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Content

Obsah

REOLOGICKÉ CHOVANIE SA POLYETYLÉNTEREFTALÁTOVÝCH KONCENTRÁTOV PRIPRAVENÝCH Z REGRANULÁTOV

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Abstrakt: *Polyetyléntereftalát (PET) je syntetický polymér, ktorého aplikačné využitie je veľmi široké. Využíva sa v obalovom priemysle, najmä ako PET fľaše, vláknarskom priemysle a pod.. Pri dennom a jednorazovom využití PET fliaš dochádza k enormnému nárastu jeho odpadu, ktorého množstvo je potrebné znižovať recykláciou. Recyklačné stupne spracovania PET odpadu ovplyvňujú výrazne aj molekulovú a nadmolekulovú štruktúru takto získavaného materiálu a tým aj reologické a mechanické vlastnosti recyklovaného PET v porovnaní s pôvodným polymérom. Zároveň sú do PET zanesené rôzne aditíva a prísady súvisiace s predchádzajúcou aplikáciou PET materiálov. Predkladaná práca sa zaoberá sledovaním a hodnotením reologického chovania sa pôvodného PET a regranulovaných PET s rôznou viskozitou a limitným viskozitným číslom. Boli namerané reologické vlastnosti – tokové krivky pre PET, regranulované PET a PET koncentráty so sadzami resp. TiO_2. Bolo zistené, že reologické chovanie sa PET koncentrátov so sadzami odráža reologické chovanie sa regranulovaných PET, z ktorých boli vyrobené. Na druhej strane, reologické chovanie sa PET koncentrátov s TiO_2 sa líši od reologického chovania sa regranulovaných PET.*
Kľúčové slová: *polyetyléntereftalát, regranulovaný polyetyléntereftalát, polyetyléntereftalátové koncentráty, reologické vlastnosti, tokové krivky.*

1 ÚVOD

Polyetyléntereftalát (PET) je jedným z hlavných predstaviteľov syntetických polymérov využívaných v rôznych oblastiach priemyslu a spotreby. K najväčším spotrebiteľom PET patria výrobcovia PET fliaš ako dodávatelia obalového materiálu pre výrobcov nealkoholických i alkoholických nápojov. Keďže PET fľaša je obalový materiál pre produkt dennej spotreby, s nárastom výroby PET fliaš rastie i množstvo odpadu po použití nápojov plnených v týchto fľašiach. Zvýšené množstvo odpadu PET fliaš je neekologickým zásahom do prírody pri ich skladovaní na skládkach z dôvodu ich dlhej doby degradácie. Zároveň takéto jednorazové použitie má negatívny ekonomický efekt súvisiaci s neefektívnym využívaním fosílnych zdrojov. Preto sa už niekoľko rokov pracuje na možnosti recyklácie PET odpadu, najmä PET fliaš. Produkty z recyklácie sa následne využívajú znova v obalovom priemysle vo forme fólií alebo PET fliaš, vo forme vlákien, prípadne recyklovaný PET s nižšou kvalitou sa využíva pri výrobe záhradného nábytku [1, 2, 3].

Využívanie recyklovaného PET je najlepšou cestou ekonomicky redukovať PET odpad. Avšak, popri stabilnej cene pôvodného PET, nové a drahé technológie umožňujúce recyklovanie PET odpadu zvyšujú jeho cenu pridanou hodnotou z procesu recyklovania v porovnaní s pôvodným PET. Recyklácia okrem ceny ovplyvňuje výrazne aj molekulovú a nadmolekulovú štruktúru a tým aj reologické a mechanické vlastnosti PET v porovnaní s pôvodným polymérom a zároveň sú do PET zanesené rôzne aditíva a prísady súvisiace s predchádzajúcou aplikáciou PET materiálov [4]. Preto ďalšie spracovanie a využitie recyklovaného PET je obmedzené a nesmie zhoršovať kvalitu spracovania ako i vlastnosti vyrobených materiálov v porovnaní s pôvodným nerecyklovaným PET.

Predkladaná práca sa zaoberá hodnotením reologického chovania sa pôvodného PET, regranulovaných PET s rôznou viskozitou a limitným viskozitným číslom a PET koncentrátov pripravených z regranulovaných PET. Boli namerané reologické vlastnosti – tokové krivky pre PET, regranulované PET a PET koncentráty so sadzami resp. TiO_2.

2 EXPERIMENTÁLNA ČASŤ

2.1 Použitý materiál

V práci boli na hodnotenie reologických vlastností použité tieto materiály:

- pôvodný polyetyléntereftalát (potravinársky pPET, NEOPET 80, intrisic viscosity = 0,8 dl/g, fa UAB „Neo Group“, Litva),
- vzorky regranulovaného polyetylénteraftalátu z odpadových fliaš (rPET)
- pripravené biele (EBC0, EBC7-11) a
- čierne (EBC1-6) polyetyléntereftalátové koncentráty rôzneho pôvodu (EBCx), ktoré sú zosumarizované v Tab. 1.

Regranulované PET (rPET) boli pripravené regranuláciou odpadu z PET fliaš a dofarbené daným farebným pigmentom bez presného zloženia. Koncentráty EBC2-11 boli pripravené z rPET2-5 a sadzí (30%) resp. TiO_2 (50%) bez presnejšieho obsahu jednotlivých zložiek rPET. EBC0 koncentrát pripravený z pPET a 50% TiO_2 bol použitý ako štandard pre biele koncentráty a EBC1 pripravený z pPET a 30% sadzí bol použitý ako štandard pre čierne koncentráty.

2.2 Použité metódy

Reologické vlastnosti sledovaných vzoriek boli merané na kapilárnom reoviskozimetri Göttfert na základe merania prietokovej resp. výtokovej objemovej rýchlosti a tlakového spádu pozdĺž kapiláry s priemerom 1 mm pri teplote T=280°C.

Šmyková rýchlosť bola určená na základe nameraného množstva taveniny pretečeného kapilárou (Q) s definovaným priemerom (R) a dĺžkou (L) za definovaný čas podľa vzťahov [5]:

$$\dot{\gamma} = -\frac{4.Q}{\pi.R^3} \quad (1)$$

$$Q = \frac{\pi.R^3}{\mu}.\frac{1}{m+3}\left(\frac{R.\Delta P}{2.\tau_0 L}\right)^m \quad (2)$$

kde $\dot{\gamma}$ - šmyková rýchlosť, μ - viskozita, τ_0 - referenčné šmykové napätie, m - koeficient odklonu od Newtonského toku kvapaliny (m=1/n), ΔP - tlakový spád v kapiláre a L - dĺžka.

Šmykové napätie τ sa stanoví zo vzťahu (2):

$$\tau = \frac{R.\Delta P}{2.L} \quad (3)$$

Na základe získaných hodnôt boli pomocou softvéru vyhodnotené tokové krivky a exponent n z Ostwald de Waele zákona, ktorý charakterizuje odchýlku od Newtonského toku:

$$\tau = K \cdot \dot{\gamma}^n \quad (4)$$

kde η - viskozita, $\dot{\gamma}$ - šmyková rýchlosť, τ - šmykové napätie, n - exponent, K - koeficient.

Pred meraním boli vzorky sušené pri teplote 160°C počas 4 hod.

Pri meraní reologických vlastností reálnych polymérnych tavenín dochádza k odchýlke od ideálnych podmienok pre ktoré boli predchádzajúce vzťahy odvodené. Je preto potrebné pre stanovenie skutočných hodnôt šmykovej rýchlosti a šmykového napätia tieto odchýlky zohľadňovať pomocou korekcií [5]. Namerané zdanlivé tokové krivky (označované ako bez korekcie) boli korigované na skutočné tokové krivky (označované ako po korekcii) pomocou Rabinowitschovej korekcie zohľadňujúcej nenewtonský charakter toku taveniny pri stene kapiláry. Pri tejto korekcii sa vzťah na výpočet šmykovej rýchlosti transformuje na rovnicu (5):

$$\dot{\gamma} = -\frac{3n+1}{4n}.\frac{4.Q}{\pi.R^3} \quad (5)$$

Index toku (MFR) taveniny udáva množstvo pretečenej taveniny v gramoch cez trysku vytlačovacieho plastomera za čas 10 min pri pôsobení zaťaženia o danej hmotnosti a pri danej teplote podľa druhu koncentrátu (STN ISO 1133, UN0709 - vnútorný predpis). Valec plastomera sa vyhreje na požadovanú teplotu a naplní sa polymérom resp. koncentrátom. Nechá sa 5 min taviť a následne sa zaťaží závažím predpísanej hmotnosti. Objemový prietok taveniny sa meria na základe meraného času a hmotnosti vytečenej taveniny medzi referenčnými bodmi piesta. Po ochladení sa odváži hmotnosť odrezkov. Prepočíta sa index toku taveniny (MFR - g/10 min) podľa rovnice: (6):

$$MFR_{(T,m_{nom})} = \frac{t_{ref}.m}{t} \tag{6}$$

kde T - teplota (°C), pri ktorej bol index toku meraný, m_{nom} - použité zaťaženie (2,16 kg), m - hmotnosť odrezkov v g, t_{ref} - referenčný čas (10 min), t - interval odrezávania (s).

Limitné viskozitné číslo (LVČ) bolo stanovené na základe merania viskozity PET materiálov v Ubbelohdeho viskozimetri (STN ISO 5351, int. metodika UN 0409). Pripraví sa 1 % roztok PET v rozpúšťadle a meria sa čas prechodu rozpúšťadla (t_0) resp. roztoku PET (t) kalibrovaným priestorom viskozimetra. Pre stanovenie chyby merania sa robia dve paralelky minimálne s 5 meraniami času. Limitné viskozitné číslo sa vypočíta podľa vzťahu:

$$[\eta] = \frac{\sqrt{\eta_{rel}} - 1}{2.k_H.c} \tag{7}$$

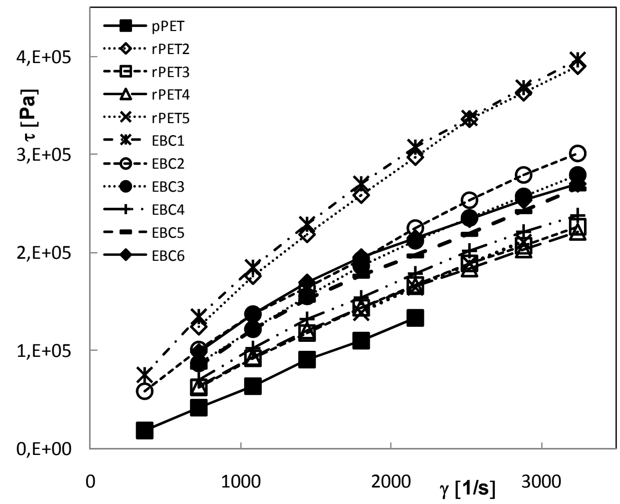
kde k_H - Hugginsova konštanta pre uvažovaný prípad (0,25), c - koncentrácia a η_{rel} - relatívna viskozita vypočítaná zo vzťahu (8):

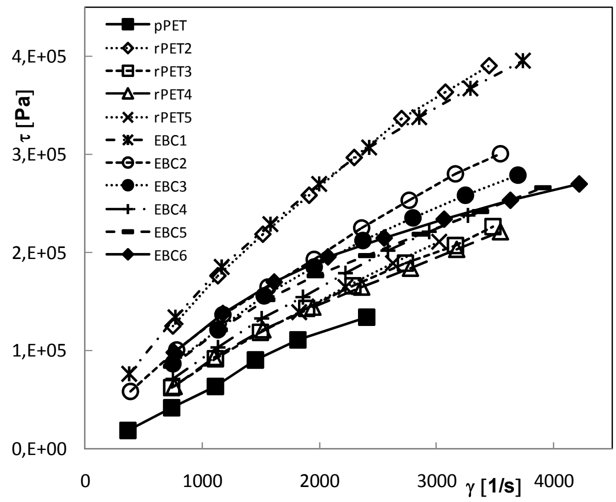
$$\eta_{rel} = \frac{t}{t_0} \tag{8}$$

3 VÝSLEDKY A DISKUSIA

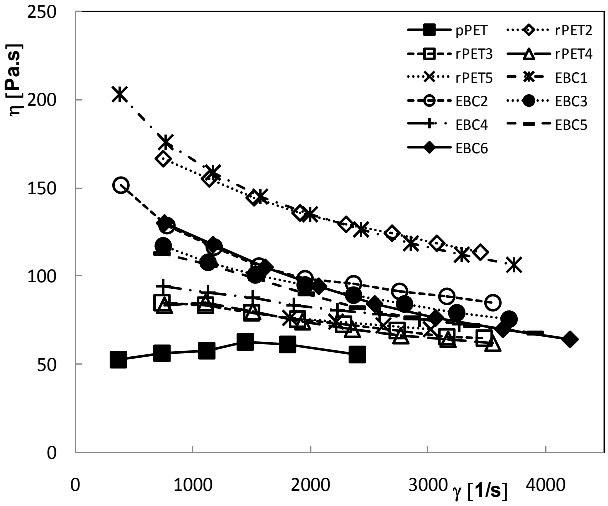
Namerané výsledky – závislosť šmykového napätia bez a po korekcii a viskozity od šmykovej rýchlosti pre sledované vzorky sú na Obr. 1-4.

Z nameraných výsledkov závislostí šmykového napätia bez a po korekcii (Obr. 1, 2) od šmykovej rýchlosti pre pPET, rPET a čierne PET koncentráty (EBC1-6) je možné konštatovať, že všetky pripravené čierne PET koncentráty (EBC2-6) i regranulované rPET použité na prípravu koncentrátov sa odlišujú od pôvodného pPET i od štandardného čierneho PET koncentrátu (EBC1). Rovnaký charakter závislosti bol získaný tak pre hodnotenie bez ako i po Rabinowitschovej korekcii zohľadňujúcej nenewtonský charakter toku taveniny pri stene kapiláry.





Obr. 1 Závislosť šmykového napätia od šmykovej rýchlosti bez (a) a po (b) korekcii pre pPET, rPET a čierne PET koncentráty EBC1-6 pri teplote 280°C



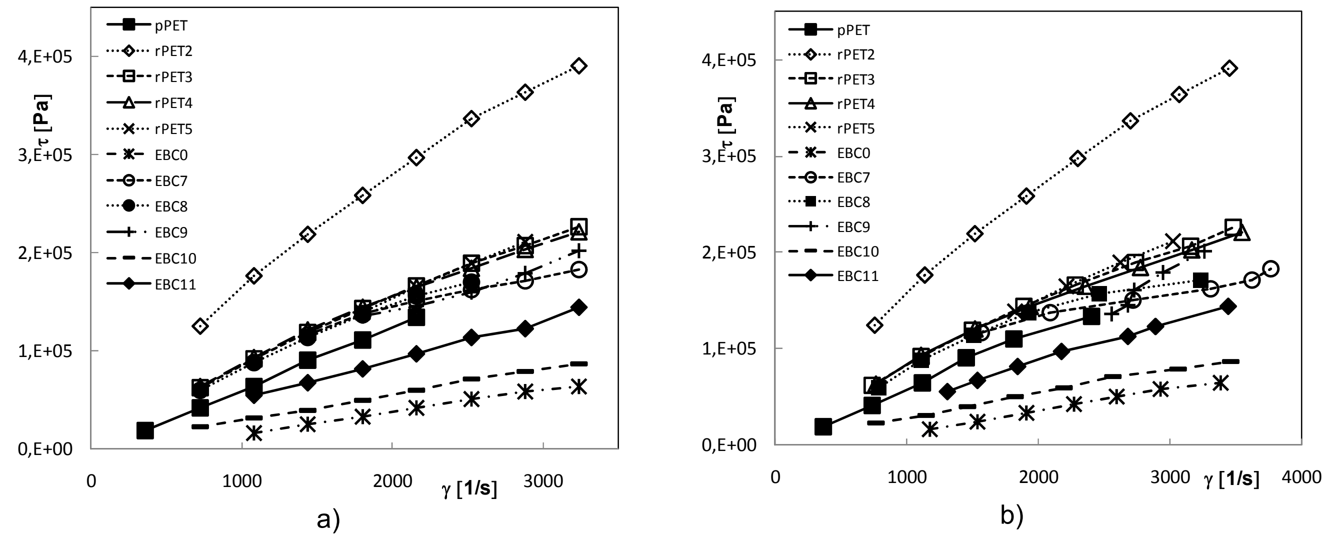
Obr. 2 Závislosť viskozity od šmykovej rýchlosti po korekcii po korekcii pre pPET, rPET a čierne PET koncentráty EBC1-6 pri teplote 280°C

Oblasť reologického chovania sa sledovaných vzoriek je ohraničená závislosťou odpovedajúcou čiernemu PET koncentrátu (EBC1) ako štandardu pripraveného z pôvodného pPET a 30 % sadzí. Spodnú hranicu vymedzuje závislosť šmykového napätia od šmykovej rýchlosti odpovedajúca pPET. Reologické chovanie sa regranulovaných rPET použitých na prípravu čiernych PET koncentrátov je možné tiež rozdeliť do dvoch skupín. Vzorka rPET2 má reologické chovanie sa zhodné s čiernym štandardným PET koncentrátom (EBC1) s pomerne nízkou hodnotou exponentu mocninového zákona (n=0,75) čiže veľkým odklonom od Newtonského toku kvapaliny. Reologické chovanie sa ďalších troch rPET3-5sa približuje chovaniu sa čistého PET, ktorých odklon od Newtonského toku je významne nižší (n=0,82-0,89).

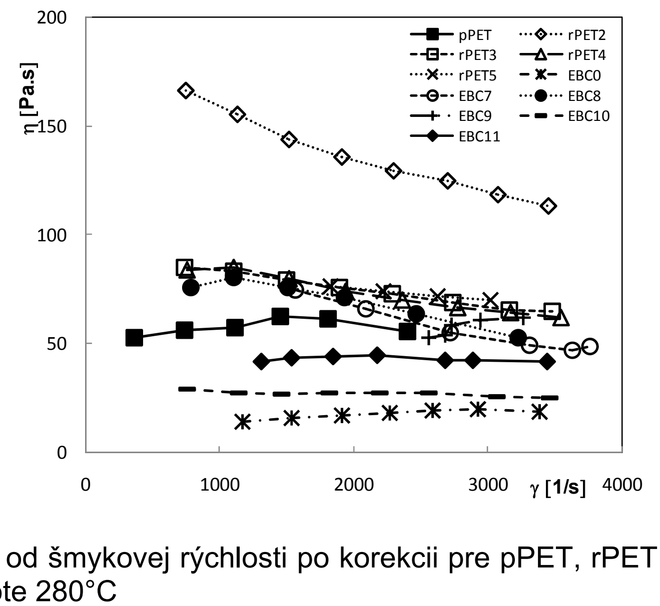
Tab. 1 Charakteristika polyetyléntereftalátu (pPET), polyetyléntereftalátových regranulátov (rPET) a polyetyléntereftalátových koncentrátov (EBCx)

Vzorka	Polymér	Farba	C_{ad}, %	IT, g/10 min	LVČ, ml/g	n
1	pPET	-	-	56	80	1,08
2	rPET2	červený	-	40	82	0,76
3	rPET3	natur	-	88	73	0,85
4	rPET4	biely	-	86	61	0,82
5	rPET5	hnedý	-	90	66	0,89
6	EBC1	čierny	30% sadzí štandard	0,5	48	0,75
7	EBC2		30% sadzí	1,8	47	0,75
8	EBC3			1,4	56	0,78
9	EBC4			2,3	50	0,80
10	EBC5			2,6	47	0,75
11	EBC6			1,0	55	0,66
12	EBC0	biely	50% TiO_2 štandard	97	56	1,25
13	EBC7		50% TiO_2	96	51	0,54
14	EBC8			82	64	0,85
15	EBC9			63	58,5	0,68
16	EBC10			127	59	0,93
17	EBC11			89	51	0,87

Ak z rPET s rozdielnym reologickým chovaním sa zmesovaním pripravia čierne PET koncentráty (EBC2-EBC6), tak na základe teórie pri príprave zmesí, ktorá hovorí o aditívnom prínose vlastností jednotlivých zložiek k reologickým vlastnostiam pripravovaných zmesí, by závislosti šmykového napätia od šmykovej rýchlosti bez i po korekcii mali byť medzi závislosťami odpovedajúcimi rPET2 a rPET3-5. Namerané výsledky tieto predpoklady potvrdili. Pripravené čierne PET koncentráty na základe nameraných závislosti je možné rozdeliť do dvoch skupín – koncentráty EBC2,3,5 a 6 a koncentrát EBC4. Kým závislosti pre EBC2,3,5 a 6 sa viac približujú k závislostiam štandardného PET koncentrátu EBC1 a regranulovaného rPET2, tak koncentrát EBC4 a približuje viac k závislosti pPET. Rovnaké rozdelenie bolo dosiahnuté aj pre závislosti šmykového napätia od šmykovej rýchlosti získané po aplikácii Rabinowitschovej korekcie.



Obr. 3 Závislosť šmykového napätia od šmykovej rýchlosti bez (a) a po (b) korekcii pre pPET, rPET a biele PET koncentráty EBC0 a EBC7-11 pri teplote 280°C



Obr. 4 Závislosť viskozity od šmykovej rýchlosti po korekcii pre pPET, rPET a čierne PET koncentráty EBC0 a EBC7-11 pri teplote 280°C

Reologické chovanie sa PET koncentrátov s TiO_2 (EBC7-11) nezodpovedá aditívnosti reologického chovania sa regranulovaných rPET použitých na ich prípravu (Obr. 3, 4). Závislosti pripravených PET koncentrátov s TiO_2 sú medzi závislosťami použitých regranulovaných rPET a závislosťou pre štandardný PET koncentrát (EBC0). Závislosti PET koncentrátov EBC7-11 sa približujú závislostiam použitých regranulovaných rPET. Závislosti PET koncentrátov EBC10-11 s 50% TiO_2 sa svojím chovaním viac podobajú závislosti štandardného PET koncentrátu (EBC0). Tomu odpovedajú aj získané hodnoty exponenta mocninového zákona, čiže odchýlky od Newtonského toku n vzoriek EBC10-11, ktoré sa približujú hodnote exponenta - odchýlky od Newtonského toku štandardného PET koncentrátu (EBC0, Tab. 1). Tu však treba povedať, že z nameraných výsledkov tokových kriviek bola hodnota exponenta, čiže odchýlky od Newtonského toku, získaná pre štandardný PET koncentrát (EBC0) vyššia ako 1, čo už odpovedá dilatantným kvapalinám.

Reologické chovanie sa všetkých desiatich pripravených PET koncentrátov (EBC2-6 a EBC7-11) do určitej miery vyplýva z reologického chovania sa použitých regranulovaných rPET2-5 na ich prípravu. Teória pri príprave zmesí hovorí o aditívnom prínose vlastností jednotlivých zložiek k reologickým vlastnostiam pripravovaných zmesí. V tomto prípade boli biele i čierne PET koncentráty pripravené zmesovaním regranulovaných PET (rPET3-5) s vyšším IT resp. nižšou odchýlkou od Newtonského toku s regranulovaným rPET2 s nižším IT resp. vyššou odchýlkou od Newtonského toku tak, aby bol pripravený PET koncentrát s požadovanou hodnotou IT. Tým sa pri ich príprave malo zabezpečiť aj ich reologické chovanie porovnateľné so štandardným PET koncentrátom (EBC0 resp. EBC1) pripravených z pPET. Zmenou technologických podmienok a rôzneho dávkovania rPET2-5 pri príprave koncentrátov boli dosiahnuté požadované vlastnosti koncentrátov.

4 ZÁVER

- Závislosť šmykového napätia od šmykovej rýchlosti rastie v sledovanom intervale šmykových rýchlostí pre všetky sledované vzorky (pPET, rPET, EBCx).
- Viskozita čiernych PET (EBC2-6) koncentrátov so zvyšovaním šmykovej rýchlosti klesá v celom sledovanom intervale šmykových rýchlostí.
- Závislosti viskozity od šmykovej rýchlosti pre taveniny čiernych PET (EBC2-6) koncentrátov sú medzi závislosťami viskozity od šmykovej rýchlosti pre taveniny rPET2-5, z ktorých boli pripravené.
- Viskozita PET (EBC7-11) koncentrátov s TiO_2 so zvyšovaním šmykovej rýchlosti v celom sledovanom intervale šmykových rýchlostí sa nemení.
- Závislosti viskozity od šmykovej rýchlosti pre taveniny PET koncentrátov s TiO_2 (EBC7-11) nie sú medzi závislosťami viskozity od šmykovej rýchlosti pre taveniny rPET2-5, z ktorých boli pripravené.

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5 LITERATÚRA

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RHEOLOGICAL PROPERTIES OF POLYETHYLENE TEREPHTHALATE MASTERBATCHES PREPARED FROM REGRANULATES

Translation of the article
Reologické chovanie sa polyetyléntereftalátových koncentrátov pripravených z regranulátov

Polyethylene terephthalate (PET) is a synthetic polymer with the expanded application. It is used in packing industry, mainly PET bottles, and fiber and textile industries. Daily and unrepeated application of PET bottles induces enormous increase of waste material. From the point of the environment improvement there is needed to decrease the waste of material, mainly with recycling. The stages of PET recycling effect molecular and supermolecular structures of this material. Recycling PET has the different rheological and mechanical properties than the original PET as well as various additives and their concentration. This paper deals with the study and evaluation of rheological properties of original PET, recycling PET with the various viscosities and limiting viscous numbers. There were the rheological properties – dependencies viscosity or shear stress on the shear rate for the virgin and recycling PET as well as PET masterbatches with the carbon black or TiO_2. Rheological behaviour of PET masterbatches with carbon black reflects to the rheological behaviour of PET recycling from that they were used. On the other hand the rheological properties of PET masterbatches with TiO_2 do not correspond with the rheological properties of PET recycling from that they were used.

BREAKING CHARACTERISTICS OF WARP KNIT NET FABRIC

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Abstract. *This paper presents results of an investigation of the braking characteristics (maximum load and strain) of warp knitted net fabric with elastomeric yarn longwise inlaying. In order to undertake the study of the influence of fillet interloping repeat and of in-layed yarn positioning different types of net fabric were produced. The array of data for the various design options provide analytical tool for making comparisons about the mechanical properties of the warp knit structures with hexagonal net. It is observed that the repeat of fillet interloping has some effect only on maximum strain of warp knit structure. In other way, the position of in-laying yarn has effect as on maximum strain, as on maximum load of warp knit net fabric. It is a consequence of a different relaxation of elastomeric yarn in the warp knit structure.*
Key words: *Fillet structure, in-laying yarn, maximum load, maximum strain.*

1 INTRODUCTION

The development of the textile industry in the world is going in the direction of use of its products at all fields of technic and medicine. Net production is one of the leading textile manufacturing. The meshes of net structure have different size and shape. The warp knitting with its fillet interlooping is an undisputed leader in technologies that are used for the production of such textile. The major advantages of warp knitting are its versatility and its high production speed.

The holes in fillet knits are usually formed in loop courses with return loops, and for this reason, an incomplete drawing-in of guide bars is necessary to produce the net structures. Symmetrical nets are produced when two identically-threaded guide bars overlap in balanced lapping movements in opposition. The honeycomb is prevalent among the large variety of net shape. The hexagonal cells are produced on warp knit machine by alternating of tricot and chain courses at the repeat (Figure 1). The vertical ribs of cell are formed by tricot loops and diagonal ribs are formed by chain loops [1].

The size and shape of the cell can be changed by the repeat of an interlooping. If the number of tricot courses has been increase, the vertical rib of cell lengthens, so that the cell extends longwise. When chain courses, which extend the diagonal rib, have been used in the repeat, the cell expands [2].

Modifying the cells shape changes significantly the properties of the fabrics. Thus, when an elastomeric yarn has been fed into the knitting zone at the highest possible tension and has been used in the structure as longwise inlayed yarn, vertical ribs of the cell converge after elastomeric yarn relaxation (Figure 2). The result is auxetic material which is expanding under tension [3].

The using sphere of auxetic materials is expanding with each passing year: from medical bandages and filters for blood to the preforms for composites in the automotive and aircraft industry. The main unique property of auxetic material is showing during its stretching. In this regard, the aim of work is to study the breaking characteristics of warp knit net fabric during the elongation in the direction of the elastomeric yarns inlaying.

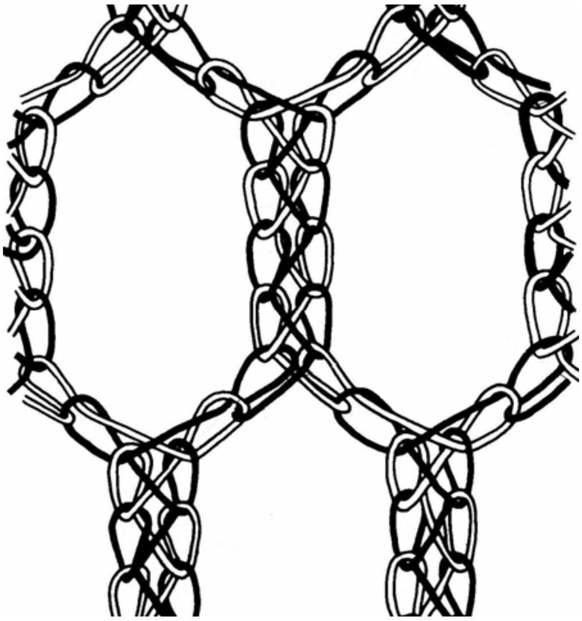

Figure 1 Fillet structure with hexagonal net

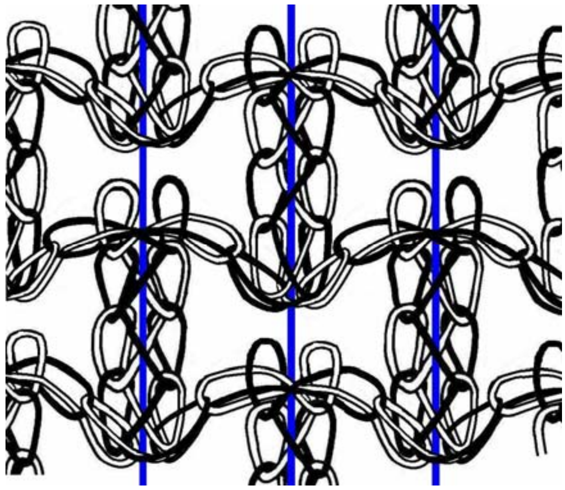

Figure 2 Structure with longwise inlayed elastomeric yarn

2 EXPERIMENTAL SAMPLES

Two-factor experiment according to plan Kono have been planned and implemented in approach to research the breaking characteristics of honeycomb net warp knit fabric. Number of tricot courses n_t (3, 5 and 7) and number of chain courses n_c (0, 1 and 2) in a repeat of fillet interlooping have been selected as an independent factors. In approach to study the effect of the inlay yarn position in the knit structure the eight variants have been selected: the elastomeric yarn is wrapped the junctures of tricot loops of one or two guide bars in one or two courses of repeat or is located between tricot loops without wrapping [4].

The warp knit fabrics were made from 250 denier polyester yarn as ground. The linear density of the polyester yarn is 250 den x 2. It is manufactured by Du Pont and its tenacity is 1.454 gf/den based on a test gauge length of 25.4 cm (10 in), and a crosshead speed of 10.16 cm/min (4 in/min). The 150 denier (96 filaments) polyester sheath serving as the cover yarn for polyurethane core yarn provided a high elastic in-lay component. The yarn is supplied by Unifi Inc. and the linear density of polyurethane core yarn is 70 deniers. Fabrics were made on a 10 gauge warp knitting machine with one needle bed.

3 METHODOLOGY

Experimental studies have been conducted according to GOST 16218.9 on tensile test machine with clamping length 50 ± 1 mm and a constant speed of clamp 150 mm/min. 5 specimens for each fabric variant have been studied, on which base the average value is determined. Coefficient of data's variation does not exceed 5%.

4 RESULTS AND DISCUSSIONS

Research results of breaking characteristics (maximum load and maximum strain) of fillet warp knitted net fabric with elastomeric in-laying yarn are shown in the Table 1.

Table 1 Breaking characteristics of warp knit net fabric

The position of inlayed yarn in fillet warp knit structure		Fabric designation	Maximum load, N	Maximum strain, %
Basic fillet structure		B	L_{max}=157.1±4.8	S_{max}= 75.7-2.9n_t
In-laying yarn turns from the back to the front side	at one course of repeat	T1	L_{max} =125.0±10.3	S_{max} = 181.1+20.0n_c
	at two courses of repeat	T2	L_{max} =110.3±6.8	S_{max} = 145.8+20.4n_c
In-laying yarn is between the tricot's junctures	at one course of repeat	L1	L_{max} =133.9±5.8	S_{max} = 211.5+15.6n_c
	at two courses of repeat	L2	L_{max} =132.4±7.1	S_{max} = 154.8+7.2n_T+14.9n_c
In-laying yarn wraps one tricot's juncture	at one course of repeat	W1-1	L_{max} =135.6±6.8	S_{max} = 235.0+13.2n_c
	at two courses of repeat	W1-2	L_{max} =135.6±7.8	S_{max} = 154.8+15.1n_T+55.0n_c-7.5$n_t n_c$
In-laying yarn wraps two tricot's junctures	at one course of repeat	W2-1	L_{max} =134.0±12.6	S_{max} = 116.8+15.0n_t+58.2n_c-7.4$n_t n_c$
	at two courses of repeat	W2-2	L_{max} =136.4±7.6	S_{max} = 134.9+16.4n_t+18.8n_c

It is observed that the maximum tensile load does not depend on the repeat of fillet interlooping. The introduction of elastomeric yarn into warp knit structure reduces the value by 15 ÷ 25% depending on the variant of the inlaying. This indicates that the tensile load of net fabric is a function of strength of elastomeric yarn.

It should be noted that net fabric, in which an elastomeric yarn turns from the front to the back side (T1, T2), has decreasing of load at break on 8 ÷ 18% as compared with other elastomeric yarn positions. At such variants value decreases with increasing number of inlay transitions from the front to the back side. It can be attributed to the increasing of friction between the ground and the inlaying yarns.

Maximum strain at break of basic fillet fabric with hexagonal cell (B) has back proportion to the number of tricot courses at a repeat of fillet interlooping, which can be explained by the increase of lengths of vertical ribs which orient at the direction of stretching.

The inlaying of elastomeric yarns leads to 2-3 times increase of strain value, which is associated with the properties of the elastomer. The highest value at break has been indicated at warp knit net fabric, in which structure the elastomeric yarn wraps tricot junctures from one guide bar only (W1-1, W1-2). The value decline is at variants of warp knit, in which an elastomeric yarn turns from the front to the back side (T1, T2). This is due to the degree of elastomer's relaxation in fabric's structure primarily.

It is observed, the maximum strain at break is directly proportional to the number of chain courses at the repeat of the fillet interlooping (Figure 3). It is associated with the length of the diagonal ribs of cell and with them re-orientation during pulling. It should be noted effect of the tricot courses at the repeat on the maximum strain at some variants (L2, W1-2, W2-1, W2-2) of net fabric (Figure 4). Tricot loops form vertical ribs of cells and they bend in the structure of these variants of net fabric [5]. Such turn is a consequence of the complete relaxation of the elastomer in knit structure.

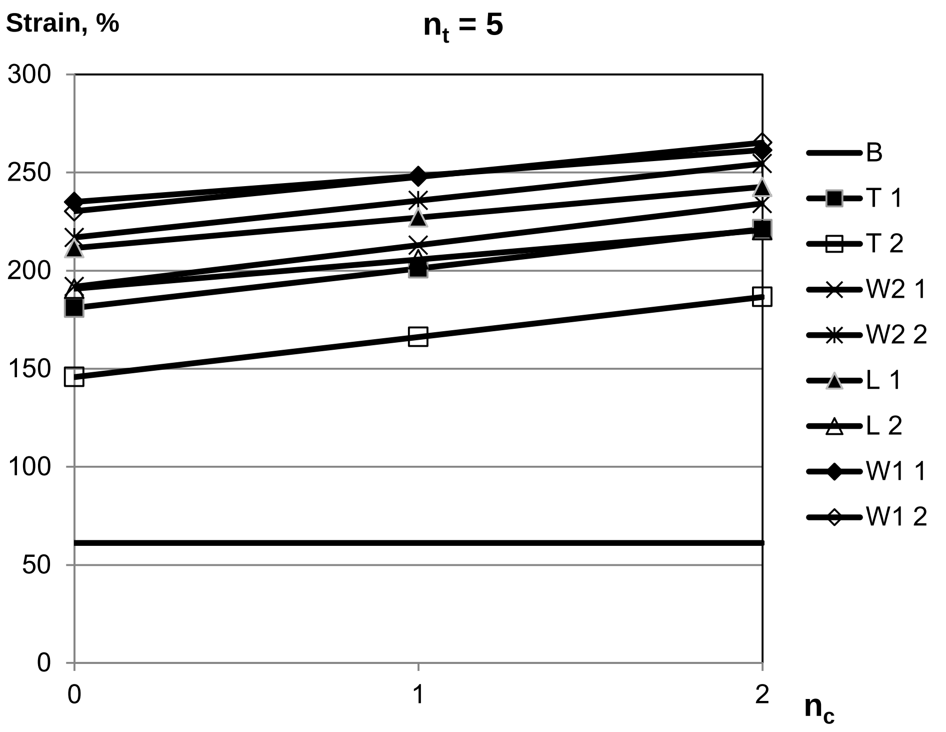

Figure 3 Dependences of maximum strain of warp knit net fabric on number of chain courses at repeat

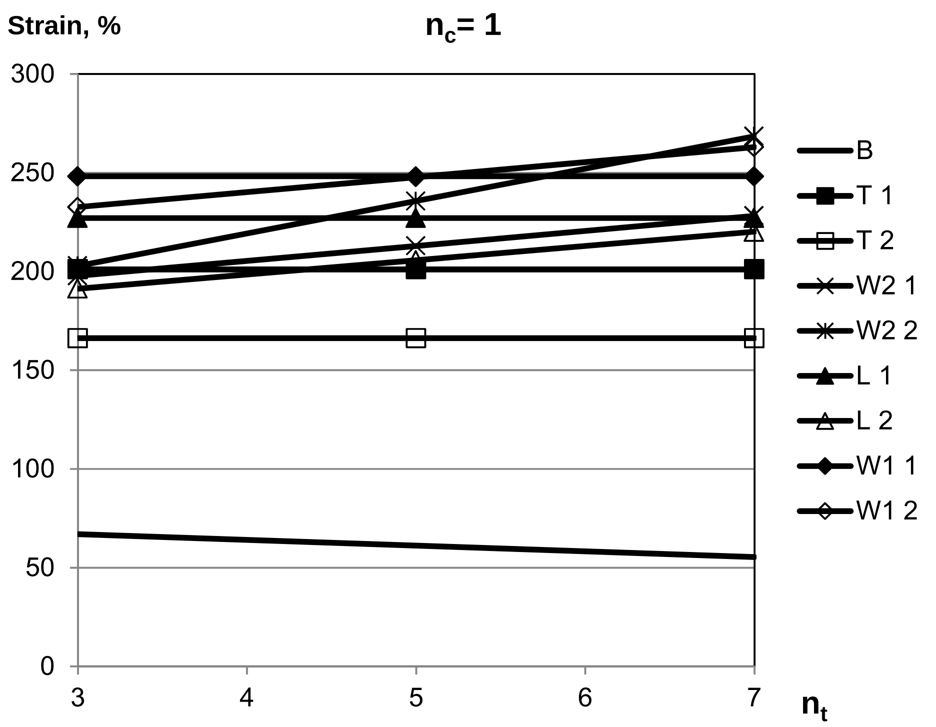

Figure 4 Dependences of maximum strain of warp knit net fabric on number of tricot courses at repeat

5 CONCLUSION

Researches of the break characteristics of warp knit net fabric indicate, that:

- the maximum tensile load does not depend on the repeat of fillet interlooping and it is function of elastomeric yarn, which is use as longwise inlay in warp knit structure;
- the maximum strain depends as on repeat of fillet interlooping as on the degree of elastomer's relaxation in the net fabric's structure.

Thus, the different positions of the inlaid yarn within the structures and the different number of tricot and chain courses on repeat of fillet interloping offer other possibilities that could be explored when designing warp knit net structures.

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PREPARATION OF STARCH OLEATES AND STUDY OF THEIR THERMAL PROPERTIES

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Abstract: *This study deals with the potato starch esterification with oleic acid chloride with weight ratio (1:3) at classical heating. The reaction conditions include utilisation of DMF and pyridine as medium. The temperature was 100°C and reaction time was 1, 3 and 5 h. The degree of substitution (DS) of starch esters with a broad range (0.18 – 2.83) was determined by alcaline saponifications. The derivatives were characterized by FT-IR and TGA. The highest substituted starch oleates showed higher thermal stability in comparison to native starch. Thermal stability of oleates starch increased due to decrease in number of hydroxyl groups.*

1 INTRODUCTION

Starch is an attractive raw material due to its abundant supply, low cost, biodegradability, biocompatibility and easy chemical modification. Starch functionality has been boosted by the ability to modify starch granules chemically, genetically and enzymatically, but the variation in starch properties is also highly dependent on plant genotype and growth environment [1]. The physical and chemical properties are related to the structural and molecular features of the starch granules. The ratio of amylose to amylopectin, length of debranched amylopectin chains, starch granule size distribution, and phosphate content are among others of some parameters known to influence the granule properties. In barley some reports state that the physical properties depend more on variety than on granule size and others can be found in relation between functional properties and granule size distribution due to a difference in amylase content [2]. Potato starch granules show a unimodal size distribution. Several properties are correlated to the granule sizes as e.g. the viscosity [3] and phosphate content with corresponding influence on quality and properties of food products. The starch granules will sediment in water due to their higher density. Native starch is a white powder with bland taste and flavor and it is insoluble in cold water. In general, cereal starches (e.g. corn, wheat, rice) contain relatively high levels of lipids (0.2-0.8%) and protein (0.2-0.5%) resulting in a lower paste transparency and a significant and persistent "raw cereal flavor" of the starch gels. Tuber (e.g. potato) and root (e.g. tapioca) starches have lower levels of lipids (0.1-0.2%) and protein contents (0.1-0.2%). Potato starch is the only native starch containing significant amounts of chemically bound phosphate ester groups (degree of substitution = 0.003 ~ 0.005) located in amylopectin molecules [4].

1.1 Esterification of starches

Indeed, modified starches have been approved for food use where they are used as in which they act as thickeners, gelling agents, as sizing agents in textiles and as adhesives for paper and paper products. In recent years, several authors [5, 6] reported starches with high degrees of substitution, using organic solvents. Reactions with starches, to prepare highly substituted derivatives, are not easy, mainly because of the almonds impossible medium without significant degradation [7]. The introduction of an ester group into polysaccharides constitutes an important synthetic task, as it modifies their original hydrophilic nature and yields enhanced or new thermal and mechanical properties [8]. Long-chain fatty acid esters of starch are intensively studied worldwide. They show a variety of promising properties, e.g. thermoplasticity [9-14]. Moreover various patents confirm their use as binders in coating, adhesive, as thermoplastic, hydrophobic coating material [15] and applications for hot-melt adhesives and in controlled release [16]. Therefore, efficient procedures for preparation are the subject of recent interest. In general, the preparation of long-chain fatty acid ester of starch is carried out by converting the polymer with the acid chloride in N,N-dimethylformamide [16], toluene [17, 15]. In the last decade, the synthesis of fatty acid starch esters has gained considerable interest by many research groups. The products have potential applications not only in the food but also in the non-food industry [7]. Examples of non-food applications are the use as a substitute for oil-based polymers especially in the packaging industry [18-20].

Fatty acid starch esters may be synthesized by reacting starch with carboxylic acids (C4–C16) [7, 22] fatty acid vinyl esters (e.g. vinyl laurate, vinyl stearate) [19, 20, 23], fatty acid chlorides [12-14] or fatty acid methyl esters (e.g. methyl palmitate, methyl laurate) as reactants, and basic salts such as potassium carbonate, sodium acetate, sodium dihydrogen phosphate, and potassium methoxide as catalysts in organic solvents such as pyridine and DMSO. A schematic representation of the esterification reaction of starch with various fatty acid derivatives is given in Figure 1.

2 EXPERIMENTAL PART

2.1 Materials

Potato starch (approximately 22% amylose and 80% amylopectin) was supplied by Spolana Neratovice. The water content was determined by drying the potato starch in a oven at 105°C until its constant weight and was found to be 10.62% (w/w). The oleoyl chloride and pyridine were obtained from Aldrich Chemie (Germany). The ethanol was supplied by the AFT Ltd, (Slovakia).

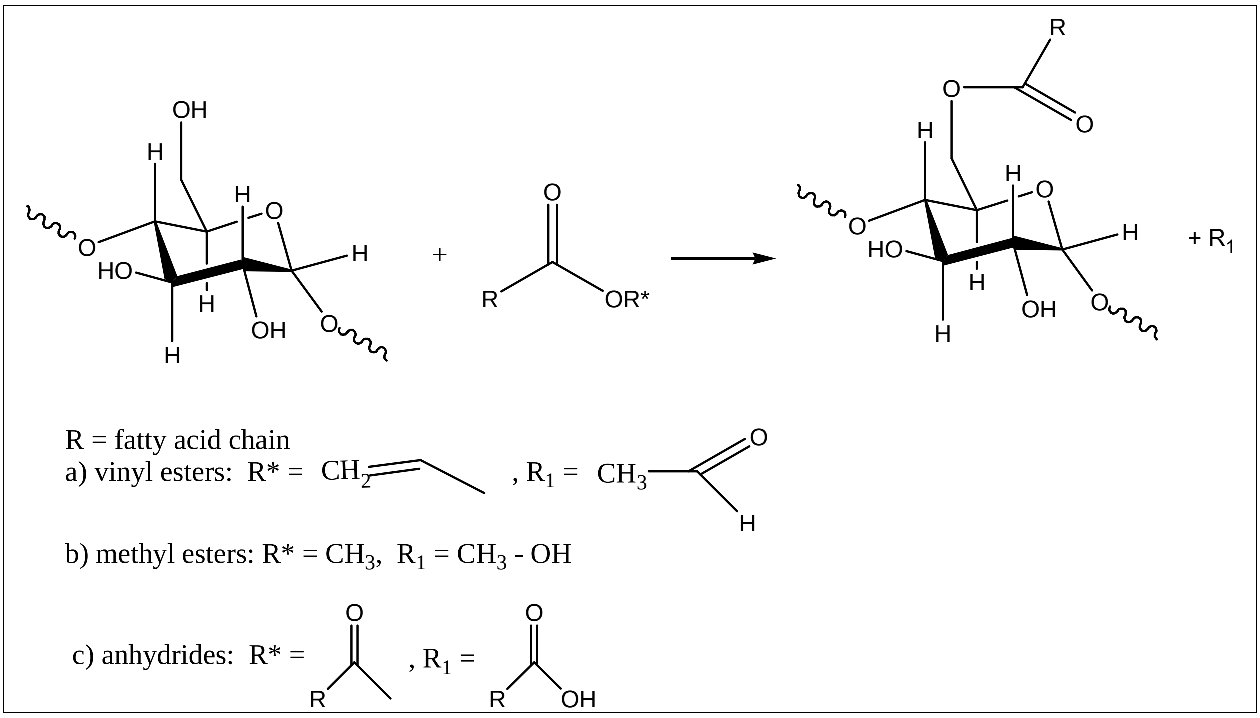

Figure 1 Starch esterification using vinyl esters (a), methyl esters (b), and anhydrides (c) [21]

2.2 Esterification of potato starch

At first 0.5 g of starch was swelled in the boiling flask in 15 ml of DMF 24 h. The given mixture was heated to the 40°C in the oil bath and subsequently 5 ml of pyridine was added at continuous stirring. After the temperature 80°C had been gained, 1.5 g of oleoyl chloride was added and the given mixture was boiled at 100°C during 3 h. After the end of reaction, the product was isolated in to ethanol. Next, product was purified by Soxhlet extraction for 12 h. Finally the pure product was dried and weighted and its DS was determined.

2.3 Determination of the degree of substitution (DS)

DS value was determined titrimetrically according to the method [24] with slight modifications. DS was calculated according to equations (1) and (2).

2.4 Methods

FT-IR spectroscopy

The FT-IR spectra of starch oleates were measured on FTIR NICOLET 5700 in KBr tablets at 4 cm^{-1} resolution and the number of scans was 64 by Company*Thermo Electron Corporation*.

TGA measurements

TGA measurements were performed on a Digitalized Derivatograph-Q 1500-D, under air atmosphere, at a heating rate of 10°C min^{-1} up to 800°C. The mass loss permits to estimate both the starch oleate content and the thermal stability of the esters.

3 RESULTS AND DISCUSSION

Starch oleates (SO) with different degree of substitution have been prepared by esterification of starch with oleoyl chloride [9] in an analogous way to method used for the modification of native starch with oleoyl chloride, in pyridine at constant weight ratio 1:3 and at temperature 100°C and at various reaction time (1 - 5 h). Reaction of esterification of starch oleates is on Figure 2.
Reaction conditions of esterification of starch with oleolyl chloride are in Table 1. The degree of substitution (DS) for starch oleates is defined as the moles of substituents of hydroxyl groups per D-glucopyranosyl structural unit of the starch polymer, with three hydroxyl groups per unit of the theoretical maximum DS where it is 3 for starch [25].

$$\%\text{oleoyl} = \frac{[\text{ml}(\text{blank})] - [\text{ml}(\text{sample})] \times c_{HCl} \times 0.282 \times 100}{\text{sample weight in grams (dry basis)}} \qquad (1)$$

$$DS = \frac{162 \times \%\text{oleoyl}}{100 \times 282 - (281 \times \%\text{oleoyl})} \qquad (2)$$

162 - molecular weight of glucose unit
282 - molecular weight of oleoyl group
281 -molecular weight of oleoyl group-1

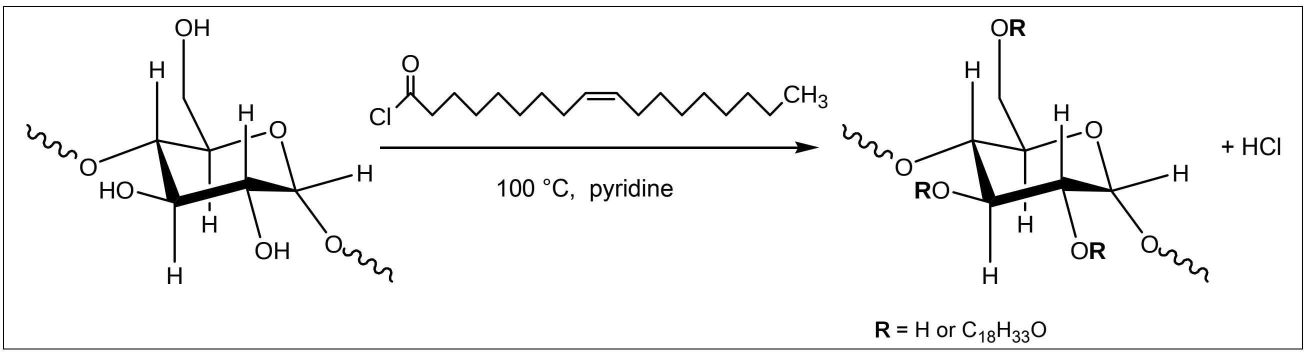

Figure 2 Reaction of preparation of starch oleates

Table 1 Reaction conditions of esterification of starch with oleoyl chloride in pyridine at 100°C and DS of starch oleates

Sample	Reaction time (h)	Weight ratio	Yield (g/g)	DS [a)]
SO1	1	1:3	0.99	0.18
SO2	3	1:3	0.96	0.69
SO3	5	1:3	0.97	2.83

[a)] determined titrimetrically according to the equations described in Experimental Part

Starch oleates SO1, SO2, SO3 are dissolved without heating in pyridine. It is not possible to dissolve the in H_2O, DMF and NaOH (c=0.2 mol.dm^{-3}) and they form suspension. After heating to 60°C they form dispersion in H_2O while this dispersion is identical to starch sebum. Only partial solubility is observed in the DMF and NaOH.

In the FT-IR spectrum of native starch (Figure 3), the characteristic band peak of starch appears at 930 - 1147 cm^{-1} and it is attributed to C–O band stretching [26]. Additional characteristic absorption bands appeared at 993, 870, 780 and 584 cm^{-1} which were due to anhydroglucose ring stretching vibrations. The intense band at ~1639 cm^{-1} is assigned to absorbed water. The region between 1459 cm^{-1} and 1147 cm^{-1} relates to the C–H and C–O bond stretching frequencies. A strong broad band appears at 3278 cm^{-1} due to hydrogen bonded hydroxyls and the symmetric C–H vibration band is observed at 2890 and 2926 cm^{-1} [27].

FT-IR spectra of starch oleates ester groups show characteristic band at~1738 cm^{-1} (Figure 3) where SO1and SO2 are lower than the SO3 through conjugation C=C bonds. The intensity peak at 1738 cm^{-1} increases with increasing DS. Peaks at the value 2922 cm^{-1} and 2851 cm^{-1} are characteristic for CH_2 groups and their intensity increases within creasing DS, as it is confirmed by substitution by oleoyl residue on the chain starch. Esterification may reduce the absorbent band of OH groups at ~3278 cm^{-1} due to the initial starch substitution of OH of initial starch by ester groups. The DS, the intensity is reduced and the maximum shifts to higher wave numbers.

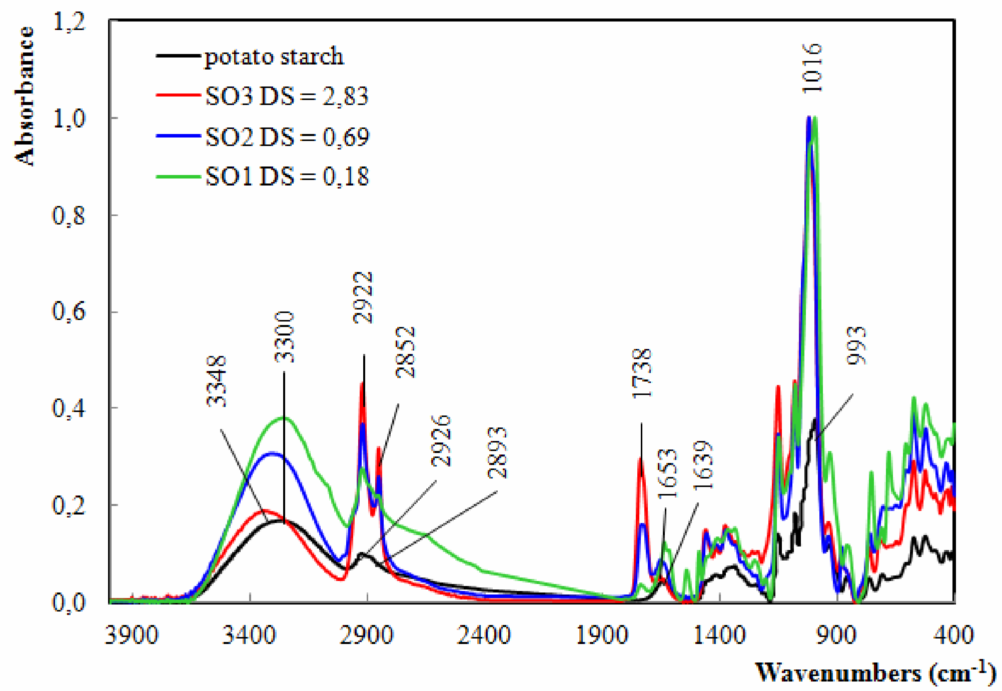

Figure 3 FT-IR spectra of prepared starch oleates compared to native starch

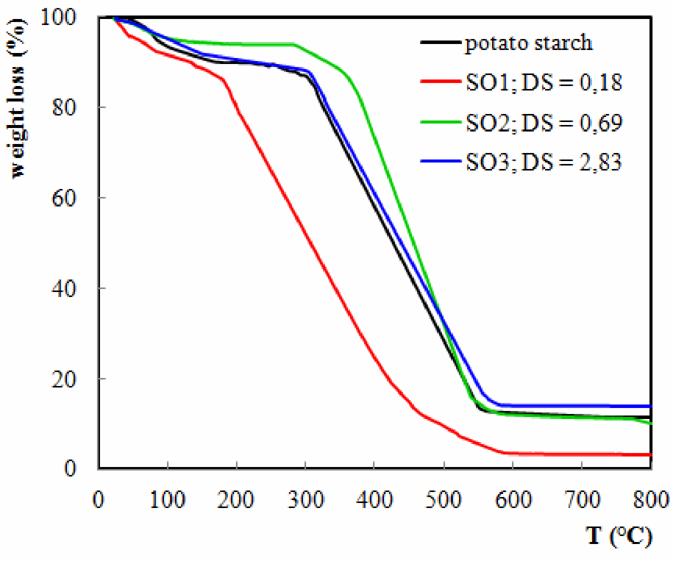

Figure 4 TG curves of native starch and starch oleates with different DS

The FT-IR spectra of prepared starch oleates shows strong bands at 1738 cm^{-1}, 2852 cm^{-1} and 2922 cm^{-1} and it represent stretching deformation of the ester carbonyl group and the methyl/methylene groups, respectively. The strong band at ~3278 cm^{-1} which is attributed to hydroxyl groups of native starch, increases after the esterification reaction owing to ester bond formation. In the spectrum there are new band peaks at ~1540 and 1480 cm^{-1}, which are attributed to C=C band stretching groups of oleate [27].

Table 2 Effect of DS on thermal properties of starch oleates

Derivates	DS	Ton_1 (°C)	Ton_2 (°C)	Weight loss at 550°C (%)
Starch	-	285	530	86
SO1	0.18	205	420	96
SO2	0.69	320	520	86
SO3	2.83	290	560	83

Ton_1 = onset of decomposition, Ton_2 = onset of ended composition

When the starch granules are heated under atmospheric conditions, they are thermally stable up to 200-230°C. Beyond 230-550°C, thermal degradation takes place, depending mainly on the water content of the starch [9]. Results from TG analysis are shown in Figure 4 and Table 2. As observed, native starch has two weight loss stages. The first one 70-150°C is due to desorption of water and the second stage, appearing at higher temperature 205-530°C is due to starch decomposition. The main product of decomposition bellow 300°C was formation of water by intermolecular or intramolecular condensation of starch hydroxyls [28]. The starch oleates show two decomposition stages, too. The first stage of the weight loss 5% at 120-150°C is due to desorption of water. The second stage appeared in range of temperature187-275°C up to 395°C (for two derivates with DS = 0.69 and DS=2.83). The SO3 has three decomposition stages, where the first stage weight loss 5% at 80-120°C is due to desorption of water. The second stage appeared in rage of temperature 205-400°C it is the separation of uncreacted oleoyl residue. The third stage corresponds to the decomposition of starch degradation and within the temperature range 415-570°C. Thus, it was evident from TG data that oleated starch with higher DS (0.69 and 2.83) was thermally more stable than native starch and decomposition temperature increased with the increase in DS.

The process of decomposition of the starch oleates passed off more slowly than it was at native starch because incurred a new structure of prepared starch esters. However, the onset of decomposition (Ton_1) of the starch esters still occurs at lower temperatures while the onset of end decomposition (Ton_2) achieved higher temperatures in comparison to native starch. At ~420°C, the weight loss is 90% for all derivates. From Figure 2, it can be seen, that temperature at 10% weight loss for SO3 was higher than in the case of native starch and the same rule was fulfilled for weight loss at 550°C. The oleated starch samples were thermally more stable than native starch. The increase in thermal stability was due to low amount of remaining hydroxyl groups in starch molecule after modification. The increase in molecular weight and covalent bonding due to the oleation of hydroxyl groups were also responsible for the increased thermal stability. In the earlier study, thermal properties of starch esters showed that the fewer the number of hydroxyl groups remained, the better was the thermal stability of the starch esters [29-31].

4 CONCLUSION

Starch oleates with different DS were prepared by esterification of native starch with oleoyl chloride at classical heating. Changes in physic-chemical properties of starch oleates were observed as compared to native starch. DS of oleated starch varied from 0.18 to 2.83. FT-IR spectroscopy and TG analysis confirmed:

- presence of ester group at 1738 cm^{-1},
- substitution of hydrogen in OH group of starch by oleoyl group,
- the highest substituted starch oleate showed higher thermal stability in comparison to native starch.

Thermal stability of oleates starch increased due to decrease in number of hydroxyl groups.

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PRÍPRAVA OLEÁTOV ŠKROBU A ŠTÚDIUM ICH TERMICKÝCH VLASTNOSTÍ

Translation of the article

Preparation of starch oleates and study of their thermal properties

Štúdia sa zaoberá esterifikáciou zemiakového škrobu s chloridom kyseliny olejovej s hmotnostným pomerom (1:3) v prostredí DMF a pyridínu pri teplote 100°C a čase 1, 3 a 5 h. Stupeň substitúcie (DS) esterov škrobu v rozsahu 0,18 – 2,83 sa stanovil alkalickou saponifikáciou. Deriváty sa charakterizovali FT-IR spektroskopiou a TGA. Vyššie substituované oleáty škrobu boli termicky stabilnejšie ako východiskový škrob.

3D DESIGNING OF THE PRODUCT AND THE EFFECT OF MECHANICAL AND PHYSICAL PROPERTIES ON THE SHAPES OF PATTERNS

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Abstract: *Automatic pattern generation is seen as a major aim of CAD system development. These days it is increasingly popular to design clothing with the aid of 3D software. This thesis introduces the formation of 2D patterns with the aid of 3D software that is able to incorporate the properties of the textile material. Our focus has been a specific object - the head: a complicated shape regarding the formation of a covering surface. The correct design methodology is important for the clothing to fit perfectly.*
A scan of a head was not used as the basic data input into the 3D system. It was created using a 3D model of a head according to the Czech technical standard. A CAD system called, "DesignConcept3D" from Lectra was used for this application. DesignConcept3D offers a method of generating 2D pattern shapes from 3D prototypes. This system presents a new approach for modelling a 3D garment around a 3D featured human model through 2D sketches. The result of this work is the creation of a 3D headform, a design for headgear and patterns obtained by generating the surface.
Key words: *3D design, Flattening process, Mechanical and physical properties, Computer-aided design, Garment industry*

1 INTRODUCTION

Currently, 3D tools are used for garment design to improve the efficiency of pattern generation and to provide more attractive design presentation. The authors of this work [1] deal with a new approach for modelling a 3D garment around a 3D featured human model through 2D sketches. The research concerns an investigation into the wearing strain on knitted clothes and a test of wearing comfort [2].
This article focuses on the creation of a headform in the DesignConcept3D program. The next step is the post-processing of the surface of the head, which is a balaclava in this case. It is customary to use a scan of a human body as input data when the surface of the human body is flattened to a 2D model. The subject of this work is unique in that the input data was not scanned, but the headform was created by 3D design tools. The aim of the experiment was to construct a dummy head in DesignConcept3D by using standard ČSN EN 960 "Headforms for use in the testing of protective helmets". Clearly, the next step is to create a variety of patterns for the balaclava and to analyse the visualization of the compression and tension results [3]. Then, to apply the mechanical properties of the various fabrics and modify the pattern parts based on the strain of the fabric. The results of the experiment are 2D pattern parts of the proposed balaclava models.

2 EXPERIMENT

2.1 Input data and modelling 3D curve network

The ČSN EN 960 standard, "Headforms for use in the testing of protective helmets" was used to design the headform in the DesignConcept3D program. These specifications cover the materials, sizing and manufacturing details for headforms used in the testing of protective headgear.
A full headform was created with size designation 555. This number is the

circumference of a given headform expressed in mm. The headform is a three dimensional approximation of the human head, excluding facial features and ears. The full headform extends down to below the chin and includes part of the neck. In Annex A of this standard, there are tables with values of polar coordinates, which are labelled according to the current nominal head's girth in increments of ten millimetres (505, 515, 525,…). Polar coordinates of the points were derived from regression equation lines. In Annex B, there are equations that specify the radii of the polar coordinates based on the girth of the headform and the angles relative to the x and y planes.

The starting point was the geometric centre point. The point on the central vertical axis, located at its intersection with the reference plane. This point is the origin for all the dimensions given in Annex A [4]. A single line was created by using polar coordinates that are specified in the standard. End points were created at the ends of the line. Boundary curves of the headform were drawn according to these endpoints and so the resulting contours of the headform were formed. A 3D network with smooth column curves was created, as shown in Figure 1.

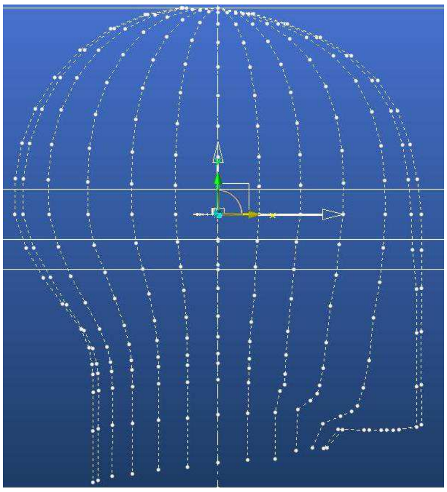

Figure 1 Contour curves of the headform

The B-spline surface was generated based on the 3D curve network. Figure 2 shows the results of surface modelling. It is the surface of headform.

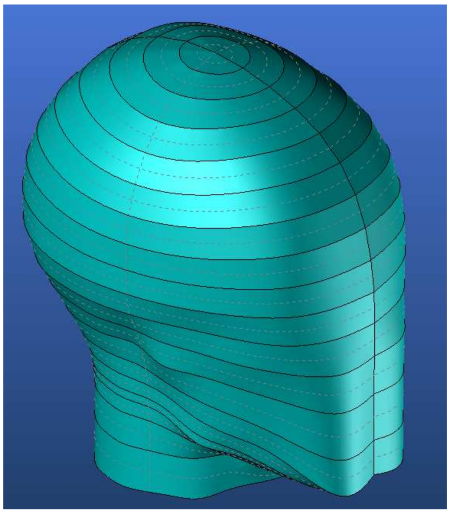

Figure 2 The resulting surface of the headform

2.2 Creation of style curves

Automatic pattern generation is seen as a major aim of development using a 3D CAD system, requiring a method to generate 2D pattern shapes from a 3D prototype. In this case, it was necessary to subdivide the surface on some regions of the headform. Style lines were created according to the imagined future design of the balaclava. By defining style curves on the 3D model, the appearance of the final headform is established. The boundary lines for each single shape are also defined in the process. This work is essential for the subsequent flattening process. Some designs of the balaclava were produced (see Figure 3).

2.3 The flattening of the 3D garment form into a 2D garment pattern

The flattening process to convert a 3D surface into a 2D pattern for apparel was performed using the following method. It was important to create a mesh (triangular grid). The use of triangle meshes has become increasingly important – especially with the rising complexity of 3D models [5]. This network is created using the Finite element method. The body is divided into small parts that are easily described mathematically. The generated geometric body model is continuously divided into elements of finite dimensions.

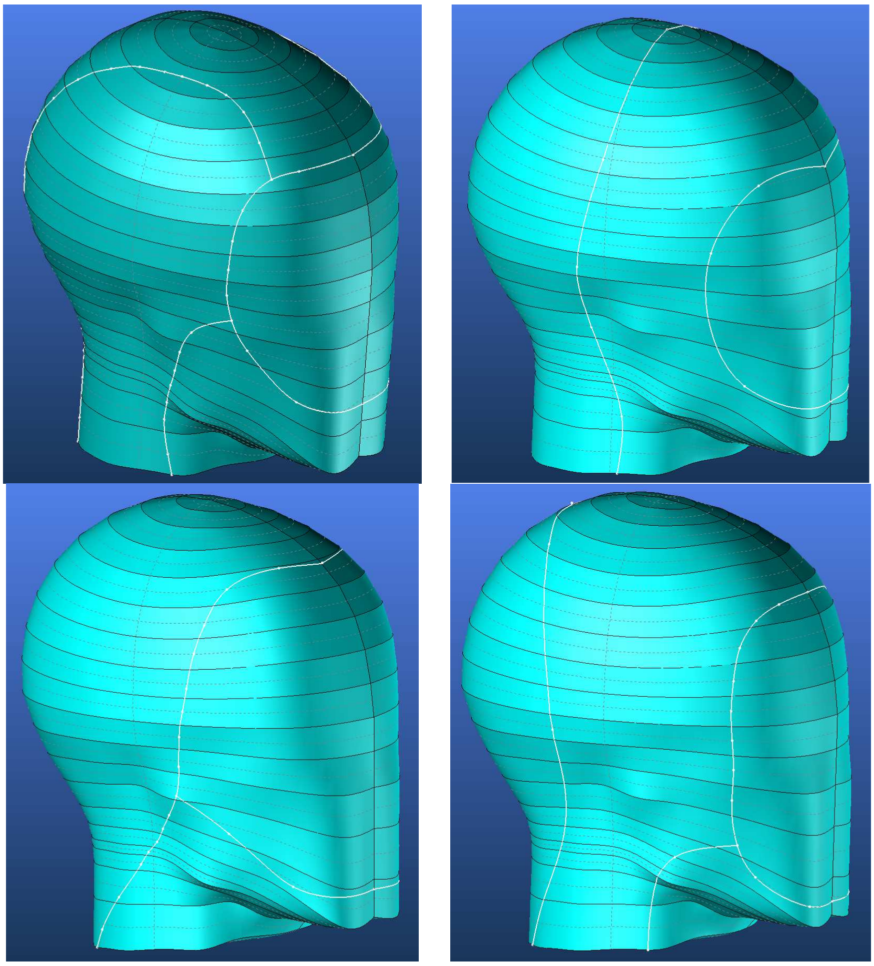

Figure 3 Designs of the balaclava styled in DesignConcept3D

The basic element in the plane is the quadrilateral, in 3D it is six sides, and sometimes it is necessary to use simplified forms of the element (triangle, tetrahedron). The corners of these elements, or some other significant points, are nodal points. Parts of these elements form a network whose density is critical to the accuracy of the results. The next steps of the experiment are shown on a selected balaclava model (Figure 4).

2.4 The analysis of compression and tension

The DesignConcept3D program enables the analysis of the mechanical properties of fabrics. Using this function, it is possible to assess the overall pressure on the model or the pressure in different directions as well as in the direction of the x-axis, y-axis and a diagonal at 45°.

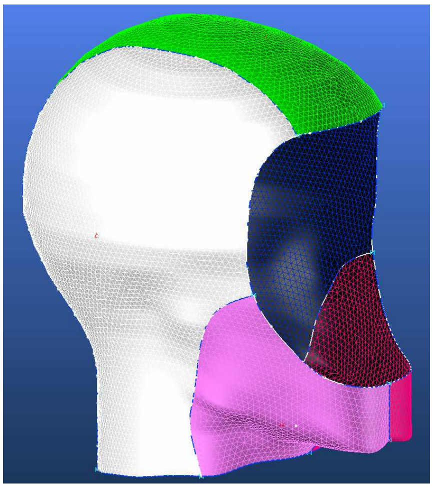

Figure 4 Creating a network to the selected product

The DesignConcept3D software enables the visualization of these models to show the pressure, curvature, strain or tension and the elongation related to the selected material. The program is loaded with data obtained by measuring with the KES-FB1 device (Kawabata´s Evalution System). The mechanical properties of fabrics under tensile and shear stress are very important characteristics. The uniaxial tensile test is popular and the combination of tensile and shear properties are sometimes very useful pieces of information when studying fabrics [6].
A knitted fabric was measured and selected for use with a headform. The mechanical properties measured correspond with the values of the knitted fabric used in the first layer of clothing (Figure 5).
In the experiment, it was necessary to carry out analysis of the pattern for compression in the horizontal and vertical directions (column and row), see Figure 6. In this way it was possible to determine whether there was too much stress or excess compression in some places. This may cause undue stress on the finished product and consequently bad garment fit.
Hence the patterns are optimized based on the visualization of the compression. This was performed using the instruction “Feasibility-post-processing Analysis”, as shown in Figure 7.

The applied stress is adjusted according to the real mechanical properties of the material. The system adapts the 2D pattern automatically. It is necessary to keep the warp and weft direction of the pattern, matching the processing technology of the product. Glombíková [7] deals with the influence of the fabric anisotropy on the drape of textiles and describes the influence of direction on draping. Model adaptation is one solution for areas with high stress. It is possible to insert a dart (a tapered tuck) in the troublesome place.

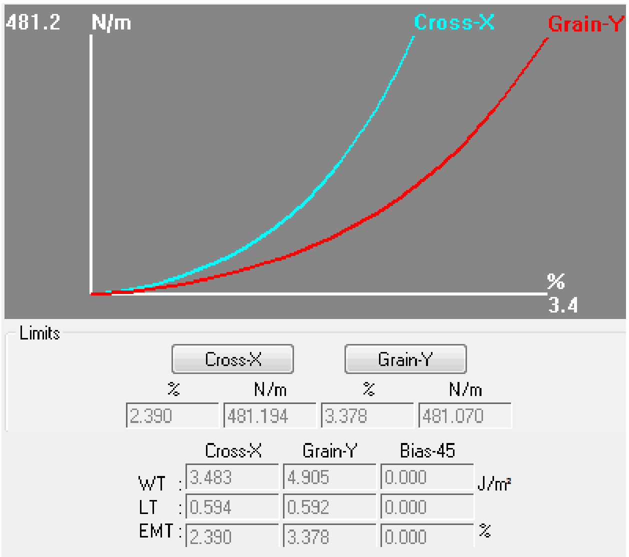

Figure 5 Data about knitted fabric used for first layer of clothing

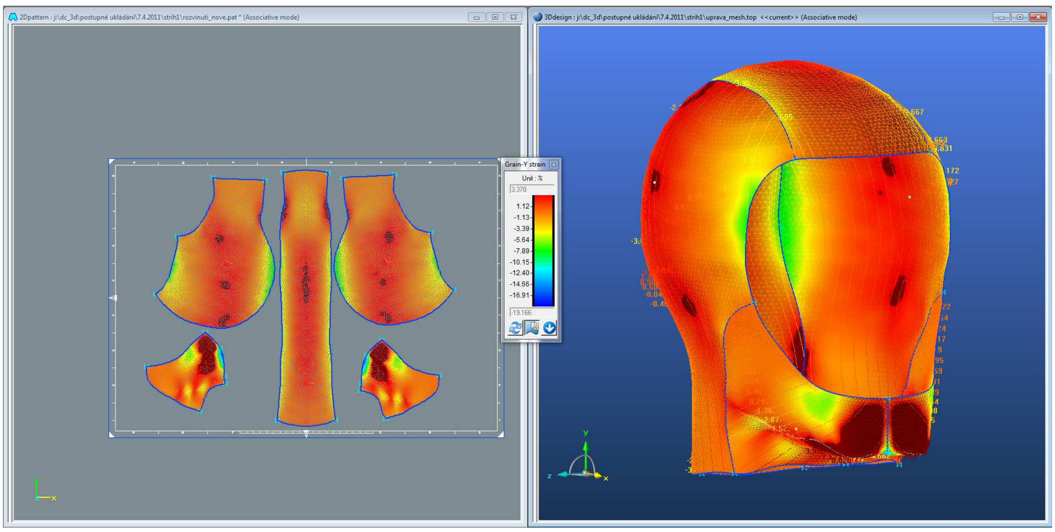

Figure 6 Visualization of the mechanical properties in the Y-direction (column direction)

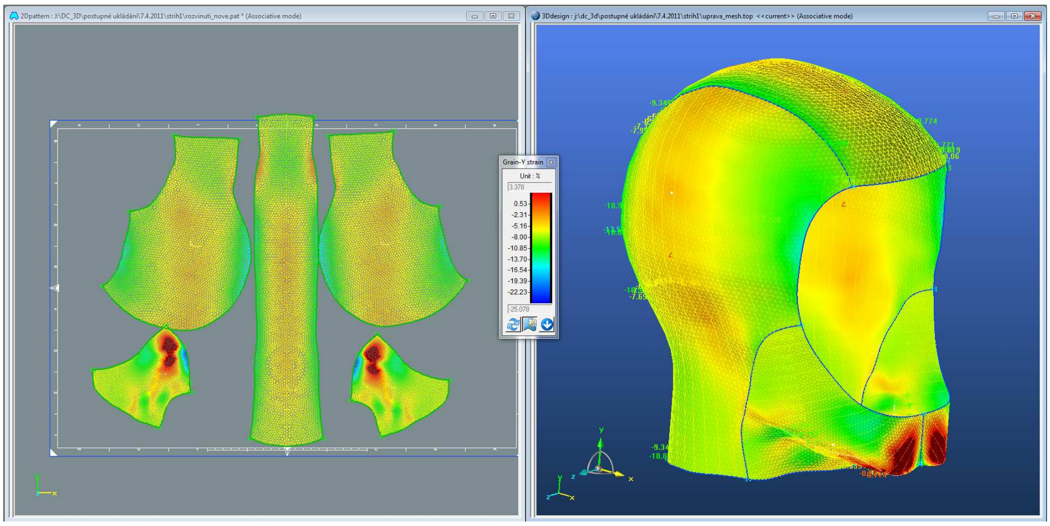

Figure 7 Patterns optimized based on the visualization of compression and tension

3 RESULT AND DISCUSSION

The visualization of a geometric model offers a more realistic representation of an article of clothing with different properties of fabrics. Step by step we were able to obtain correct 2D patterns. The changes made to the 3D patterns are reflected in the 2D patterns (Figure 8).

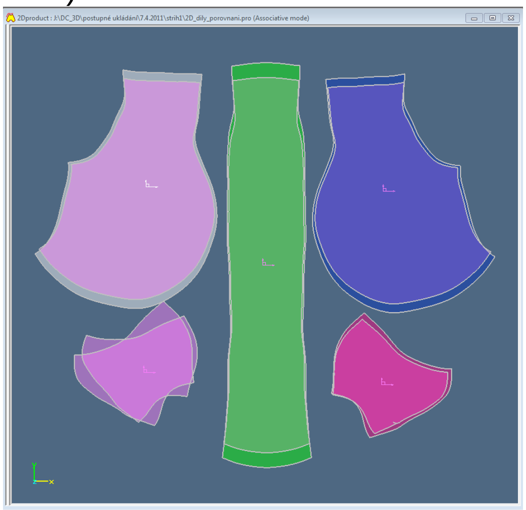

Figure 8 Compared the patterns before and after processing

The principle of determining the optimum fit of clothing is related to the pattern construction, design allowances and the thickness of material layers. Musilová et al. tried to describe a way to change the approach to methods of clothing design [8]. They described the assessment method of the design allowances for the looseness in the horizontal measurement around the body girth in regard to the looseness of the clothing and the sequence of the clothing layers.

4 CONCLUSION

This paper presents a concrete example of the use of DesignConcept3D for the design of the product. DesignConcept3D is a parametric and associative 3D/2D CAD solution tailored for textile applications. It allows the import or modelling of shapes and designs 3D patterns; it performs the flattening; analyzes the feasibility of a style; creates virtual 3D prototypes and simulates new concepts with a high degree of realism.
One of the most fundamental problems is the accurate definition of flexible materials and the real behavior of the fabric. In summary, the next steps of research will be to verify the applicability of different materials and confront the real product. It is necessary to test the specific relationships between the form of the body and flexible textiles.

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NÁVRH VÝROBKU VE 3D A VLIV MECHANICKO FYZIKÁLNÍCH VLASTNOSTÍ MATERIÁLU NA VÝSLEDNÉ TVARY STŘIHOVÝCH DÍLŮ

Translation of the article

3D designing of the product and the effect of mechanical and physical properties on the shapes of patterns

Automatické generování střihů je považováno za jeden z cílů vývoje CAD systému. V současné době je trendem tvorba oděvů pomocí 3D software. Tato práce představuje tvorbu 2D střihů pomocí 3D software, který je schopen zohlednit mechanicko-fyzikální vlastnosti textilního materiálu. K definici aplikovaného materiálu byly použity data naměřené na zařízení KES-FB1 (Kawabata Evalution System). Materiál byl definován charakteristikami tahové deformace ve směru osnovy a útku.

Středem našeho zájmu byl objekt – hlava, která je svým tvarem konstrukčně složitým útvarem pro pokrytí povrchu. Správná konstrukce střihu je důležitá pro perfektní padnutí oděvu. Vstupem do systému nebyla naskenovaná hlava. Byl vytvořen 3D model hlavy dle české technické normy. K provedení této aplikace byl využit systém "DesignConcept3D" firmy Lectra. DesignConcept3D nabízí metodu pro generování 2D tvarů z 3D prototypů. Tento systém prezentuje nový přístup k modelování 3D oděvu vzhledem k 3D tvarům těla pomocí 2D nákresu. Výsledek této práce je vytvoření makety hlavy ve 3D, návrh kukly a střihové díly získané rozvinutím povrchu.

3D SIMULATION TOOL FOR EVALUATION OF ERGONOMICS AT WORK

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Abstract: *The article focuses on the verification of the ergonomic aspects of manual operations at different production stages and working environments using digital human models in Tecnomatix Jack, a 3D simulation program. The analysis was carried out in four workplaces and demonstrated while working at a basic sewing machine using OWAS and RULA methods with virtual people suitable for the production activity. The results show working postures in a simulated environment with simulated movements of the virtual people. We can then monitor and assess the effect of work activities and the workplace on people and select the most suitable activity and types of people in order to adjust the workplace and make organizational changes.*
Key words*: ergonomics, physiognomy, anthropocentrism, 3D simulation of production, space with virtual people*

1 INTRODUCTION

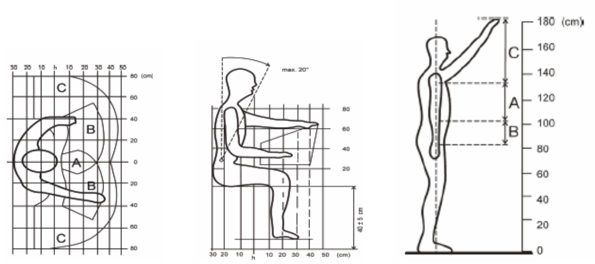
The beginnings of ergonomic thinking appear in connection with the development of work activity of humans. The end of the 19th century brought expansion of the scientific organization of work. F. W. Taylor was considered the founder of the scientific analysis of work. He was the first to attempt to manage production scientifically using new systematic methods. His way of work analysis; i.e. analysis of work movements, layout of the workplace, methods of work, systems of record-keeping and control, etc., were major contributions and examples of the time. Between the wars, scientific management of production and the principles of ergonomics spread. Research and recruitment became much more important. Besides these areas, further research within other basic disciplines such as psychology, physiology, anthropology, management, etc. was developing. The term ergonomic quality, which means the quality of the system of a human – equipment – environment – that determined the level of assurance of health and psychophysical comfort of a person was implemented too[1].

Technical development, centralization and the concentration of production led to the use of equipment that did not respect variance in people, regarding their dimensions, strength, skills, etc. Ergonomics is credited with the adoption of such a mechano-centric approach (a person – adapted to a machine) as it enforces the correct anthropocentrism. This means that equipment must respect human limitations - physical as well as psychological because humans are the most vulnerable and also the most important part of this system. Humans, together with the equipment and the environment, create an integrated ergonomic system.
Currently there are software products that enable us to solve the questions connected with the ergonomic parameters of workplaces. One of them is a 3D simulation program tool called **Tecnomatix Jack**, which complexly allows the evaluation of ergonomics during work and the simulation, control and evaluation of the effect of work activity and the workplace on the human body.

2 WORKING ENVIRONMENT WITH REGARD TO ERGONOMICS

The general aim of ergonomics is to constantly adjust work to humans despite growing demands on their performance and labour productivity. It can also be understood as an integral part of social efforts to maintain the national health. In most cases, a machine, equipment and aids are not used solely by one person and that is why the primary concern is for the groups of people that will work with it.
Many scientific disciplines are concerned with human activities and, in this way, individual sciences overlap. This overlapping can be seen also with ergonomics and anthropometry. Anthropometry is a part of anthropology. It monitors the effect of body dimensions on efficiency of work and it is applied in the production of tools, equipment and consumer items. By its character, anthropometry provides technology with human character. That is why we talk about so-called industrial anthropology, the results of which form an important base for the field called ergonomics.
But designers usually select the dimensions of machines, tools and equipment based on the dimensions of an average body type. Human performance is biologically and psychologically limited; moreover it is limited by external factors such as working postures, physical load, lighting, noise, vibrations, climatic conditions, hazardous radiation, harmful chemical substances, occurrence of dusts and aerosols and even by perceptions and effects of colours, etc. With respect to psychology, the internal limitations depend on mental capacity, abilities, skills and knowledge and the external limitations depend on the performance of work, shift schedule, work at night, monotony and, conversely, significant variability of work can be considered [2].
The most frequent problems connected with work activities are back, shoulder, elbow, wrist and hand pains. These problems occur through unpleasant, uncomfortable working posture, through frequent carrying of loads, through small repeated actions with high frequency or through long periods of work without a break [4].
The primary area of ergonomics is work activity. However, it is necessary to transfer its principles and requirements into aspects outside of work [2].
Working conditions for protection of workers at work are based on the Decree No. 361/2007 Coll. [3], they are set for:

- the range of movement of upper limbs while standing and sitting Figure 1a
- the reach of upper limbs in the vertical plane while working in a sitting position Figure 1b
- the reach of upper limbs in the vertical plane while standing Figure 1c



a. b. c.

Figure 1 Reach of upper limbs while sitting at a desk a), reach of upper limbs in a vertical plane while sitting at a desk b), reach of upper limbs while standing c) [3]

In a correctly designed workplace, the actions carried out most frequently must be at the optimum height, angle and distance for the worker.
By modelling and simulation of changes in a 3D program, we can find various designs of the workplace and work activities and we can choose the best one in order to adjust the workplace and make organizational changes [2].

3 TECNOMATIX JACK

Tecnomatix Jack is a 3D simulation program tool for optimizing the work environment and work activity. It enables the adaptation and evaluation of human behaviour while working and the adjustment of work to suit people.

Tecnomatix Jack was developed by Siemens. The program allows us to improve the ergonomics of product designs and to perform industrial tasks better even in the initial stages of the production process, whether through ergonomic adjustment of the product (vehicle, plane, machine, etc.) or in the production process itself. The digital environment can be filled with virtual people and its arrangement can be modified so that it corresponds to the number and physiognomy of workers. By using a bio-mechanically accurate digital model of a person with a realistic physiological range of joint movements and anthropometry, we can rapidly create a simulation of movements using inverse kinematics. Jack allows us to create the set up of a given workplace and to evaluate its load using analyses. It is not only a suitable tool for designers, technologists and assembly experts, but also a tool for occupational physicians, experts in ergonomics and technicians. By using this program, impairment of health at work can be prevented and work performance can be optimized [2, 4].

3.1 The methods for evaluating the work load on the body

The methods for evaluating the effect of work load on the human body are called OWAS (Ovako Working posture Analysis) and RULA (Rapid Upper Limb Assessment) and they have their own criteria.

3.1.1 OWAS method

OWAS evaluates working postures and load during the performance of work. The load of the head, arms, back and legs is taken into consideration. This method works on the assumption that workers work in such postures so that they are not in discomfort, do not over-strain muscles and do not load the body unsuitably. It has 4 types of loading factors – for the position of the back, the position of arms, the position of legs and the intensity of the load Figure 2.

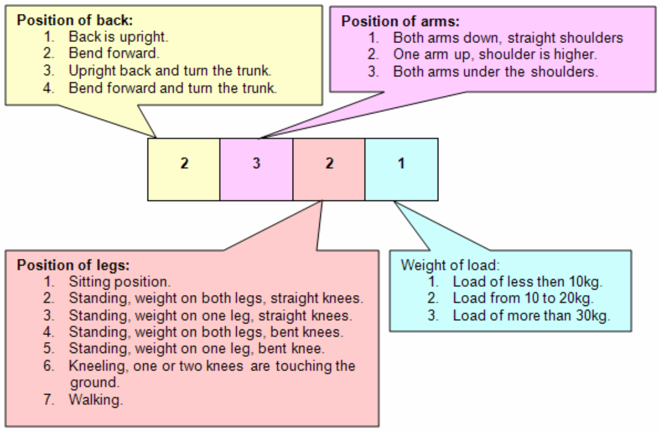


Figure 2 Code identification as per OWAS method [5]

3.1.2 RULA method

This method monitors the risks to the arms, forearms, wrists, neck, trunk and legs Figure 3. It is often used with repetitive work. It is based on the monitoring of several work cycles, from which a work task or a stance that is significant when loaded is selected. Points are assigned to individual postures of the body, types of work and load. The evaluation also includes the aspect of strength taking account of the forces and loads acting during work.

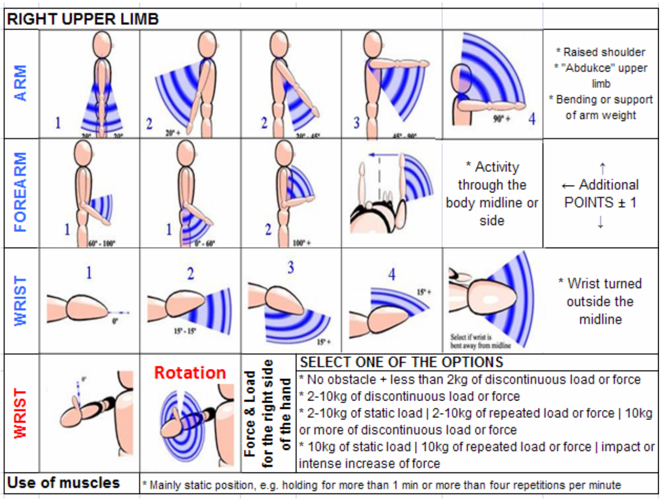


Figure 3 Work cycles and loading of upper limb as per RULA method [5]

An example of this method's output, that is total muscular + force score, is shown in Table 1.

Table 1 Total muscular and force scores
a) postures of upper limb – wrist ***Score C***
b) posture of neck, trunk and legs ***Score D***

Score C	Total score / Score D 1	2	3	4	5	6	7	8	9
1	1	2	3	3	4	5	5	5	5
2	2	2	3	4	4	5	5	5	5
3	3	3	3	4	4	5	6	6	6
4	3	3	3	4	5	6	6	6	6
5	4	4	4	5	6	7	7	7	7
6	4	4	5	6	6	7	7	7	7
7	5	5	6	6	7	7	7	7	7
8	5	5	6	7	7	7	7	7	7
9	5	5	6	7	7	7	7	7	7

3.2 Evaluation of OWAS and RULA methods

The final evaluation and the total score for working postures and the load on the human body in the Jack program using OWAS and RULA are in Table 2.

Table 2 Categories of postures' ergonomic demands in the Jack program [5]

OWAS		RULA	
1	Changes are not needed	1 – 2	Changes are not needed
2	Changes in near future	3 – 4	Changes may be necessary
3	Change only what is possible	5 – 6	Carry out changes asap
4	Carry out changes as soon as possible	7	Carry out changes as soon as possible

4 EXPERIMENT

4.1 Assembly of a workplace for 3D simulation in Jack program

In order to analyse postures found in a production workshop using virtual people, workplaces at a clothing factory were chosen i) at a basic sewing machine, ii) at fixed press, iii) during inter-operational ironing and iv) at a special perforating machine.

To create the simulation of individual workplaces, full-scale 3D models of individual machines were first created in Autodesk Inventor 2011. These models were imported into Jack, then an environment for creating simulations of human activities during work processes was set up and the ergonomic parameters were evaluated.

4.2 Analysis of the stresses of postures of selected workplaces in clothing production

The ergonomic stress of postures in a workplace were analysed using a basic sewing machine as an example. The analysis was divided into six postures that consists of a virtual figure performing various levels of work simulated using the Jack program.

First posture Figure 4 - the basic position at a sewing machine. The virtual figure is sitting upright in the chair, hands placed on the basic desk and lower limbs placed on the sewing machine pedals.

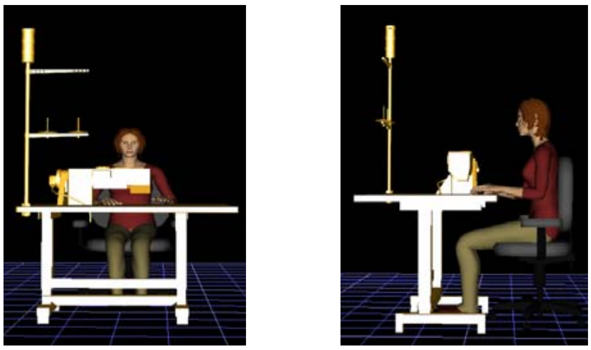


Figure 4 Example of a workplace simulation – a basic position at a basic sewing machine using ergonomic aspects [5]

Second posture Figure 5 - grasping material. In this posture, the virtual figure's trunk is slightly twisted and leaning forward and the upper limbs are outstretched, the lower limbs are placed on the sewing machine pedals.

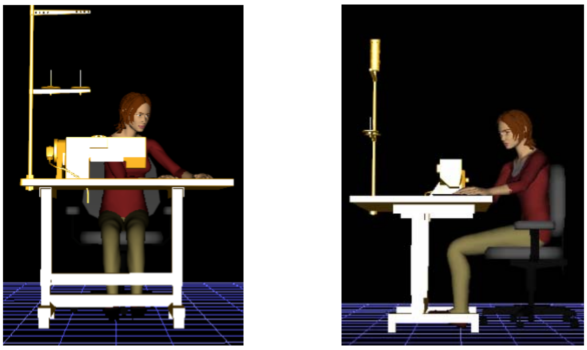


Figure 5 Illustration of grasping material [5]

Third posture Figure 6 - inserting material under the machine foot. In this basic position, the virtual worker's trunk is slightly twisted and the upper limbs holding the material are bent.

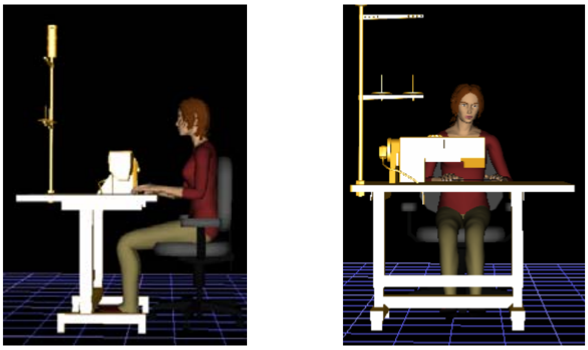


Figure 6 Example of a workplace simulation – the posture when inserting material under the sewing machine foot using ergonomic aspects [5]

***Fourth* posture** Figure 7 - sewing the edges of the material together. In this posture, the virtual worker's trunk is leaning forward, the upper limbs are outstretched and the pedal is pressed by the right lower limb.

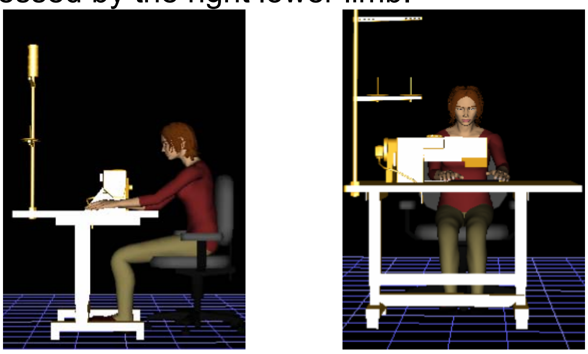


Figure 7 Example of workplace simulation – the posture when sewing the edges of clothing parts together using ergonomic aspects [5]

Fifth posture Figure 8 - removing material from under the sewing machine foot. The virtual worker's trunk is upright, the upper limbs are close to the body and bending up. The hands are holding the material, the lower limbs are loosely placed on the pedal.

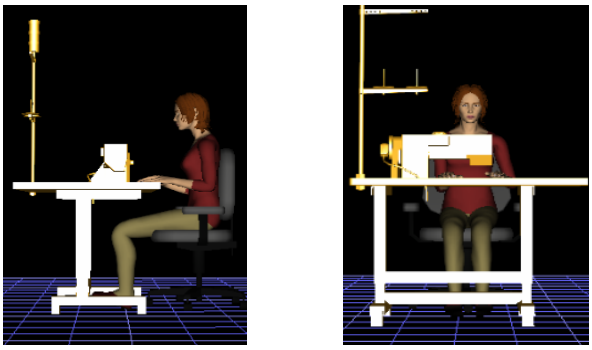


Figure 8 Example of workplace simulation – the posture when removing a clothing part from under the sewing machine foot using ergonomic aspects [5]

Sixth posture Figure 9 - putting material aside. In this posture, the virtual worker turns their trunk and stretches their upper limbs with the material to the drop-off desk. The lower limbs are loosely placed on the sewing machine pedals.

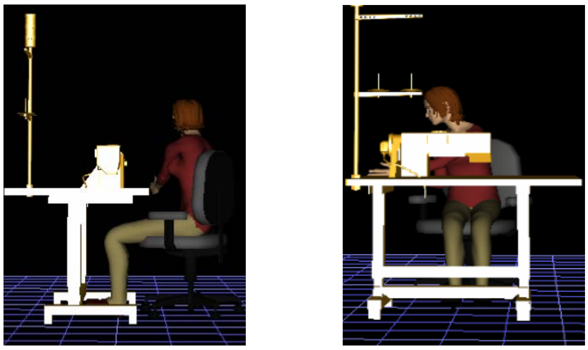


Figure 9 Example of a workplace simulation – the posture when removing a clothing part from under the sewing machine foot and putting it aside using ergonomic aspects [5]

4.3 Results of posture evaluation using OWAS and RULA methods

The results of evaluating the first of the working postures at a sewing machine using Jack by OWAS are illustrated in Figure 10 and by RULA in Figure 11.

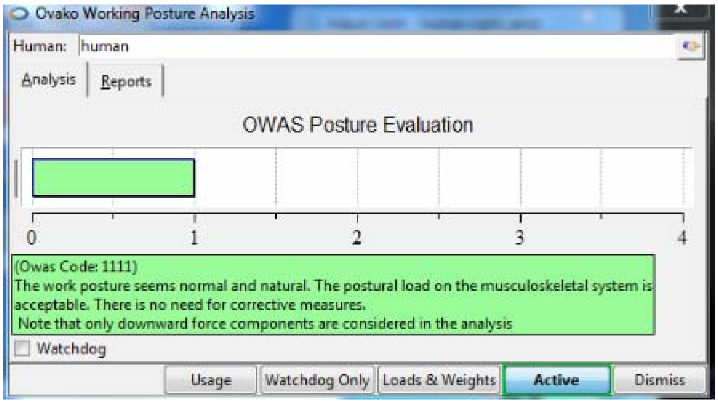


Figure 10 Ergonomic evaluation of posture 1 simulation by OWAS [5]

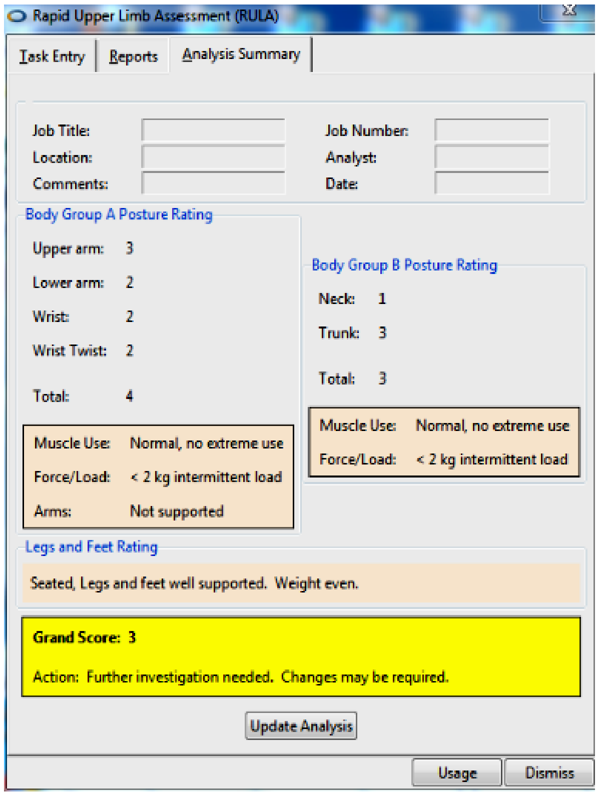


Figure 11 Ergonomic evaluation of posture 1 simulation using RULA [5]

The level and evaluation of a simulation of the ergonomic stress of work in a variety of postures with a basic sewing machine are shown in Figure 12 and in Table 3.

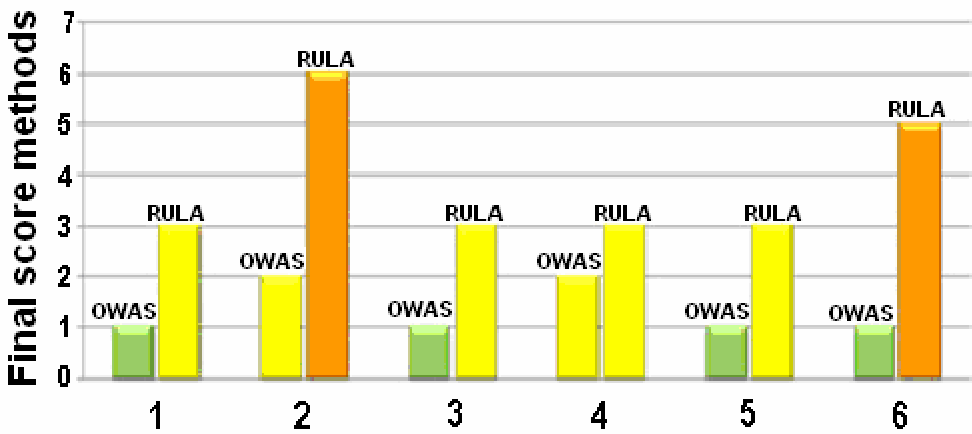


Figure 12 Evaluation of simulation of workplace postures 1-6 with a basic sewing machine using the OWAS and RULA [5]

Table 3 Ergonomic evaluation of simulation of posture stresses with a basic sewing machine in the Jack program

Posture No.	OWAS method			RULA method		
	Evaluation		Changes	Evaluation		Changes
1	1	no corrective measures needed		3	another evaluation needed, changes are necessary	more loosened sitting, turning wrist
2	2	carry out corrective measures in the near future		6	changes need to be done without delay	turning wrist
3	1	no corrective measures needed		3	another evaluation needed, changes are necessary	turning wrist
4	2	carry out corrective measures in the near future		3	another evaluation needed, changes are necessary	leaning trunk forward, turning wrist
5	1	no corrective measures needed		3	another evaluation needed, changes are necessary	turning wrist
6	1	no corrective measures needed		5	changes need to be done without delay	turning trunk

With the RULA method, the critical value is in postures 2 and 6.

After analysing the postures in the selected workplace and comparing the results, it may seem that evaluation by OWAS is more positive than evaluation by RULA. The differences, however, occurred because RULA, unlike OWAS, takes loading and twisting of the joints into consideration.

The other above mentioned workplaces, i.e. on pasting machine, during inter-operational ironing or work on special perforating machine, can be performed similarly.

4.4 Dimensional solution of working environment with virtual people

The Jack program was also used to analyse a given working environment with virtual people, which can be adjusted so that it mimics different demographic characteristics. 3D simulation was used to assess whether an individual is suitable for work in the workplace based on their height. On such a basis, the figures of women and men in height groups (women ranging from 158 cm to 176 cm and men from 164 cm to 194 cm) were assigned to a workplace – a sewing machine. By OWAS and RULA methods, working postures were tested and it was assessed whether it is suitable for the individual to work in the workplace based on their dimensions and the dimensions of the sewing machine and its parts and also ergonomic requirements.

Based on the 3D simulation carried out, it is evident that the height groups being suitable to operate sewing machine are women as well as men with heights ranging between 164 and 170 cm; (Figure 13). With these heights, the virtual workers are sitting upright, straight trunk, upper limbs placed on the work desk and their lower limbs on the sewing machine pedals. They have sufficient space for working at the sewing machine.

Virtual machine operators with their body height over 170 cm have little or no space for manipulation of their lower limbs and insufficient angle of vision; (Figure 14).

This working posture forces the machine operator to bend forward more and to make more effort, but it needs to be considered as a risk or even unsuitable for such a person to work with this equipment. The Jack program has allowances for postures and their ranges. If the ergonomic parameters are exceeded, the system stops working. A similar situation is in the example with inter-operational ironing at an ironing board; (Figure 15).

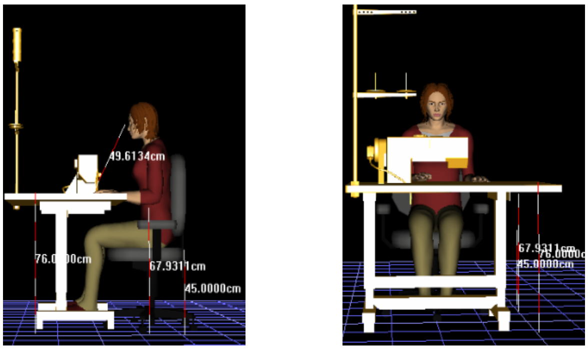


Figure 13 Ergonomic evaluation of the dimensions of the workplace and a virtual worker – the posture at a basic sewing machine [5]

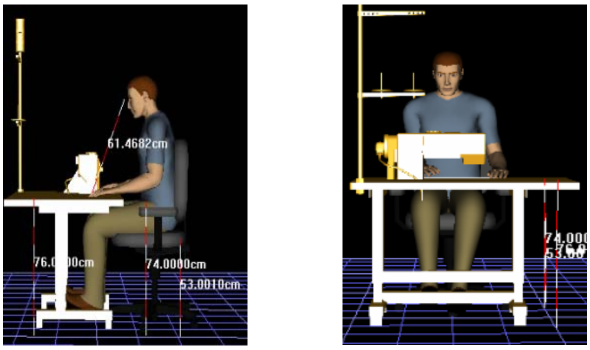


Figure 14 Risk posture of ergonomic simulation of the dimensions of the workplace and a virtual worker – posture at a basic sewing machine [5]

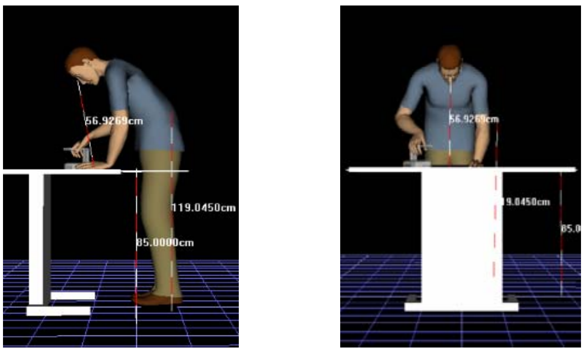


Figure 15 Risk posture of ergonomic simulation of the dimensions of the workplace and a virtual worker – posture at ironing board [5]

A virtual operator of height 188 cm is standing upright, their trunk is bent forward, their right upper limb is on the iron handle, their left upper limb on the surface of the ironing board. Such a worker is too tall for this work posture because it forces more forward bending and more effort, which is not suitable for the ironing board worker or for sewing machine operators.

4.5 Height distribution of men and women working in clothing production

With dimensional design of the machine, it must be taken into account that the machine will be used by various people who differ in size and strength. Most machines, however, are designed in accordance with the average male figure. This means that such machines will not be suitable for women. The correct solution must also accommodate smaller female figures. To ensure working comfort, it is necessary that an item (usually the seat) is adjustable. In practice the range of the average value plus one or two standard deviations can be sufficient.

Based on this claim, the outputs from the Jack program were compared to the results of somatometric measurements taken in 1990 when 1000 men and 1066 women were measured. The average values and the standard deviations of selected heights of these women and men are shown in the following graphs. The distribution of women's heights of 162.9±6.4 cm is shown in Figure 16 and men's heights of 175.3±6.8 cm are in Figure 17.

By comparing these results to the outputs from Jack, the research found that women and men whose heights range between 164 and 176 cm are suitable for work with sewing machines. The areas are marked in bold continuous lines in Figures 16 and 17.

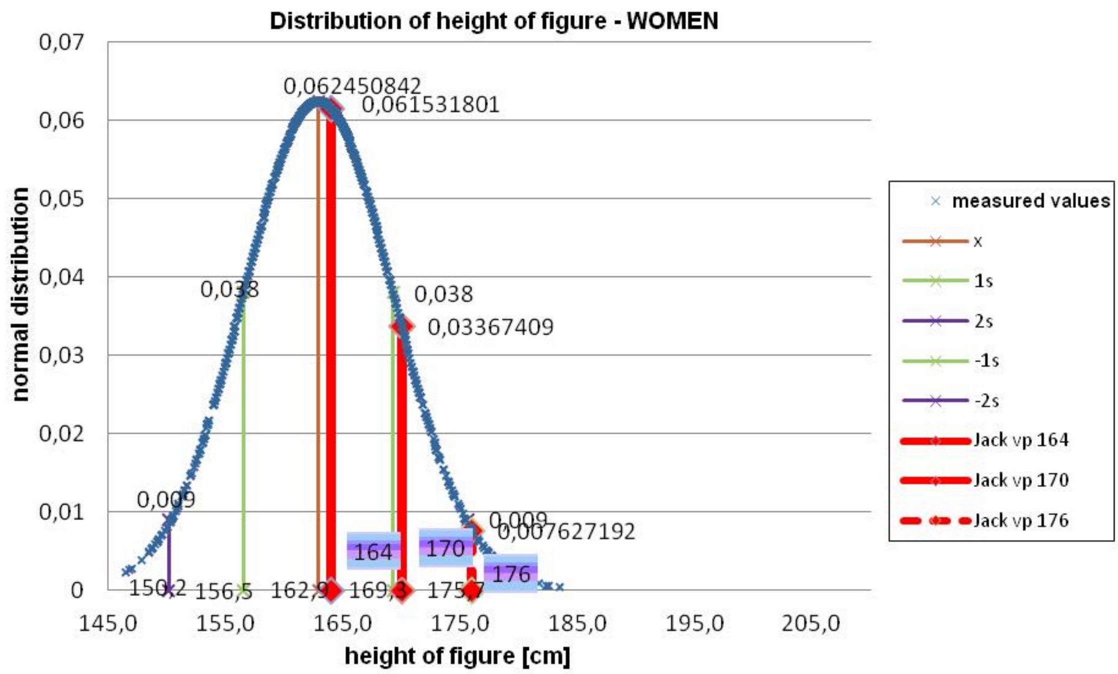


Figure 16 Distribution of women's heights and the optimum range for working at a sewing machine and ironing board

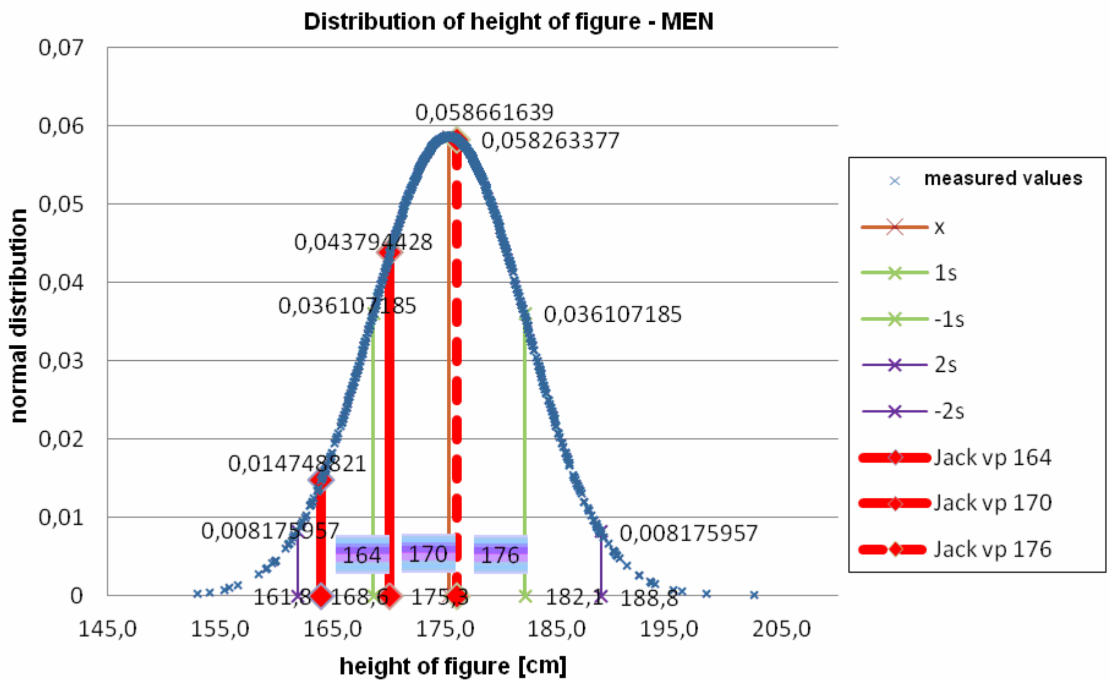


Figure 17 Distribution of men's heights and the optimum range for working at a sewing machine and ironing board

To work at an ironing board, the ***height of the figure*** and the ***height of the waist*** are decisive. The results indicate that ***women and men*** whose ***heights range between 164 and 176 cm*** are suitable for working ***at an ironing board***. The range is indicated in Figures 16 and 17 in bold by dashed lines.

The heights of women's waists are shown in Figure 18 and the height of men's waists in Figure 19.

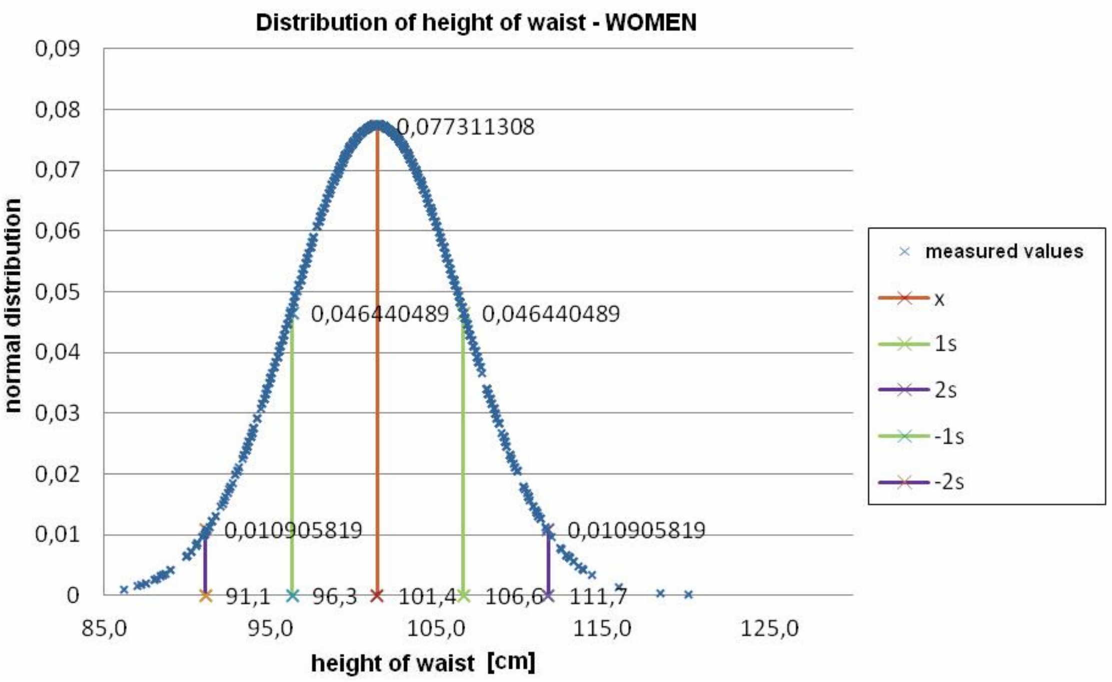


Figure 18 Distribution of the heights of women's waists and the optimum range for working at ironing board

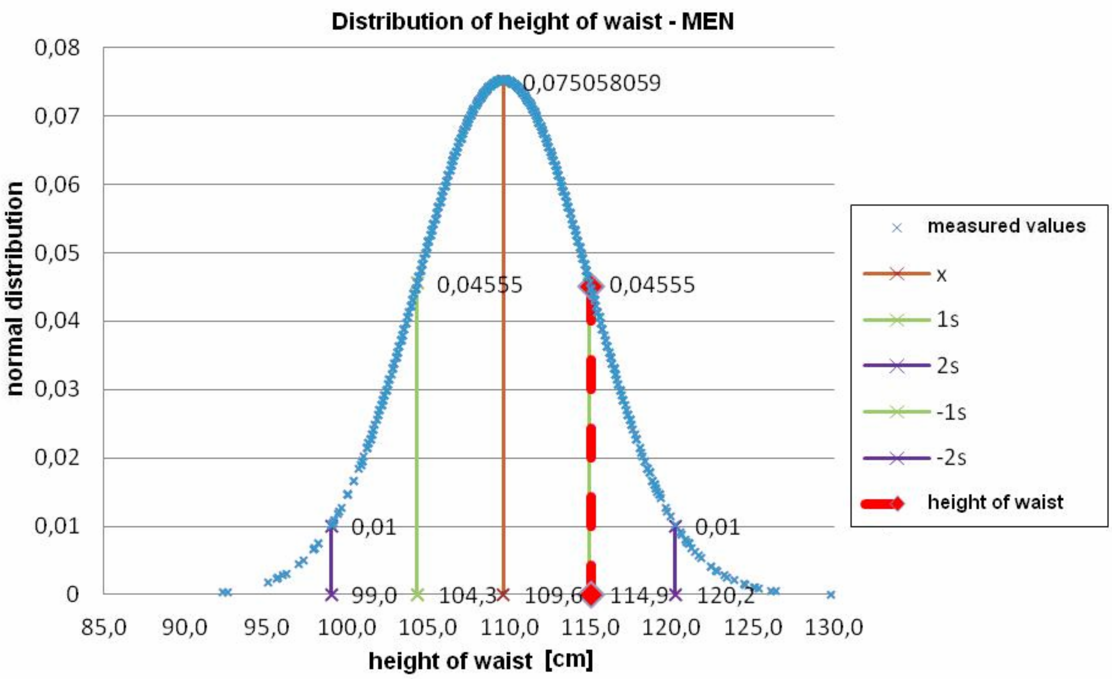


Figure 19 Distribution of height of men waist and optimum range for work at ironing desk

The range of waist heights for working at an ironing board is 91-115 cm, which represents average values plus one to two standard deviations for women; Figure 18 and minus two and plus one standard deviations for men; Figure 19.

In addition to the above mentioned heights, the distance from the pedal to the ironing board (55 cm) is also decisive for working at an ironing board, which is connected with the height of women's knees (Figure 20) and men's knees (Figure 21).

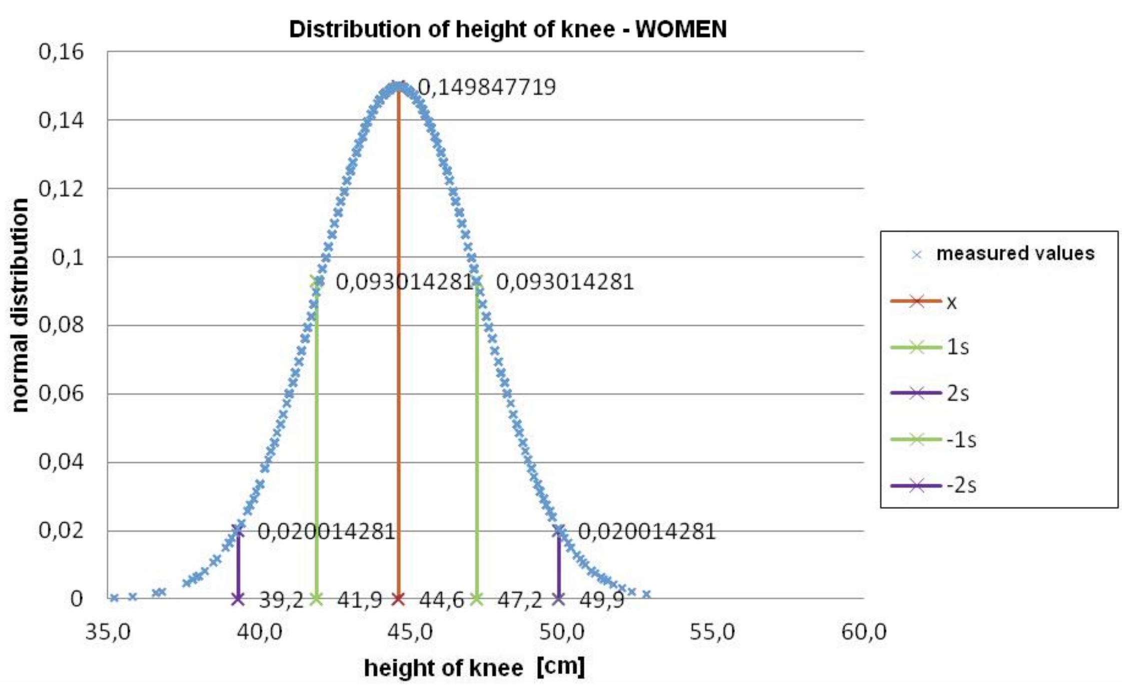


Figure 20 Distribution of the height of women's knees

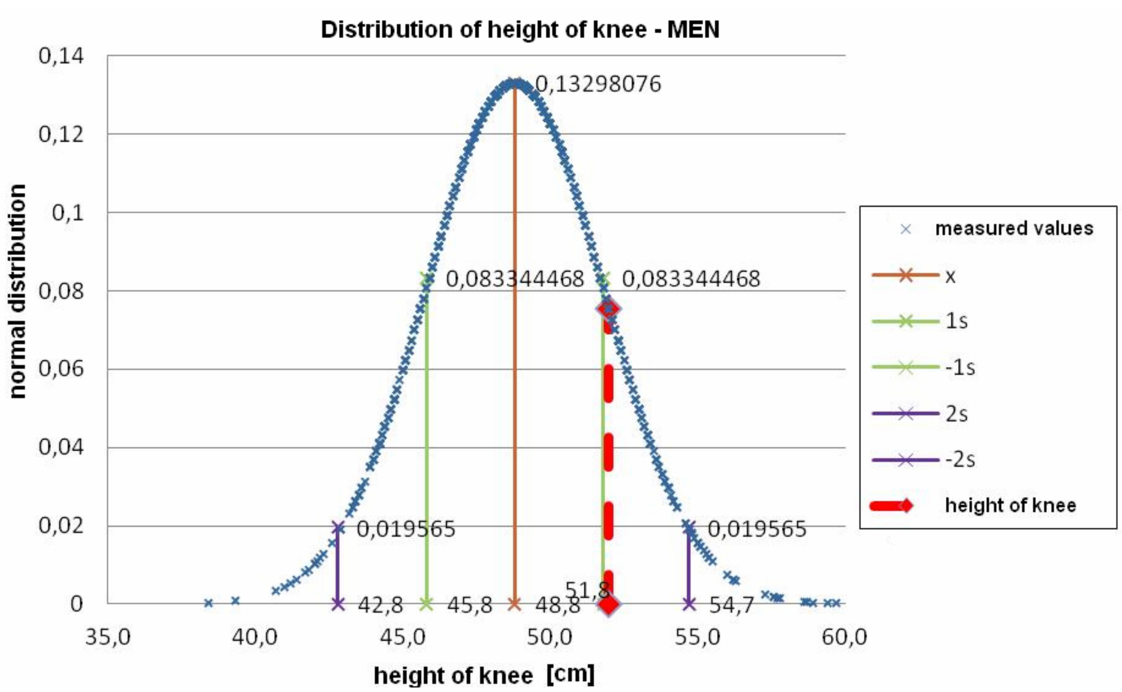


Figure 21 Distribution of the height of men's knees

This means that the optimum height of knees for working at a sewing machine in women and men can range between 42 and 52 cm, which represents the average values of the knee height plus one to two standard deviations for women (Figure 20) and minus two and plus one standard deviations for men (Figure 21).
By comparing these measurements to the outputs from Jack, shows that the dimensions of the body and its proportions are limiting because when recommended limits are exceeded, the Jack program warns about the errors and requests correction with respect to worker's suitability or workplace layout because Jack stops working in critical situations.

5 CONCLUSION

The ergonomic aspects of manual operations and postures in workplaces within the production process can currently be analysed directly in the working environment and with virtual people. The solution was carried out using Inventor and Tecnomatix Jack programs and the 3D simulation was verified and assessed using the OWAS and RULA methods. First it was necessary to typify workplaces, which occur during the production of clothing most frequently and to create a working space with virtual people suitable for production. The experiment confirms how important the operators' body dimensions and the dimensions of the machines and equipment and their arrangement within the work space are with respect to occupational safety. The results of the research confirmed that from an ergonomic point of view, people with height ranging between 164 and 176 cm are suitable to work in clothing production and particularly in the production process. The workplace can, however, be adapted by adjusting the height of the machine or seat and by adapting the workplace to the dimensions of extreme figures. Today the producers of new machines are starting to look at these requirements.
The performance of the person, which is given by motor function and physical fitness, the function of sense organs and mental ability is also influenced by gender, age and the impact of many other working conditions and factors of equal importance.
In the Jack program, not only 3D simulation but also video recording of workplaces, eventually of the whole workshop including a wide range of human factors, injury risks, timing, user's comfort, accessibility, angle of vision, energy expenditure, limits of fatigue and other important ergonomic parameters of correct anthropocentrism can be created.
Optimization of working actions leads to higher productivity of work.
The advantage of Tecnomatix Jack is that using ergonomic analytical tools it allows us to ensure safety at work within the environment and to improve and control adherence to ergonomic norms and visually capturing and recording of well-established procedures.
By properly designing the workplace, the work stations and the correct organization of work activities, we can prevent increased absenteeism due to health complications, reduce employee turnover and the related costs of retraining and so avoid compensation for injured employees.

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3D SIMULAČNÍ NÁSTROJ PRO HODNOCENÍ LIDSKÉHO CHOVÁNÍ PŘI PRÁCI

Translation of the article
3D simulation tool for evaluation of human behaviour at work

Článek je zaměřen na ověření ergonomických aspektů manuálních operací různých fází výroby a pracovního prostředí pomocí digitálních lidských modelů s využitím 3D simulačního programu Technomatix Jack. Analýza byla provedena na čtyřech pracovních místech a ukázkově předvedena při práci na základním šicím stroji metodami OWAS a RULA s virtuálními lidmi vhodnými pro danou činnost výroby. Výsledky řešení ukazují pracovní pozice, u nichž je možné simulovat prostředí a v něm pohyb virtuálních osob a vidět a hodnotit působení pracovní činnosti a pracovního místa na člověka a vybrat tu nejvhodnější činnost a typy lidí pro realizaci úprav pracoviště a organizačních změn.

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