures at higher thicknesses. Other woven fabrics are more compact and much thinner, which results in good sound absorbing properties. The research proved that the best absorbing properties were in the cases of satin, double cloth and back weft weaves. At higher frequencies thickness also had an insignificant effect on sound absorption. It can then be concluded that if there is air space inside and behind a fabric, sound absorption possibilities move through the frequency range. Similar results were obtained by other researchers using different testing method (inside a reverberation room) for cases of coated and uncoated textiles [18].

The proposed honeycomb fabrics can be used in combination with other acoustic adaptations, such as partially blocking and transmitting the sound to a deeper sound damping installations that, due to different reasons, must be otherwise hidden. They can also be used, for example, as covers for voice or loudspeakers systems. The honeycomb fabrics could protect the loudspeaker against the wind or other severe weather conditions without negatively affecting the good quality of the sound. In such cases, modern printing techniques allow creating interesting artistic decorative motifs, for example in concert halls, where acoustic performance is critical, and fabric’s job is not only to absorb sound itself, but also to allow other acoustic sound adaptations behind the fabric to absorb sound in more predictive manner. In such cases the main task of a fabric is not to hinder or reflect the sound but to control the hall or room environment and act as additional finishing protective layer. The presented results can also be useful for interior designers and architects as the experiments were performed for the first time on such materials and compared to standard fabrics [19].

5 TEXTILE REINFORCEMENT COMPOSITE

The search for new materials of better properties than those traditionally used in techniques (metal alloys, wood, construction ceramics, etc.) resulted in creating the group of materials referred to as composites. Today, technological progress is inseparable from material engineering which deals with the creation of new materials. Engineers constructing innovative materials base on designing conditioned by the operating conditions and loads they will be subjected. Composite materials can meet these demands. Composites are now a rapidly expanding field linking issues of textiles, metallurgy, mechanics and polymer chemistry as well as plastics processing [20, 21].

The main components of the construction composite are matrix and reinforcement. The matrix is more or less homogeneous material filling the space between the reinforcing elements. The matrix volume fraction *Vm* is usually 20-80%. The reinforcement can be a different material arranged to increase the strength and stiffness of the composite. Due to the properties of textiles, they are the most common type of reinforcement in the composites. They may be woven, braided or knitted fabrics, non-wovens or parallel-arranged fibres. The composite resulting from wearing several layers of fabric in a "pile" is not suitable for any application because of its deformability, even under its own weight and the lack of permanent connection of layers. Both of these effects are eliminated in the second stage of producing the composite - lamination step i.e. creating a permanent connection of layers in the stiff construction element. The process involves hardening a sequence of layers arranged complying with the appropriate parameters of temperature, pressure and holding time.

In connection with the development of flat textile structures and the expansion of the area of their applications there is a need to assess the isotropy of their mechanical properties. Classical orthogonally built fabrics (weft threads arranged perpendicular to the warp threads) and less those of the orthogonal structure are one of the types of the sandwich composites reinforcement. They are characterized by isotropic properties only in the directions designated by the systems of threads which may be the same when the threads of both systems have the same mechanical parameters.

In order to provide the layered composite materials with suitable isotropic properties, the fabrics being next layers of the reinforcement are placed at different angles to the main axis of the composite. The number of layers and their layout angles are a result of mechanical requirements for composite construction. In the aeronautics the composites of carbon fibre reinforcement have on average six times higher tensile strength and three times higher modulus of elasticity than steel although they have four times lower weight.

When human safety conditions are not needed to be ensured, glass, aramid or natural fibres are often used as the reinforcement. One of the natural fibres are flax fibres that have mechanical properties similar to glass fibres and significantly better than iron and aluminium. The flax fibres show the new direction of work of the new quality and new product.

The challenge is to create such composite of natural fibres which would compete with composites of glass reinforcement as well as aluminium and iron [22, 23].

During the research work at international cooperation with Politecnico di Milano and KU Leuven the research focused on analysing the flax fabric used as a reinforcement of the composite. The fabric was subjected to biaxial tensile, bending and shearing in order to determine formability and mechanical properties of the product. The second part of the experiment focused on the analysis of flax fabric structure deformation at the tetrahedral form. During the formation of complex shaped composites the important parameter characterising the textile product is its drape. Among other things, this parameter determines the mechanical properties of the finished product.

The obtained results of the study are the complete set of data needed to characterize the deformation capacity of this flax product during the formation of the complex shapes of the finished composite product. These results also provide a reference data for numerical modelling. On the basis of the analysis it was found that this type of flax fabric has good deformability at low shear angles when forming on complex moulds and has better quality in this respect than other fabrics used as reinforcement of composites [24, 25].

This is mainly textile isotropy that, together with raw material and finish, decides of the textile product capabilities, hence the necessity for its insightful analysis. Finished products have mostly dimensional structure, which results in that the internal structure of the woven product is not homogeneous. These changes can result in differences in the mechanical, performance and filtration properties and in the finished product manufacturing processes.

Properties of the individual components are different from the properties of the composite but significantly influence it; hence the need for analysis of the composites components.

Traditional textiles are characterized by, depending on their structure, different degrees of anisotropy of physical and mechanical properties. Meanwhile, the new, non-classical applications of textiles not only require materials with high strength, but also of higher and higher isotropy of its properties. The alternative to classical fabrics having large anisotropy are the multiaxial fabrics. The Institute of Textile Architecture, Lodz University of Technology for many years conducted research on innovative multiaxial woven structures under the guidance of prof. Marek Snycerski. Among other things, globally innovative technologies producing 3, 4, 5 and even 6-axis textiles were developed [26-29].

Multiaxial woven structure is the name of the flat textile product, formed from at least three sets of threads connected by interlaces. Design of such structure is the formation of a grid where the nodes represent intersections of no more than two threads, and then the introduction of interlaces. The grid only shows the mutual layout of the threads (geometry), presenting them in as straight lines with directions consistent with the directions of the axis structure.

Triaxial fabrics have long been known and described in the literature [30-35]. There is significantly less information published about fouraxial fabrics and it mainly relates to methods of their production [36-40].

The main criterion used to classify the multiaxial structures is the number of thread sets (axes), another is the type of grid and the manner of thread interlacing, i.e. the weave. Theoretically, it is possible to create many types of such fabrics weaves. Multiaxial fabric structures can actually be oriented to any thread sets. Due to the shed method of producing classical fabrics, it was agreed that multiaxial fabrics will be oriented to the set which can stand for weft (threads arranged horizontally).

Fouraxial fabrics can be created from three warp sets and one weft set. Spans arise between the threads of these sets. Their shape and regularity depend on the weave and the values of thread scales. The sixaxial fabrics are formed by six sets of threads: five warp and one weft [Figure 3]. Their grids can be modelled by combining respectively mutually rotated classical fabrics [26]. The sixaxial fabric of plain weave was formed in the Institute of Textile Architecture. The fabric has large spans and the largest of them take the dodecagon shape. Structurally the fabric belongs to the group of heterogeneous scale.

An alternative to the parallel-arranged fibres or classical fabrics are multiaxial fabrics of increased isotropy.

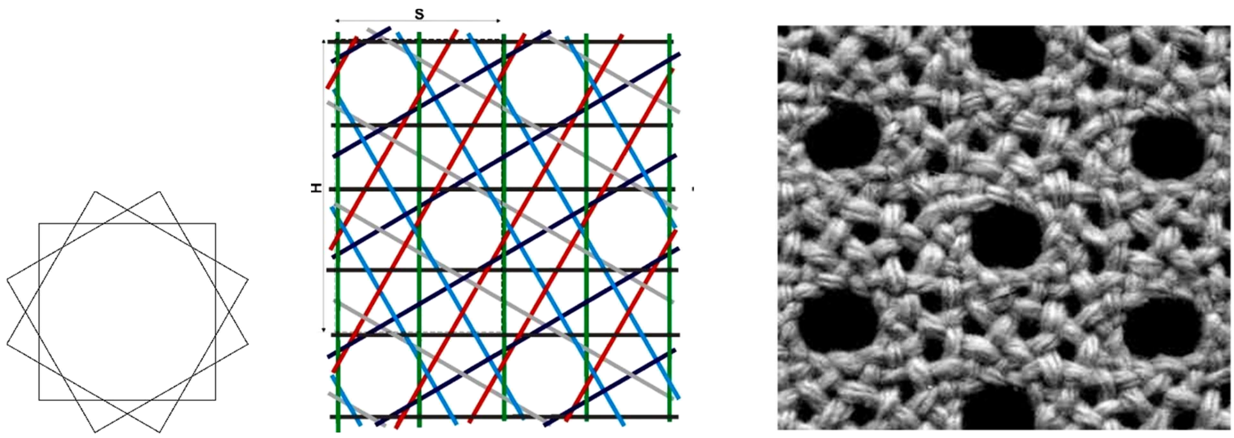


Figure 3 Base for modelling sixaxial grid, report of sixaxial fabric of plain weave and heterogeneous grid, picture of the sixaxial fabric sample [31]

6 SUMMARY

This article presents selected issues regarding designing and formation of woven structures for a specified purpose. Scientific research is focused on formation new woven structures of complex, modified, multi-axial, and spatial, for a specified purpose, which can be used, among others, as textile reinforcements of various composites or acoustic barriers. A wide spectrum of technical application possibilities of textile products has been presented. The manuscript indicates the need for further actions regarding new applications of textile products not yet fully recognized.

7 REFERENCES

1. Masajtis J.: Structural analysis of fabrics, Lodz 1999, (in Polisch)
2. Janusz T.: Weaving, part. III, Warsaw 1963, (in Polisch)
3. Peirce F.T.: 5 - The geometry of cloth structure, Journal Textiles Institute Transaction 28(3), 1937, pp. T45-T96, https://doi.org/10.1080/19447023708658809
4. Szosland J.: Laboratory of the fabric construction and technology, Lodz 1984, (in Polisch)
5. Szosland J.: Basics of fabric construction and technology, Warsaw, 1991, (in Polish)
6. Frontczak-Wasiak I.: Laboratory of the basics of mechanical fiber technology - weaving, Lodz, 1987, (in Polish)
7. Milašius V.: Woven fabric's cross-section: problems, theory, and experimental data, Fibres and Textiles in Eastern Europe 4(23), 1998, pp. 48-50
8. Barburski M., Masajtis J.: Modelling of the change of structure of woven fabric under mechanical loading, Fibres and Textiles Easter Europe 1(72), 2009, pp. 39-45
9. Barburski M.: Analysis of the mechanical properties of conveyor belts on the three main stages of production, Journal of Industrial Textiles 45(6), 2016, pp. 1322-1334, https://doi.org/10.1177/1528083714559567
10. Barburski M.: Analysis of the pipe conveyor belt pressure on the rollers on its circuit, Journal of Industrial Textiles 45(6), 2016, pp. 1619-1634, https://doi.org/10.1177/1528083714567242
11. Barburski M., Goralczyk M., Snycerski M.: Analysis of Changes in the internal structure of PA6.6/PET fabrics of different weave patterns under heat treatment, Fibres and Textiles Easter Europe 23(4), 2015, pp. 46-51, DOI: 10.5604/12303666.1152722
12. P.404943 Barburski M. Snycerski M.: The method for producing the reinforcing fabrics, particular carcass in pipe conveyors belt and reinforcement fabric, particular carcass in the pipe conveyor belt UPRP 2013-08-01
13. EU Commission: Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise
14. WHO, 2011: Burden of disease from environmental noise. The WHO European Centre for Environment and Health, Bonn
15. Tang X., Yan X.: Acoustic energy absorption properties of fibrous materials: a review, Composites Part A: Applied Science and Manufacturing Vol. 101, 2017, pp. 360-380, DOI: 10.1016/j.compositesa.2017.07.002
16. Tiuc A., Vermeşan H., Gabor T., Vasile O.: Improved sound absorption properties of polyurethane foam mixed with textile waste, Energy Procedia 85, 2016, pp. 559-565, https://doi.org/10.1016/j.egypro.2015.12.245
17. Maderuelo-Sanz R., Nadal-Gisbert A.V., Crespo-Amorós J. E., Parres-García F.: A novel sound absorber with recycled fibers coming from end of life tires (ELTs), Applied Acoustics 73(4), 2012, pp. 402-408, https://doi.org/10.1016/j.apacoust.2011.12.001
18. Memon H., Wang N, Zhu C.: Study on sound insulation properties of different coated woven fabrics, Journal of Fiber Bioengineering and Informatics 8(4), 2015, pp. 645-656, DOI: 10.3993/jfbim00170
19. Barburski M, Blaszczak J.R., Pawliczak Z.: Influence of designs of weaves on acoustic attenuation of fabrics, Journal of Industrial Textiles, 2018, DOI: 10.1177/1528083718769945

20. German J.: Introduction of basic information about materials, Kraków 2005, passim
21. Oczoś K.E.: Fiber composites - properties, application, machining; Mechanic - Monthly of Scientific and technical 7, 2008, pp. 1-9
22. Wang Wei, Huang Gu: Characterisation and utilization of natural coconut fibers composites, Materials and Design 30(7), 2009, pp. 2741-2744, https://doi.org/10.1016/j.matdes.2008.11.002
23. Boisse P., Buet K., Gasser A. Launay J.: Meso/macro-mechanical behaviour of textile reinforcements for thin composites, Composites Science and Technology 61(3), 2001, pp. 395-401, https://doi.org/10.1016/S0266-3538(00)00096-8
24. Vanleeuw B, Carvelli V, Lomov S.V, Barburski M, Vuure A.W.: Deformability of a flax reinforcement for composite materials, Key Engineering Materials 611-612, 2014, pp. 257-264; Trans Tech Publications, Switzerland, https://doi.org/10.4028/www.scientific.net/KEM.611-612.257
25. Vanleeuw B., Carvelli V., Barburski M., Lomov S.V., Aart W. van Vuure: Quasi-unidirectional flax composite reinforcement: deformability and complex shape forming, Composites Science and Technology 110, 2015, s. 76-86, http://dx.doi.org/10.1016/j.compscitech.2015.01.024
26. Balcerzak M., Frontczak-Wasiak I., Snycerski M.: Four-axis fabric without clearances, The patent application P-392601 from 07.10.2010; Owner: Technical University of Lodz 07.10.2010
27. Snycerski M., Cybulska M, Frontczak-Wasiak I., Suszek H.: Patent PL Six axis fabric (in print), the application P-383907 from 07.08.2007; Owner: Technical University of Lodz
28. Frontczak-Wasiak I., Snycerski M., Stempień Z., Suszek H.: Patent No. 209689, Method and device for evaluating the isotropy of the mechanical properties of flat textile Owner: Technical University of Lodz
29. Frontczak-Wasiak I, Snycerski M.: Characteristics of multi-axial woven structures, Fibres & Textiles in Eastern Europe 13(4), 2005, pp. 27-33
30. Cybulska M., Frontczak-Wasiak I.: Modeling and properties of multiaxial woven structures, 2nd Autex Conference, Ghent, Belgium, 2002
31. Dow N.F., Tranfield G.: Preliminary investigations of feasibility of weaving triaxial fabrics (doweave), Textile Research Journal 40(11), 1970, pp. 986-998, https://doi.org/10.1177/004051757004001106
32. Schwartz P., Fornes R., Mohamed M.: An analysis of the mechanical behavior of triaxial fabrics and the equivalency of conventional fabrics, Textile Research Journal 52(6), 1982, pp. 388-394, https://doi.org/10.1177/004051758205200606
33. Schwartz P., Fornes R.E., Mohamed M.H.: Tensile properties of triaxially woven fabrics under biaxial loading, Journal of Engineering for Industry 102(4), 1980, pp. 327-332
34. Boisse P. Zouari B, Daniel J.L.: Importance of in-plane shear rigidity in finite element analyses of woven fabric composite performing, Composites Part A 37(12), 2006, pp. 2201-2212, DOI: 10.1016/j.compositesa.2005.09.018
35. Xue P. Cao J. Chen J.: Integrated micro/macro-mechanical model of woven fabric composites under large deformation, Composite Structures 70(1), 2005, pp. 69-80, https://doi.org/10.1016/j.compstruct.2004.08.013
36. Araujo M., Lima M. Costa N.: New weaving concept for multiaxial fabric, TECNITEX 2001, Technical Textilies: “Designing Textiles for Technical Applications”, 1st Autex Conference, Minho, Portugal, 2001
37. Iliej M, Jais T., Czu W.: Termouprugij analiz triechaprwlennych tkanych kompozitow Tkanye konstrukcionnyje kompozity Izdatielstwo „MIR” 1991 g s.302-314, red. Czu T.W, Ko F.
38. Skelton J.: Triaxially Woven Fabrics: their structure and properties, Textile Research Journal 41(8), 1971, pp. 637-647, https://doi.org/10.1177/004051757104100801
39. Trost W.C., Le tissage triaxial: la machine TW 2000, Industrie Textile 1068, 1977, pp. 339-343; Chemiefasern/Textil-Industrie 5, 1977, pp. 444-446
40. Shigenobu I.: Multiaxial fabric with triaxial and quartaxial portions, pat. No 5,472,020, Dec. 5, 1995