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NEW DEVELOPMENT IN FLAME RETARDANT FINISHING OF COTTON AND COTTON BLENDS

BY

CHARLES Q. YANG*

The University of Georgia, USA,
Department of Textiles, Merchandising and Interior

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Abstract. The fire hazards of cotton clothing represent genuine risk to consumers. Government regulations have always been the driving force for developing durable flame retardant finishes for textiles. 1950-1980 was the golden age of flame retardant research. Most of the major semi-durable and durable flame retardant chemicals used today were developed during that period. Examples of the successful flame retardants for cotton developed during this period and still being used today include ammonium polyphosphates (APP), tetra(hydroxymethyl)phosphonium salts (THPX), N,N'-dimethylol dialkyl phosphonopropionamids (MDPA), and the combination of halogen-containing organic compounds and antimony oxide for back-coating. It is apparent that the major durable flame retardants for cotton have various deficiency and could not meet all the expectation for their end uses, such as limited loss of fabric mechanical strength, retention of fabric soft hand and other aesthetic properties, formaldehyde-free, and compatibility with the traditional pad-dry-cure facility. Since 2000, more attempts have been made to develop higher performance, lower cost and environmentally sustainable alternative flame retardants for cotton and other textile fibers. In addition, no practical flame retardant treatments for polyester-cotton blends, the most widely used fabrics in protective work clothing, were developed despite enormous efforts made for several decades. The needs for flame retardant finishing technology for polyester-cotton blends

*Corresponding author; *e-mail*: cyang@uga.edu

were undoubtedly recognized. This paper discuss and the recent development of flame retardant finishing technology for cotton. The challenges facing the industry lay in the following areas: (1) continuing to improve the performance and to reduce the negative environmental impact of those existing flame retardants; and (2) developing new more environmental-friendly alternative condensed phase flame retardants, finding replacement for halogenated flame retardants for back-coating, and developing the flame retardant technology for cotton blends.

Key words: cotton, flame retardant cotton, flame retardant finishing, cotton blends, finishing.

1. Introduction

Cotton was among the most widely used textile fiber in history. In spite of rapid development and growth of synthetic fibers since the 2nd world war, cotton is still the most commonly used and most important textile fiber today. Cotton is also one of the most flammable textile fibers. The fire hazards of cotton clothing represent genuine risk to consumers because of cotton's ease of ignition and vigorous burning. A study carried out in Norway, Spain and the United Kingdom for European Commission indicates significant fire risk by clothing textiles based on results of manikin tests and household survey (Laitala, 2004). The study results showed that 3.2% of households reported hazardous fires incidents involving clothing in Spain. It was reported that at least 750 clothing flammability accidents occur in the UK each year, 11% of which were fatal (http://www.dti.gov.uk/). Another study in the U.S. confirmed that textiles constituted 44% of the items first ignited for 500 fatal fires happening between 1999 and 2002 (Hirschler & Piansay, 2007).

The government regulations have always been the driving force for developing flame retardant finishes for textiles. 1950-1980 was the golden age of textile flame retardant research (Horrocks, 2011). Most of the major semi-durable and durable flame retardant chemicals used on cotton today were developed during this period. Examples of the flame retardants for cotton developed during this period and still being used today include ammonium phosphate, ammonium polyphosphates (APP), tetra(hydroxymethyl)phosphnium salt (THPX), N-methylol dimethylphosphono-propionamide (MDPA), and combination of halogen-containing organic compounds and antimony oxide for back-coating (Horrocks, 2011). In the next twenty years (1980-2000), no novel flame retardants were developed for commercial applications whereas the existing flame retardants were continuously being improved for better performance. The efforts in flame retardant research were also focused on addressing the environment- and toxicity-related issues associated with the flame retardants developed in earlier years (Horrocks, 2011).

Since 2000, more attempts have been made to develop higher performance, lower cost and environmentally sustainable alternative flame retardants for cotton and other textile fibers (Horrocks, 2011). It is apparent that the major durable flame retardants for cotton have various deficiencies and could not meet all the expectation for their end uses, such as limited loss of fabric mechanical strength and abrasion resistance, retention of fabric soft hand and other aesthetic properties, formaldehyde-free, and compatibility with the traditional pad-dry-cure facility (Lewin, 2011). The environmental impact of bromine-containing flame retardants, which were mostly used as back-coating on fabrics of cotton and other fibers, were assessed aggressively during this period (Horrocks, 2011). Polyester-cotton blends were very important fabrics for both consumer and industrial uses, but no practical flame retardant treatment has been developed despite enormous efforts made for several decades. The needs for flame retardant finishing technology for polyester-cotton blends were undoubtedly recognized (Lewin, 2011).

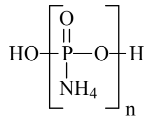
2. Non-Durable and Semidurable Flame Retardants for Cotton

2.1. Ammonium Phosphates

Ammonium phosphates, first identified in 1821 as flame retardants, are still being used today on cotton as non-durable flame retardants. Ammonium phosphates are effective at add-ons in the range of 1-2% phosphorus content relative to the weight of cotton fabrics to provide adequate fire-resistance. Many commercial formulations have surfactants to improve wetting and penetration of ammonium phosphates into a cotton fiber's lumen. Urea is often added to aid cellulose swelling as well as to enhance flame retardancy by providing synergistic nitrogen (Weil & Levchik, 2009). The performance of ammonium phosphates (or polyphosphates) can be enhanced by adding ammonium bromide to give additional vapor phase activity. Ammonium sulfamate or ammonium sulfate is also included in some ammonium phosphate formulations. An enhancement of efficiency is often found with such sulfur-phosphorus combinations (Weil *et al*., 2002).

2.2. Ammonium Polyphosphate (APP)

APP (CAS number: 68333–79–9) is an ammonium salt of polyphosphoric acid with possible branching. APP was produced by the reaction between phosphoric acid and ammonia (Young, 1977). APP-based flame retardants have been used worldwide since early 1960s. The molecular formula of APP is shown in Scheme 1, in which n is the degree of polymerization.



Scheme 1 − The molecular formula of APP.

Under high temperatures, APP decomposes to form phosphoric acid and ammonia, thus causing phosphorylation of cotton. The solubility of APP depends on its degree of polymerization, and branching also increases APP's solubility. APPs with low degree of polymerization have high solubility in water and can easily by used as nondurable flame retardants for cotton fabrics with good hand property. Many of the APP commercial products contain urea as an additive so that the APP-treated cotton fabrics can be cured to improve laundering durability. Another effect of adding urea to a APP formulation is to facilitate the penetration of APP into the interior of cotton (Horrocks, 2003, 224−225−8), and it also helps reduce the acid damage to the cotton and provides synergistic nitrogen. APPs with degree of polymerization higher than 1,000, available as powder, have very low solubility in water (<0.1 g/100 mL). The high molecular weight water-insoluble APP can be applied to textile fabrics with an acrylic polymer or melamine-formaldehyde as binders. Such treatment is often applied as back-coatings to curtains, carpets, upholstery, bedding and the like. A further use of insoluble APP is in intumescent coatings (Weil, 2011).

2.3. Other Types of Phosphates and Inorganic Non-Phosphorus Flame Retardants

More recently, diguanidine hydrogen phosphate (DGHP) or monoguanidine dihydrogen phosphate (MGHP), as shown in Scheme 2, were reported as inexpensive alternative non-durable flame retardant for cotton (Vroman *et al.*, 2004). The cotton fabric was treated with DGHP and MGHP, individually or in combination with 3-aminopropylethoxysilane (APS). The cotton fabric treated with DGHP or MGHP could achieve LOI as high as 30-40%. When the formulations contain APS, the treated fabric's LOI was increased to 60%. Those treated cotton fabric samples fail the flammability test after a water soaking, therefore those phosphates must be considered as nondurable flame retardants.

DGHP MGHP

Scheme 2 − The molecular formula of (A) MGHP and (B) DGHP.

A number of inorganic compounds were used as nondurable flame retardant for cotton. Those non-durable flame retardants could be divided into three groups. The first group includes those compounds which have relatively low melting points and can produce a layer of foam on top of a substrate as a barrier between flame and the substrate. Boric acid and sodium borate or the mixtures thereof are the typical flame retardants for the first group. The second group is inorganic acids and their salts which release acids upon heating, thus causing cellulose's dehydration and promoting char formation. This group is exemplified by sulphamatic acid, ammonium sulphamate, phosphoric acid and its salts as already discussed, and Lewis acids such as zinc chloride. The flame retardants of the third group, such as carbonate and ammonium salts, release non-flammable vapors (Lewin & Sello, 1975).

2.4. Semi-Durable Flame Retardants for Cotton

The term “semi-durable flame retardants”, according to Weil, refers those flame retardants which survive water soaking or leaching to various degree. Some of APPs discussed above with higher degree of polymerization can be applied as a semi-durable flame retardant on cotton. A recent Milliken patent showed that a formula containing APP and urea was used to treated unconsolidated loose cotton with heating to 140-200°C, thus bonding the treated fibers onto a nonwoven textile with leach-durable flame retardancy (Weil & Levchik, 2009).

Phosphoric acid is able to react with the -CH_2-OH group of cotton cellulose under elevated temperatures to produce cellulose phosphate. Since the cellulose phosphate can hydrolyze under alkaline conditions, phosphoric acid is a semi-durable flame retardant. Treatment of cotton using phosphoric acid in the presence of urea or dicyandiamide could improve the performance of such a system (Fang, 2007). A recent Ciba patent used organic phosphonic acids exemplified by methanephosphonic acid [$CH_3PO(OH)_2$] as a flame retardant for cotton with boric acid and urea/dicyandiamide as additives. It claimed that the use of boric acid in the formulations resulted in higher flame retardancy (Dermeik *et al.*, 2002). Recently, aluminum hydroxyphosphate (AHP) formed in-situ in the luman of cotton by the reaction of aluminum sulfate and sodium phosphates was used as a semi-durable flame retardant. The flammability of the treated cotton fleece passes the 16 CFR 1610 flammability test (Wu & Yang, 2008).

3. Durable Flame Retardants for Cotton

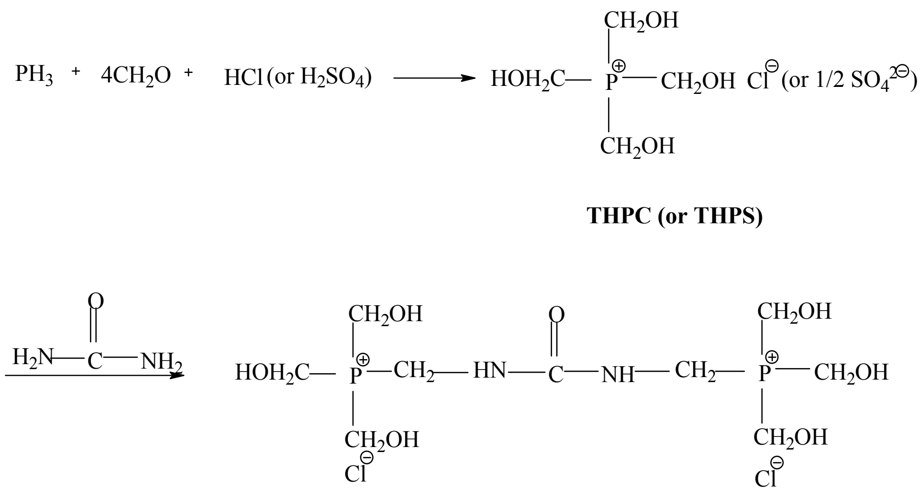
3.1. Tetra(Hydroxymethyl)Phosphnium Salts

The flame retardants for cotton based on THPX have been among the most important commercial flame retardants for cotton for almost half a century

(Cole, 1978; Cole, 1982). THPX is based on the product of the reaction between formaldehyde and phosphine in the presence of an acid. Phosphine can be obtained as a byproduct of the production of sodium hypophosphite from phosphorus and sodium hydroxide (Scheme 3). Both the chloride and the sulfate salts (THPC and THPS, respectively, shown in Scheme 3) are available. THPX (usually THPC) is mixed with urea in a 2:1 ratio (1:1 P/N molar ratio) to form THPX/urea pre-condensate. The THPC/urea pre-condensate has better penetration into the microstructure of a cotton fiber whereas the double charged THPS is larger in size and has lower levels of penetration and consequently lower laundering durability (Horrocks, 2003).

The cotton fabric with THPC-urea pre-condensate is dried and then passed to a special “ammoniation chamber”, where exothermic crosslinking reaction of the THPC/urea pre-condensate by ammonia takes place, forming a crosslinked polymeric network with a P/N molar ratio of 1:2 on cotton as shown in Scheme 4. The cotton fabric thus treated is finally treated by H_2O_2 to oxidize the poly(phosphine) to the poly(phosphine oxide) for higher stability.

$$4\ P + 3\ OH^- + 3\ H_2O \rightarrow 3\ H_2PO_2^- + PH_3$$



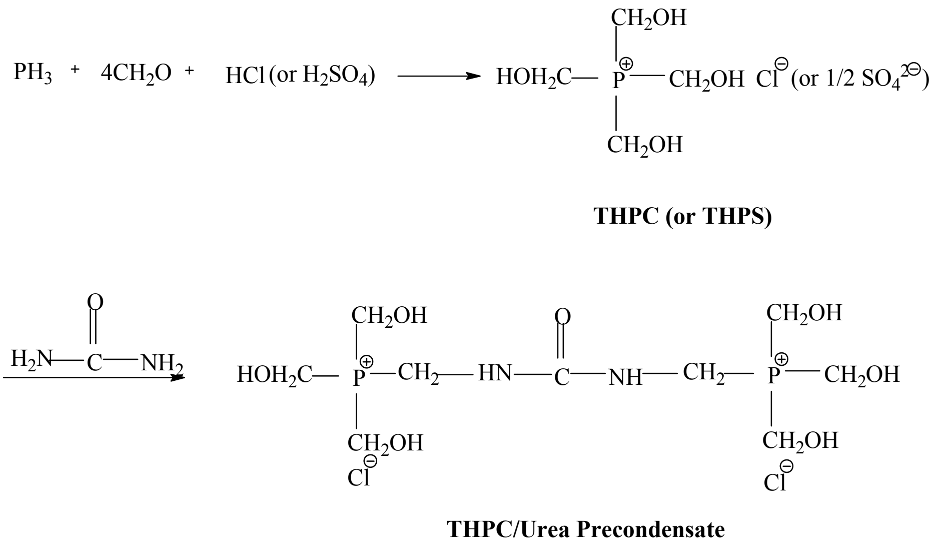
THPC (or THPS)

THPC/Urea Precondensate

Scheme 3 − Formation of HTPC/urea pre-condensate.

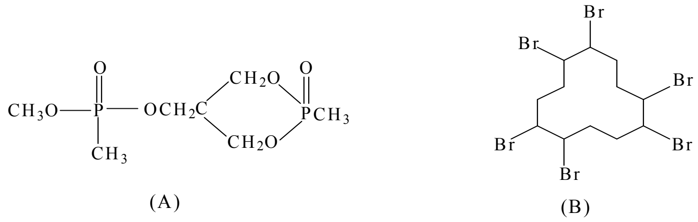
The nitrogen in the system provides synergistic affect to enhance the char-forming phosphorus. If a final treated fabric can have >2% phosphorus (w/w), it should achieve acceptable flame retardancy. Since there are not hydrolysable linkages in the crosslinked polymeric THPX network inside the cotton, the finished cotton fabric is durable to 100 industrial laundering cycles, significantly more durable than other flame retardants used on cotton (LeBlanc, 1997).

More recently, the operation procedures and conditions for drying and ammoniation for the Proban® treatment were optimized in the newer patents (Zakikhani & Lei, 1996; Cole, 1999). The cotton fabrics with the Proban® treatment is marketed as Westex's Indura®, Banwear®, FR-7A®, and Ultrasoft® (Weil & Levchik, 2009). Those flame retardant cotton fabrics are widely used in the production of protective clothing.



Scheme 4 − The "Proban" process.

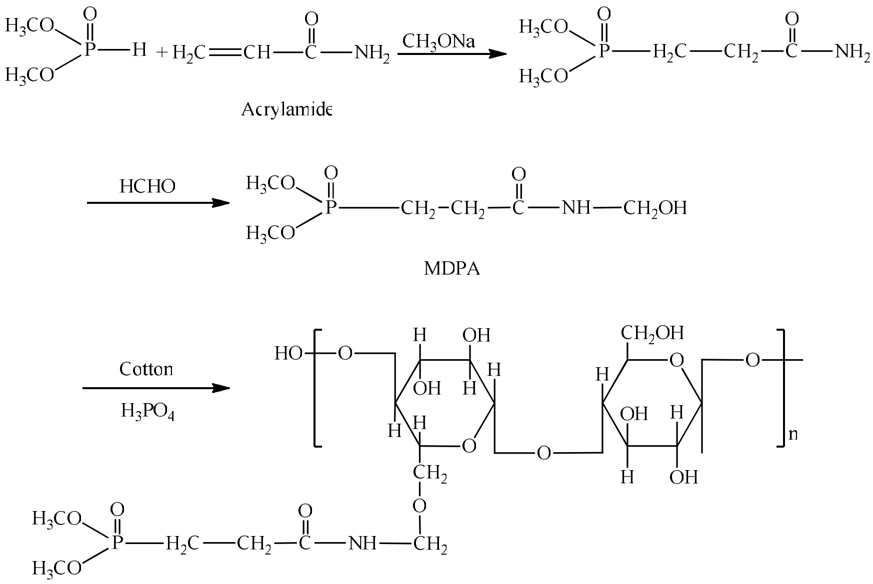
The THPX/urea/NH3 systems were also applied to fabrics of cotton blends with cotton as the major component fiber, as reflected in the patent literature (Smith, 1990; Fleming & Green, 1995; Fleming & Green, 1996). Blends of 88% cotton and 12% nylon treated with THPC/urea/NH3 are sold by several companies, such as Indura Ultra Soft® by Westex (Weil & Levchik, 2009). Patent literature also indicate that the flame retardant finishing of cotton blends with as much as 35% nylon could be done by combining THPX/urea/NH3 with a cyclic methylphosphonate ester flame retardant known as "Antiblaze® 19" shown in Scheme 4A below (Hansen, 1988; Hansen, 1989). A similar treatment was used to produce flame retardant cotton/polyester blends fabrics (Johnson, 1989). Another alternative method uses the combination of THPX/urea/NH3 and hexabromocyclodecane shown in Scheme 5B (Hauser & Triplett, 1988; Roth, 1978; Beninate *et al.,* 1968).



Scheme 5 − (A) The cyclic methylphosphonate ester flame retardant and (B) Hexabromocyclodecane.

3.2. Phosphonoamide Finishes

Phosphonoamide finishes, exemplified by Pyrovatex® CP of Ciba (now Huntsman), is the second important durable flame retardant for cotton. The principal component in Pyrovatex® CP and similar products is N-methylol dimethylphosphonopropionamide (MDPA). The early research on flame retardancy and other properties of the MDPA-treated cotton fabrics was done by Ciba researchers in the 1960s (Aenishansli *et al.,* 1969). It is made by the reaction between dimethylphosphite and acrylamide to form dimethylphosphonopropionamide, which further reacts with formaldehyde to yield MDPA as a methylol derivative (Scheme 6). The compositions and impurities of Pyrovatex® CP were investigated and reported in the literature (Kapura, 1996).

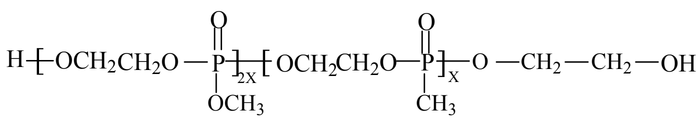


Scheme 6 − The synthesis of MDPA and its bonding to cotton.

MDPA has a methylol group and is able to react directly with cotton cellulose to form an “aminal” linkage. Methylolated melamines, typically trimethylolmelamine (TMM), are usually used in a MDPA formulation as a co-reactant. The investigation of the bonding of MDPA on cotton was reported more recently. The data demonstrate that approximately 50% of the MDPA was bound to cotton under the curing condition and the percent fixation was independent of the MDPA concentration. The data also show that TMM not only increases the bonding of MDPA to cotton, but also increase the flame retardancy of the treated fabric by providing more synergistic nitrogen (Wu & Yang, 2006; Wu & Yang, 2007). A flame retardant with structure similar to that of Pyrovatex CP® is Thor’s Aflammit® KWB, which is claimed to be a much purer product and to have increased fixation levels. The phosphoric acid catalyst level and the curing temperature can also be lowered, and volatile emissions and fabric strength loss are also reduced (Weil & Levchik, 2009).

3.3. Hydroxy-Functional Phosphorus-Containing Oligomers (HFPO)

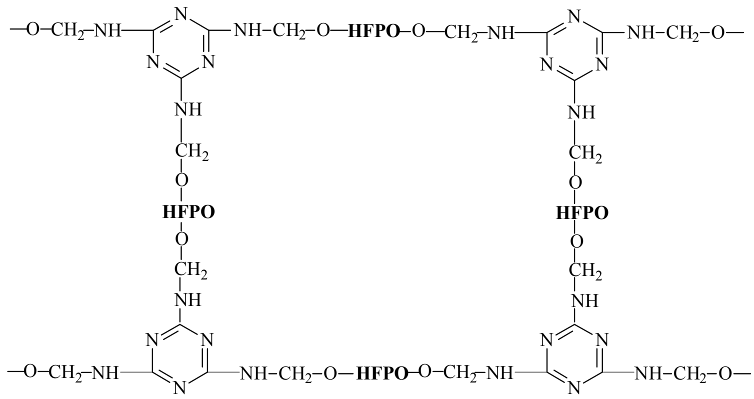
HFPO, originally used for the flame retardant treatment of paper in automotive air filters, found new applications for the flame retardant finishing of cotton and cot ton blends in 2000s (Yang *et al*., 2006; Stowell *et al*., 2001). The HFPO is a reactive oligomeric alcohol having methylphosphonate units and methylphosphate units with two hydroxy terminal groups as shown in Scheme 7. HFPO was initially developed by Stauffer Chemical and Akzo Nobel as Fyrol® 51 primarily for resin-treated paper air filters (Weil, 1975; Weil, 2004; Stowell, 2000; Weil, 1982; Fearing, 1980). It was later renamed by Akzo Nobel as Fyroltex® HP, but was discontinued due to company reorganization in 2005. Similar products are available from Dymatic Chemicals in China as DM 3070.



Scheme 7 − Molecular formula of HFPO.

HFPO does not have a functional group reactive to cellulose. Therefore, it is necessary to use a bonding agent to react with both cellulosic hydroxy and the hydroxy of HFPO forming a “bridge” between them so that HFPO can be covalently become durable to multiple laundering cycles. Two formaldehyde-based reagents, TMM and dimethyloldihydroxylethyleneurea (DMDHEU), were used as the bonding agent for HFPO (Wu & Yang, 2004; Yang *et al*., 2005). DMDHEU, commonly used as a durable press finishing agent for cotton, is a more effective crosslinker between HFPO and cotton than TMM; and the crosslinking between cotton and HFPO formed by DMDHEU is more durable to launderings than that formed by TMM. TMM is a better provider of synergistic nitrogen to enhance the performance of HFPO. DMDHEU, as an effective crosslinking agent for cotton by itself, causes higher fabric wrinkle resistance and higher fabric strength loss (Wu & Yang, 2004). It was also reported that TMM and HFPO forms crosslinked polymeric network on cotton, as shown in Scheme 8 (Yang *et al*., 2005). The formation of such crosslinked polymeric network increases the laundering durability of the treated cotton fabric.

The flame retardant performance of HFPO as a durable flame retardant agent for cotton was compared with that of MDPA (Wu & Yang, 2006; Wu & Yang, 2007). Because MDPA is able to react directly with cotton whereas HFPO requires the use of a bonding agent on cotton, the effectiveness and concentration of the bonding agent play a critical role in determining the percent fixation and the laundering durability of HFPO on cotton.

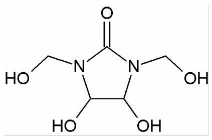


Scheme 8 − Crosslinked polymeric network of TMM/HFPO on cotton.

The initial percent fixation of HFPO onto cotton is moderately higher than that of MDPA. The phosphorus content of HFPO (~20%) is significantly higher than that of MDPA (~15%). Consequently, the initial percentage phosphorus concentration of the HFPO-treated cotton is much higher than the MDPA-treated cotton after one laundering cycle when the two flame retardants are used at equal concentrations. However, the MDPA bound to cotton has significantly higher laundering durability than the HFPO (Wu & Yang, 2006). TMM has the same effectiveness in enhancing flame resistance of HFPO and MDPA (Wu & Yang, 2007). The cotton fabric treated with HFPO/TMM show competitive flame retardancy during 30 home laundering cycles, but MDPA demonstrates higher performance after 30 laundering cycles.

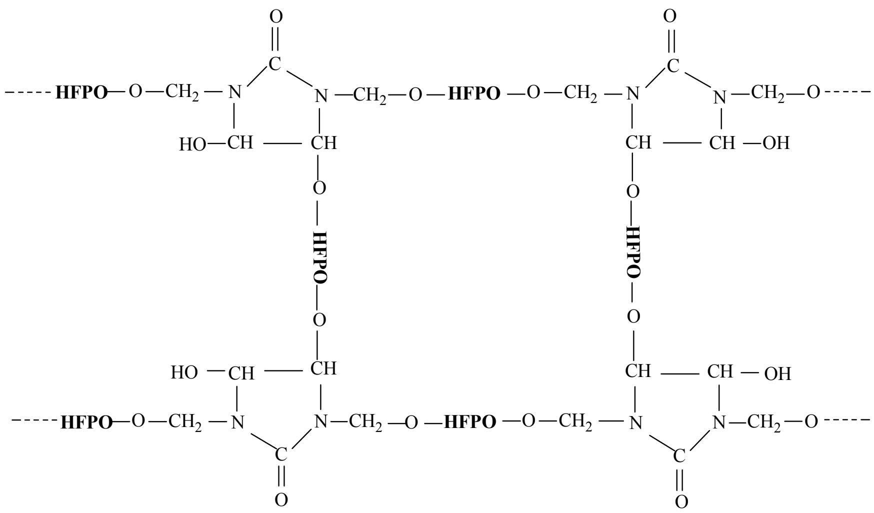
The combination of HFPO and DMDHEU was able to bond HFPO on 100% nylon fabric and the bonding was durable to home laundering. The nylon

6.6 fabric was first treated with the combination of 32% HFPO and DMDHEU at different concentrations, cured at 165ºC for 2 min, and finally subjected to 1 and 10 laundering cycles. The structure of DMDHEU was presented in Scheme 9.



Scheme 9 − DMDHEU.

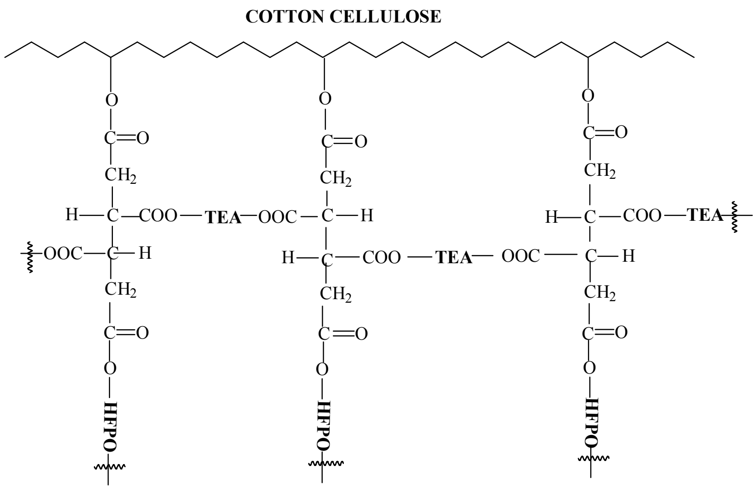
The data show that 75 and 45% of HFPO was bound to the nylon fabric after 1 and 10 launderings, respectively (Yang & Yang, 2009). For comparison, the nylon fabric was treated with 32% MDPA and DMDHEU at different concentrations, then cured at 165ºC for 2 min, and finally subjected to 1 laundering cycle. Very little phosphorus was bound to the fabric thus treated after one laundering cycle. Both HFPO and DMDHEU had multiple functional groups whereas MDPA, shown in Scheme 6, only has one reactive methylol group. Such a fundamental difference indicated that HFPO/DMDHEU probably formed a crosslinked polymeric network on nylon shown in Scheme 10, which was resistant to multiple launderings. The 50/50 nylon/cotton blend fabrics was treated with 32% HFPO and DMDHEU at different concentrations, cured at 165ºC for 2 min and subjected to home launderings. The data show that the fabrics treated with the formula at high DMDHEU concentrations passed the vertical burning test after 40 launderings (Yang & Yang, 2008).



Scheme 10 − Crosslinked polymeric network of TMM/HFPO on cotton.

1,2,3,4-Butanetetracarboxylic acid (BTCA), a well known nonformaldehyde crosslinking agent, was used as a bonding agent for HFPO as a formaldehyde-free flame retardant system on cotton (Yang & Wu, 2003a; Yang & Wu, 2003b). The free carboxy groups of BTCA on the cotton fabric treated with HFPO/BTCA form insoluble calcium salt on the fabric during laundering, thus diminishing the flame retardant performance of the HFPO-treated cotton (Yang & Wu, 2003a). The use of triethanolamine (TEA) as a co-reactant is able to estertfy the free carboxy groups of BTCA under the curing conditions, thus reducing the amount of calcium salt formation on the fabric. TEA also provides synergistic nitrogen to improve the flame retardancy of HFPO on cotton. The cotton fabric treated with the HFPO/BTCA/TEA is able to pass the vertical burning test after 5 home laundering cycles (Yang & Wu, 2003b). The HFPO/BTCA system was also used for the flame retardant finishing of silk. The treated silk fabric could retain ≥1.0% phosphorus and pass the vertical burning test after 15 hand washes (Guan *et al*., 2009).

The HFPO/BTCA/TEA system was used for the flame retardant finishing of nomex/cotton (65/35) blend military fabric (Yang & Yang, 2007). Nomex has been commonly used to produce fire-resistant protective clothing. Blending Nomex with cotton not only reduces the cost but also improves comfortability. However, the Nomex/cotton blend fabric containing more than 20% cotton is not self-extinguishable (Fukatsu, 2002). TEA has three hydroxy groups in its molecule and is able to react with carboxylic acid groups of BTCA by esterification. The data showed significantly increased laundering durability of HFPO at optimized TEA concentrations, which can be contributed to the formation of the BTCA/HFPO/TEA/cotton crosslinked network as shown in Scheme 11 (Yang & Yang, 2007).



Scheme 11 − Formation of BTCA/HFPO/TEA crosslinked network on cotton.

The Nomex/cotton blend fabric treated with 12% HFPO, 4%BTCA and 3%TEA has char length of 48 mm after 30 home laundering cycles with 27 and 20% tensile strength loss at the warp and filling directions, respectively (Yang & Yang, 2007).

Recently, new technologies such as nano particles and plasma surface treatment have been applied to cotton flame retardant finishing. However, such new technologies are not only very difficult to apply to cotton and extremely expensive, the flame retardant perofrmance and laundering durability of the treated cotton fabrics are far inferior than those treated with the traditional flame retardants (Yang (in print)).

4. Future Trends

Government regulatory activities on the flammability of various textile materials will likely continue to intensify in the decades to come. Since the annual structure fire fatality is still high (close to 3,000 in the U.S.), the flammability requirements for textiles used in home furnishing particularly are likely to become more stringent.

Public concern regarding the negative environment impact of flame retardants and related issues such as bio-accumulation will continue to be strong and scrutiny of the existing flame retardants will be vigorous. Public and regulatory agencies will remain hostile towards halogen-based flame retardants, and a few bromine flame retardants will be phased out or in some cases replaced by alternative new products with no migratory tendency. The formaldehyde-based flame retardants, which have been widely used for many years, will continuously be under pressure. Low formaldehyde release for flame retardant treatment will be required, and efforts to find replacement will continuously be intensive since formaldehyde has been upgraded to “carcinogenic to humans” by the working group of WHO International Agency for Research on Cancer in 2004 (Cogliano *et al*., 2004).

Demands for flame retardants in developed countries as well as in emerging markets, such as China, will continue to grow. Both the search for new more environment-friendly flame retardants and improvement of existing flame retardants will be accelerated due to strong demands, competition and cost considerations. Emphasis in flame retardants development will likely on increase of performance of the existing flame retardants and development of alternatives to replace the existing chemistry such as halogenated flame retardants and antimony oxides.

The flame retardant finishing of cotton blends will be of great interest in the coming decades since those blends are widely used in protective clothing due to their higher mechanical strength, easier drying and relatively low cost compared with aramid. The search for more effective and hydrolysis-resistance flame retardants for cotton blends, particularly cotton/polyester blends, will intensify.

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NOI DEZVOLTĂRI ÎN IGNIFUGAREA FIBRELOR DE BUMBAC ŞI A AMESTECURILOR CU BUMBAC

(Rezumat)

Inflamabilitatea reprezintă un risc real pentru utilizatorii de îmbrăcăminte din bumbac. Normativele impuse la nivel guvernamental au impulsionat dezvoltarea tratamentelor de finisare ignifugă a materialelor textile. Perioada 1950-1980 a reprezentat vârful cercetării în domeniul ignifugării. Cele mai multe substanțe folosite în tratamentele permanente şi semi-permanente de ignifugare au fost dezvoltate în acea perioadă. Exemplele de substanțe ignifuge pentru materiale din bumbac des utilizate includ: polifosfați de amoniu (APP), săruri de tetra(hidroximetil)fosfoniu (THPX), N,N'-dimetilol dialchil fosfonopropionamidă (MDPA) şi combinațiile de compuşi

organici cu halogen şi oxid antimonic folosite pentru peliculizare. Este clar că substanțele folosite pentru ignifugarea materialelor din bumbac prezintă diferite deficiențe şi nu îndeplinesc corespunzător cerințele impuse de destinație, precum menținerea rezistenței mecanice la un anumit nivel, menținerea tuşeului şi a altor proprietăți estetice, eliminarea prezenței formaldehidei în produsele textile şi compatibilitatea cu procesele de finisare prin fulardare-uscare-condensare. Începând cu 2000 s-au înregistrat mai multe tentative de a dezvolta substanțe pentru ignifugarea materialelor din bumbac şi alte tipuri de fibre mult mai eficiente, cu costuri reduse şi respectând cerințele privitoare la protecția mediului. În plus, în ciuda eforturilor depuse de cercetători pe durata mai multor decade, nu au fost obținute tratamente de ignifugare eficiente pentru îmbrăcămintea de protecție realizată din amestecuri poliester-bumbac. Se poate afirma că dezvoltarea unor tehnologii de ignifugare pentru amestecurile bumbac-poliester este o necesitate stringentă. Lucrarea ia în discuție cele mai noi dezvoltări ale tehnologiilor de ignifugare a materialelor din bumbac. Actualele provocări la nivel industrial se referă la: (1) continuarea procesului de îmbunătățire a performanței substanțelor ignifuge existente şi de reducere a impactului acestora asupra mediului; (2) dezvoltarea de noi variante ecologice de substanțe ignifuge, înlocuind substanțele de ignifugare pe bază de halogeni utilizate în peliculizarea materialelor textile cu bumbac în amestec.

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A STUDY ON THE INFLUENCE OF FIBRE PARAMETERS ON YARN EVENNESS USING STATISTICAL TECHNIQUES

BY

L.N. KINUTHIA[1*], J.R. OCHOLA[2] and J.I. MWASIAGI[2]

[1]Egerton University, Kenya,
Faculty of Education and Community Development Studies
[2]Moi University, Kenya,
School of Engineering

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Abstract. The evenness of a ring spun yarn could be considered as one of the most fundamental features of yarn attribute in the textile industry. The study of yarn evenness using statistical models characterizing yarn evenness as a function of fibre parameters is of at most importance in the process of yarn formation. In this paper yarn evenness and fibre characteristics data, were used to build Linear regression models for the estimation of the yarn evenness. Yarn count and twist were selected as predictors because of their great effect on the yarn properties. The sensitivity analysis from the input parameters on the output value showed that the fibre length and strength, besides yarn count and twist were the most dominant factors that influence the yarn evenness.

Key words: cotton yarn, cotton fibre, ring spinning, regression analysis, yarn quality.

*Corresponding author; *e-mail*: lydiankatha@yahoo.com

1. Introduction

Yarn evenness deals with the variation in yarn fineness and is commonly measured as the variation in mass per unit length along the yarn; it is therefore influential on various properties of fabrics made from it. Such variations are inevitable, because they arise from the fundamental nature of textile fibres and from their resulting arrangement. In this connection, the evenness of the yarn mass is of the greatest importance. In order to produce an absolutely regular yarn, all fibre characteristics would have to be uniformly distributed over the whole thread. The main aim of this investigation was to determine the relationship between ring spun yarn parameters and the fibre measurements using statistical techniques (El Mogahzy *et al.,* 1990; El Mogahzy *et al.,* 1988; Üreyen *et al.,* 2006; Hunter, 2004).

2. Materials and Methods

In this work, a total of 100 different cotton samples were collected in fibre form from a spinning mill in Kenya. Since the yarn manufacturing system is assumed to be an ergodic system, for every fibre sample collected, the yarn made from that lot was also collected at the ring frame. Fibre properties were measured from samples collected in the blow room section. Fibre length (ln), fineness (fi) and short fibre content (sf) were evaluated using the comb sorter. The fibre trash content (tc) was measured using the Shirley trash analyser while the micronaire value (mi) was measured on the micronaire tester. The fibre bundle strength (st) and fibre elongation (fe) were measured using the stellometer.

The yarn samples collected were of the following counts: Nm 14 (71.43 tex), Nm 18 (55.56 tex) and Nm 43 (23.26 tex). For a given yarn count collected the machine parameters were kept constant. These are the standard settings normally used by the spinning factors. Other spinning conditions were kept constant. For each yarn sample ten cops were collected and tested. The yarn twist (tp) was measured using the twist tester, yarn linear density (tx) was measured using the count tester and yarn irregularities (unevenness, neps, thick and thin places) were evaluated on the Uster tester. The measurements of the main fibre and yarn properties are shown in Table 1.

The linear regression method was chosen for establishing the model because it has the advantage of simplicity in describing the quantitative relationship between textile material properties. Therefore this method was selected for establishing the relationships between fibre and yarn properties. Due to the large number of fibre properties linear relationship between fibre properties and yarn properties was assumed, a linear regression analysis method was chosen for the study in order to establish a quantitative relationship of yarn properties with respect to fibre properties, yarn linear density and yarn twist.

Statistical analyses were performed using the SPSS 19 and Minitab 15 programs.

Table 1
Cotton Fibre and Yarn Properties

Parameters	Sf	Ln	fi	Fe	st	Mi	tc	Tp	Tx	tn	tk	Np
Units	[%]	[Mm]	[mm/g]	[%]	[cN/tex]	–	[%]	[tpi]	[tex]	–	–	–
Mean	5.89	28.47	1.23	4.3	31.23	2.74	7.97	14.71	50.53	10.01	2.14	38.98
Maximum	9.4	32.4	1.85	9.7	33.8	3.3	19.85	24.49	80.81	55	16	135
Minimum	2.8	23.6	0.63	1.2	27.5	2.45	2.7	9.07	19.73	0	0	2

where: uv − yarn unevenness, tp − yarn twist, tx − yarn linear density, sf − short fibre content, ln – fibre length, fi − fibre finness, fe – fibre elongation, st – fibre strength, mi – micronaire value, tc – trash content.

Regression analysis is the most common statistical method for estimation of the relationship between a dependent variable and one or more independent variables. This method has the advantage of simplicity in describing the quantitative relationship between textile material properties. Therefore, the multiple regression analysis method was selected for establishing the relationships between fibre and yarn properties. At the beginning, the types of relationship between selected properties (independent variables) and yarn evenness (dependent variables) were checked individually by using curve estimation and correlation analysis. Statistical analysis indicated that there was a near linear relationship between fibre properties and yarn properties. Hence, the linear regression analysis method was chosen for this study and the forward stepwise method was selected for linear regression analysis.

3. Results and Discussions

The model for predicting yarn evenness was developed using fibre parameters with yarn twist and yarn linear density as predictors.

3.1. Design of Regression Models

The fitted linear regression model (Eq. 1) exhibited an R value of 0.74 and as shown in Table 2; the model was acceptable since the F value was more than the F significant value.

Table 2
ANOVA Results for the Linear Model

	Df	SS	MS	F	Significance F
Regression	9	585.331	65.037	13.34	0.000
Residual	98	477.873	4.876		
Total	107	1063.204			

$$E = 34.6 - 0.0511ln - 0.120sf - 0.636fn - 0.007st + 0.256el - 3.61mi + 0.0521tc - 0.247tw - 0.109ct \quad (1)$$

3.2. Correlation Between Yarn Strength and Fibre Properties

The effect of fibre properties on yarn strength is given in Fig. 1. The factors with the highest effect are yarn count (ct), fibre strength (st) and fibre length (ln) giving a cumulative effect of 72.70%. Then fibre strength and fibre length stands out as the most influential fibre property which affects yarn evenness in ring spun yarn. This result agrees with the general industrial practice where fibre length is considered the most important fibre property in ring spinning. The fibre length also emerged as the most influential factor on yarn evenness; this is probably because high fibre length allows for more inter-fibre overlap leading to more cohesion between fibres. More fibre cohesion results in higher yarn evenness.

However, if the fibres are shorter *i.e.*, at low fibre length there is less inter-fibre overlapping and this would lead to less fibre cohesion thus production of yarns with low evenness on the ring frame machine, this is why the short fibre content (sf) also showed considerable influence of 4.93% on yarn evenness.

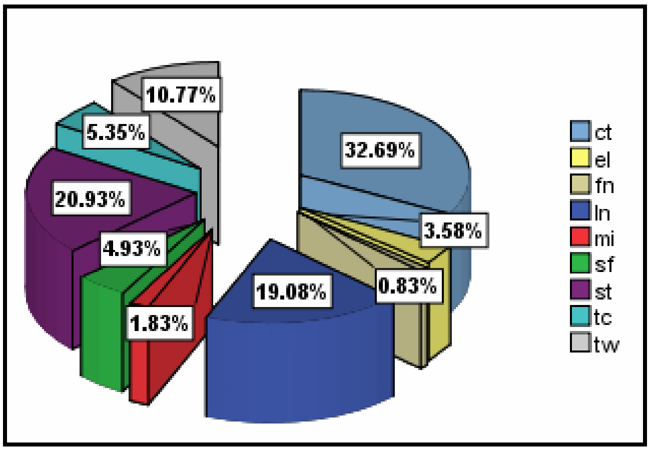

Fig. 1 – Effect of fibre properties on yarn evenness.

The trash content (tc) also had impact of yarn evenness of 5.35%. This is due to the fact that trash in the cotton lint could have an influence of yarn evenness mainly due to problems in cotton ginning and spinning process. If the trash in cotton was not removed in the ginning and in the subsequent spinning process, then it will have a negative impact on yarn evenness.

Other inputs that influenced the yarn evenness are: fibre elongation (el), micronaire value (mi), and fibre fineness (fi).

4. Conclusions

A study of the correlation between ring spun yarn evenness and cotton fibre properties was undertaken using regression models. The cotton and yarn samples were collected from factories in three factories in Kenya. The cotton samples were measure using efficient textile testing Instrument and selected factors together with yarn evenness used to design regression models. The linear regression model was used to study the influence of the fibre parameters on yarn evenness. The model exhibited a high R value and so it was used to study the correlation between yarn evenness and fibre properties. The results obtained in this research paper indicated that the most influential fibre factor which affected yarn evenness were fibre length and fibre strength. Other factors which recorded a substantial influence on yarn evenness were trash content and short fibre content. While it is normal for fibre length and strength to show a strong influence on yarn evenness, short fibre content and trash could have shown influence on yarn evenness due to problems during the growing and processing of the Kenyan cotton fibre.

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UN STUDIU PRIVIND INFLUENȚA PARAMETRILOR FIBRELOR ASUPRA UNIFORMITĂȚII FIRELOR FOLOSIND METODE STATISTICE

(Rezumat)

Uniformitatea firelor filate poate fi considerată ca una din cele mai importante caracteristici ale firelor folosite în industria textilă. Studiul uniformității firelor utilizând modele statistice pentru a define uniformitatea funcție de parametrii fibrelor este extrem de important în procesarea acestora. În lucrare se folosesc date experimentale legate de uniformitatea firelor şi caracteristicile fibrelor pentru a defini modele matematice de regresie linear în scopul estimării gradului de uniformitate a firelor. Parametrii finețe fir şi torsiune au fost aleşi pentru a caracteriza firele studiate, datorită influenței lor semnificative asupra proprietăților firelor. Analiza statistică a datelor a arătat că, pe lângă finețea şi torsiunea firelor, variabilele de intrare lungimea fibrelor şi rezistența fibrelor au cea mai mare influență asupra uniformității firelor.

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MATHEMATICAL MODELING FOR THE BREAKING STRENGTH OF THE JUTE FIBRES DEPENDING ON THE COMPONENTS OF THE EMULSIFYING SOLUTION

BY

VICA MOISĂ*

“Gheorghe Asachi” Technical College of Bucharest

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Abstract. Jute fibres spinnability is improved by the compatibility between the emulsifier, the change of the organo-mineral composition and the processed fibrous mass. After enriching the emulsion with emulsifiers, positive effects are generated upon the physical-mechanical characteristics (average fiber length, breaking force, and flexibility) that are also influenced by different technological factors (emulsification degree, percent of the oily/greasy substance, and emulsifying temperature).

Key words: jute fibres, emulsion, enriching, organo-mineral, Urea.

1. Introduction

The structure of the bast fibres and their lignin content determine many problems during the technological processing.

In order to improve spinnability, it is possible to act technologically by modifying the physical-mechanical characteristics of fibres through the components that form the emulsion, but also by changing the processing conditions as the emulsification degree (Moisă, 2006; Cuzic-Zăvonaru, 2001; Cojocaru, 1986; Buchman, 1980).

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*Corresponding author; *e-mail*: vica_moisa@yahoo.com

The results of the fibrous mass enriching during the experiments are materialized in the finished product (yarn) through the following effects: average length of fibres; yarn fineness (count and linear density); unevenness of linear density; breaking strength; breaking elongation. To test the efficiency of the enriching emulsifier over the low spinnability fibres, there were considered two cases, encoded V_1 and V_2 (Tossa jute fibres), that were treated with the emulsifying recipes R_1 (standard emulsion) and R_2 (modified emulsion) - as seen in Table 1.

Every physical-mechanical characteristic of bast fibres can be analyzed in correlation with processing technology and the emulsifying solution components; they are considered dependent variables Y_i. For the average length of fibres there were studied four dependent variables encoded Y_1, Y_2, Y_3, Y_4 (Moisă, 2006). They are not mentioned in this paper.

For the mathematical modeling of the breaking strength depending on the emulsification degree and the content of the greasy substance in the enriching emulsion, it was used a rotatable central composite design with two independent variables: X_2 quantity of greasy/oily substance, expressed in (%), and X_3 emulsification degree, also expressed in (%) (Moisă, 2006).

The codes and the real values of the independent variables are given in Table 2. Technically speaking, the encoding covered the entire domain of existence of the considered variables.

The dependent variables are: Y_5 − the breaking strength of fibres for experimental variant V_1, and Y_6 − the breaking strength of fibres for experimental variant V_2.

2. Materials and Methods

The components used in different concentrations, necessary for conducting the experiments, are given in Table 1.

Table 1

Components Used in Different Concentrations for Standard Variant and Best Variant

Nr.	Name of the component	R_1		R_2	
		V_1		V_2	
		[Kg]	[%]	[Kg]	[%]
1	Mineral oil	220	18	−	−
2	Diesel oil	60	5	−	−
3	Soap paste	48	4	48	4
4	Caustic soda	1.7	0.1	1.7	0.1
5	Marvelate	−	−	−	−
6	Organo-mineral salts	−	−	−	−
7	Urea	−	−	10	0.8
8	Solid fatty acid	−	−	75	6.2
9	Water	870.3	72.5	1065	88.7
	Total	1200	100	1200	100

For mathematical modeling and optimization of the dependent variables Y_5 and Y_6 it was used the software *Mathematics version 2.2*, but can be used *Matlab* too.

Table 2
Codes and Real Values for the Independent Variables

Variant	Parameter	UM	Code	Encoded values				
				−1.414	−1	0	+1	+1.414
V_1	Emulsification degree	[%]	X_3	10	12	17	23	25
	Quantity of greasy substance	[%]	X_2	20	23.4	31.5	39.6	43
V_2	Emulsification degree	[%]	X_3	2	3	4	5	6
	Quantity of greasy substance	[%]	X_2	22	23	25	27	28

The experimental data are shown in the following tables:

− breaking strength (cN) variation with the greasy substance (%) and the emulsification degree (%) – variant V_1 − Table 3;

− breaking strength (cN) variation with the greasy substance (%) and the emulsification degree (%) – variant V_2 − Table 4.

The emulsification degree is symbolized Ne, expressed in %, and the greasy substance is named St, also expressed in %.

Table 3
Matrix of Experiments for the Standard Variant (V_1)

Nr.	Code X_3	Real Ne, [%]	Code X_2	Real St, [%]	Y_5 Experimental values, [cN]	Y_5 Calculated, [cN]
1	+1	23	+1	39.6	90.7	90.626
2	+1	23	−1	23.4	83.7	84.208
3	-1	12	+1	39.6	136.1	135.90
4	-1	12	−1	23.4	112.8	113.20
5	−1.414	10	0	31.5	141.9	142.1
6	+1.414	25	0	31.5	89.6	89.625
7	0	17	−1.414	20	86.1	85.813
8	0	17	+1.414	43	105.8	106.40
9	0	17	0	31.5	133.7	131.91
10	0	17	0	31.5	133.7	131.91
11	0	17	0	31.5	133.7	131.91
12	0	17	0	31.5	133.7	131.91
13	0	17	0	31.5	133.7	131.91

Table 4
Matrix of Experiments for the Improved Variant (V_2)

Nr.	Code X_3	Real Ne, [%]	Code X_2	Real St, [%]	Y_6 Experimented, [cN]	Y_6 Calculated, [cN]
1	+1	5	+1	27	88.4	87.979
2	+1	5	−1	23	79.7	80.541
3	−1	3	+1	27	132.1	131.37
4	−1	3	−1	23	108.7	109.24
5	−1.4144	2	0	25	136.8	137.30
6	+1.414	6	0	25	86.3	86.336
7	0	4	−1.414	22	82.9	82.308
8	0	4	+1.414	28	102	103.21
9	0	4	0	25	129	127.14
10	0	4	0	25	129	127.14
11	0	4	0	25	129	127.14
12	0	4	0	25	129	127.14
13	0	4	0	25	129	127.14

3. Results and Discussions

The results were analyzed by using the regression equation type (1):

$$Y_0 = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{\substack{i,j=1 \\ i£j}}^{k} b_{ij} x_i x_j + \sum_{i=1}^{k} b_{ii} x_i^2 \tag{1}$$

The experimental data processing was done according to a second-order polynomial model (Moisa, 2006, Taloi, 1987). The computing was automatically achieved by the specialized program *Mathematics version 2.2.* The validation of the models was obtained by using tests t (Student) and F (Fisher).

For variant V_1, the experimental data led to the following equation:

$$Y_5 = 131.910 - 18.560\, X_2 + 7.280\, X_3 - 8.017\, X_2^2 - 4.070\, X_2X_3 - 17.907X_3^2 \tag{2}$$

The statistical coefficients for the breaking force of jute fibres variant V_1 are:

$b_0 = 131.910$; $b_1 = -18.56$; $b_2 = 7.280$; $b_{11} = -8.017$; $b_{12} = -4.070$; $b_{22} = -17.907$;

$t_1 = 130.109$; $t_2 = -23.57$; $t_3 = 9.07$; $t_4 = -9.32$; $t_5 = -20.82$; $t_6 = -3.60$.

The coefficients 1, 4, 5 and 6 are significant. The adequacy was validated with F-test, the statistical value being equal with $F_c = 0.056$.

The optimal point is:

Code $X_3 = -1.245$; real [%] = 11.34;
Code $X_2 = 0.34$; real [%] = 34.26;
$Y_{5,max.} = 136.66$ [cN]

The contour of the response surface (Fig. 1) corresponds to the mathematical model (2) and features an elliptic paraboloid, whose optimal point is the maximum point $Y_{5,max} = 136.66$ cN. Moreover, the performance function shows an increased density in quadrates 1, 2 and 4.

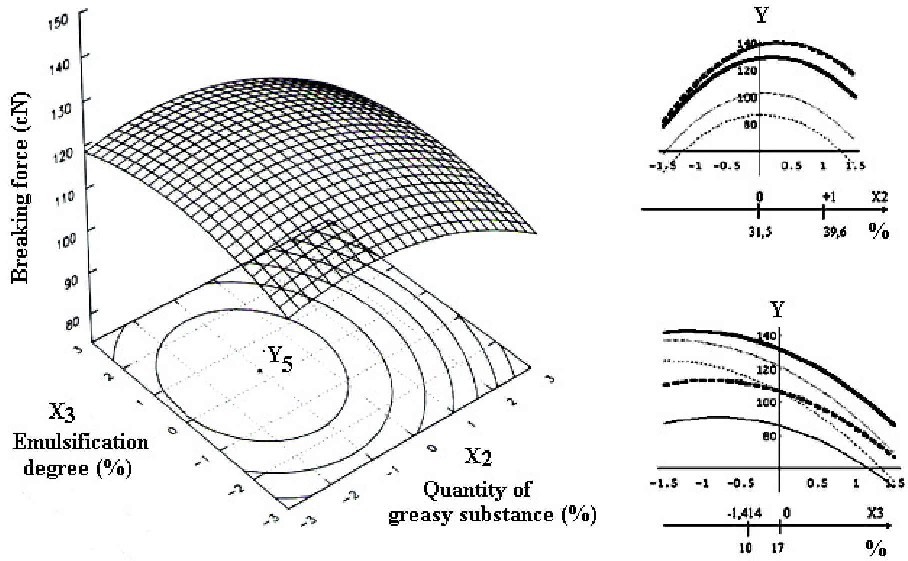

Fig. 1 − The response surface for Y_5 – variant V_1.

For variant V_2, the experimental data led to the following equation:

$$Y_6 = 127.146-18.024X_2+7.392X_3-7.664X_2^2-3.673X_2X_3-17.198X_3^2 \quad (3)$$

The statistical coefficients for the breaking force of jute fibres variant V_2 are:

$b_0 = 127.146$; $b_1 = -18.024$; $b_2 = 7.392$; $b_{11} = -7.664$; $b_{12} = 3.673$; $b_{22} = -17.198$;

$t_1 = 130.1$; $t_2 = -23.3$; $t_3 = 9.55$; $t_4 = -9.25$; $t_5 = -20.75$; $t_6 = -3.36$

All the coefficients are highly significant. The adequacy was tested by F-test, the statistical value was $F_c = 0.27$.

The optimal point is:
Code $X_3 = -1.26$; real [%] = 2.7;
Code $X_2 = 0.35$; real [%] = 25.7;
$Y_{6,max.} = 132.34$ [cN]

For Eq. (3), the contour of the response surface is represented in Fig. 2, showing an elliptic paraboloid whose optimal point is the maximum one: $Y_{6,max.}$ = 132.34 cN. The performance function shows an increased density in quadrates 1 and 4.

In both cases, the breaking force of the jute fibres is influenced by the emulsification degree and the quantity of greasy substance which create a lipid layer that plays a protective role for the surface of the fibres.

The new enriching emulsion which contains Urea and solid fatty acid, replacing the mineral oil and Diesel oil in standard emulsion, gives almost the same level of optimal breaking strength but with less percent of greasy substance (25.7% instead of 34.26%) and less emulsifying degree (2.7% instead of 11.34%).

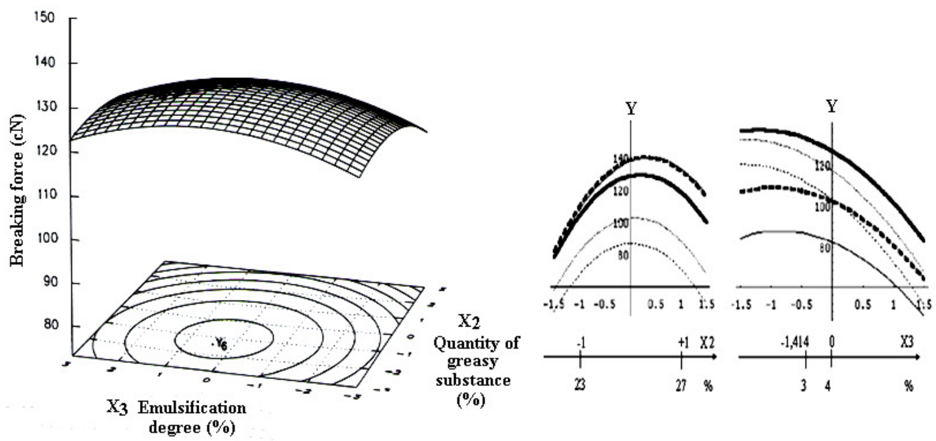

Fig. 2 – The response surface for Y_6 – variant V_2.

The new enriching emulsion which contains Urea and solid fatty acid, replacing the mineral oil and Diesel oil in standard emulsion, gives almost the same level of optimal breaking strength but with less percent of greasy substance (25.7% instead of 34.26%) and less emulsifying degree (2.7% instead of 11.34%).

The results of the conducted experiments confirm the necessity of ensuring an enriching level of the jute fibres because that will bring maximum efficiency of the technological processing.

4. Conclusions

1. The breaking strength of jute fibres reaches similar values (Figs. 1 and 2) corresponding to variants V_1 and V_2, enriched with the emulsification recipes R_1 and R_2. Variation limits for this characteristic, in the domain $X_2 \in [0; 1]$

and $X_3 \in [-1.414; 0]$ allow a proper processability of the jute fibres emulsified with recipes R_1 and R_2, in maximum efficiency conditions (Moisă, 2006).

2. The response surfaces for breaking force show a higher density in quadrates 1, 2 and 4 (Fig. 1), and quadrates 1 and 4 (Fig. 2) which proves a positive influence on the mechanical characteristics.

3. In conclusion, the researches underline the importance of independent variables X_3 (emulsification degree – level of emulsion load - %) and X_2 (greasy/oily substance content - %). These are the most important parameters for the mechanical characteristics because they set an optimum area for the response characteristics, taking in consideration both technical and economical considerations.

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MODELAREA MATEMATICĂ A REZISTENȚEI FIBRELOR DE IUTĂ ÎN FUNCȚIE DE COMPONENTELE SOLUȚIEI PENTRU EMULSIONARE

(Rezumat)

Filarea fibrelor de iută este îmbunătățită pe baza compatibilității între emulgator, modificarea compoziției organo-minerale şi masa fibroasă. În urma înnobilării rețetei de emulsionare cu emulgatori, apar efecte pozitive asupra caracteristicilor fizico-mecanice ale fibrelor de iută (lungimea medie a fibrelor, sarcina de rupere, flexibilitate), ce depind de o serie de factori (gradul de emulsionare, de procentul de substanță uleioasă/grasă şi de temperatura de emulsifiere). Efectele pozitive sunt argumentate prin optimizarea caracteristicilor fizico-mecanice ale fibrelor, folosind programe specializate precum *Matematica 2.2* sau *Matlab*.

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STUDY ON THE TECHNICAL WOVEN USED FOR MANUFACTURING BACKPACKS

BY

ADRIAN BUHU* **and LILIANA BUHU**

"Gheorghe Asachi" Technical University of Iaşi,
Faculty of Textiles & Leather Engineering and Industrial Management

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Abstract. Textiles are used in all areas of sport, in many games, such as sports equipment and sports footwear and other sports products. The clothing used in practicing various sports activities are made of textile materials, which ensures product's resistance, hygienic and aesthetic properties. Textile materials used are made from wool, cotton, chemical fibres or blends. The paper proposes a study of the physical and mechanical properties of fabrics used in the production of backpacks. It was studied in two types of materials existing on the market.

Key words: backpack, textile, coated weaves.

1. Introduction

Textiles are used in all areas of sport, in many games, such as sports equipment and sports footwear. Sports articles sector of the textile industry exhibit a great diversity in the market not only for fibrous materials, but also for modern technology as the other technologies in the sector of high-tech products. High-tech products are in a limited number, quality and design, to carry them

*Corresponding author; *e-mail*: adibuhu@tex.tuiasi.ro

out with more quality and not price. Articles for sports can be grouped by destination, thus:

− sports equipment;
− other sport products.

Each group comprises a varied assortment of articles that are, as the sport grows, work in a continuous diversification such as items of clothing for sports performance, fitness, dance, extreme sports (water sports, mountaineering, climbing, skiing, etc.), footwear for sport. The clothing used in practicing various sports activities are made of textile materials, which ensures product's resistance, hygienic and aesthetic properties. Textile materials used are made from wool, cotton, chemical fibres or blends. Clothing for sport is so accomplished that it satisfies the requirements of the destination (Bartels & Umbach, 2002).

The category of other sports including articles intended for various sports and activities can be classified according to the branch, in the following groups: articles for athletics and gymnastics; balls for games; articles for game room; articles for game field; articles for boxing, wrestling and weightlifting; winter sports articles; articles for water sports; articles for hunting and fishing. This category includes backpacks, umbrellas and tents.

Backpacks are now available in a wide variety of sizes, styles and types; some of them are economically designed for high-strength of nylon or polyester. Usually, there are weaves coated with PVC-based products, acrylates or polyurethane. Umbrellas can be polyester or acrylic; they have excellent resistance to UV radiation. The absorption of UV radiation for protection against skin cancer has become an important factor in the present. Tents are usually made of PVC-coated nylon or polyester. The material must be to prevent the water penetration. You may use and plain weaves covered with polypropylene.

Textiles for sports products used as raw materials of synthetic and natural polymers, inorganic materials (glass, metal, ceramic, carbon). The features that products must meet are: easy maintenance, comfort (air permeability, thermal insulation), UV protection, quick drying, anti-static, antibacterial capability behaviour and resistance to abrasion, tensile and low contraction. These features can be achieved by layering several textile products and not only (Braddock & O'Mahony, 1999).

Of the fabrics used, very popular fabrics are covered with nylon and polyurethane. These materials are covered, but cause the wearer discomfort. For this reason it was looking to obtain materials that may be water-proof, and allowing the skin to breathe. The main technical considerations for the protection of laminated fabrics are: durable, aesthetics and design, flexibility, tensile strength, resistance to abrasion (including peeling), dimensional stability (to wash), lightness and easy care.

The paper proposes a study of the physical and mechanical properties of fabrics used in the production of backpacks. The backpacks appeared in the 1920's, before them there was nothing but a bag tied with two belts, an object that became less comfortable as the increased weight. Lloyd F. Nelson is the one who has realized that the extra outer layer that makes the bag left behind by then to be more resistant and separates the objects in the backpack behind him whom they carried, to be more comfortable. Backpack, as we know it today was improved by some inventions of the 1950′s, which belong to Dick Kelty (Tao, 2001).

The fabrics used in making backpacks are trying to make a balance between strength and weight. The woven fabrics of polyamide (nylon) or polyester yarns increase resistance to friction and water infiltration. In the case excursionists backpack, reducing the weight of a few tens of grams can be done through the use of coated fabric with a layer of silicone, keeping the resistance.

2. Materials and Methods

Were studied two types of materials existing on the market, respectively: a black fabric in polyester, which is treated with a coating to increase the resistance of the product (sample 1), and a chequered fabric made of polyester that is attached to the heat sealed film offering resistance and impermeability of the product (sample 2). From the point of view of the structure, sample 1 is a fabric with 2/1 twill weave, and sample 2 is a fabric with 2/2 twill weave. A characteristic of twill weaves is the firmness. This strongly decreases as you increase the weave repeat.

Table 1
Mechanical Properties of Weaves

<table>
<tr><th colspan="2">Sample name</th><th>Breaking force [N]</th><th>Elongation [%]</th><th>Limit of proportionality [mm]</th><th>Absolute elongation [mm]</th><th>Mechanical work [J]</th></tr>
<tr><td colspan="2">Sample 1 warp</td><td>456.67</td><td>25.68</td><td>10.65</td><td>58.43</td><td>13.12</td></tr>
<tr><td colspan="2">Sample 1 weft</td><td>446.83</td><td>18.18</td><td>3.29</td><td>45.81</td><td>11.39</td></tr>
<tr><td rowspan="2">Sample 2 warp</td><td>1 (with film)</td><td>322</td><td>20.25</td><td>3.3</td><td>132</td><td>22.27</td></tr>
<tr><td>2 (without film)</td><td>169.4</td><td>14.4</td><td>5.55</td><td>55.8</td><td>6.17</td></tr>
<tr><td rowspan="2">Sample 2 weft</td><td>1 (with film)</td><td>227.3</td><td>23.12</td><td>4.32</td><td>71.7</td><td>10.87</td></tr>
<tr><td>2 (without film)</td><td>73.5</td><td>16.88</td><td>4.72</td><td>70.9</td><td>2.72</td></tr>
</table>

Durability is ensured through a set of properties that evaluates the performance of fabrics to mechanical stress: traction, tearing and abrasion. Testing was done on the dynamometer H5K-T for yarn and fabric, with calculation software QMAT TEXTILES.

The variation limits of the tensional properties of fabrics indicators (Table 1) are differentiated according to: the fibre composition of yarns, the parameters of the structure of the fabric, the parameters of processing and finishing of the yarn/fabric applied.

Resistance of fabrics from abrasive wear, as determined by various methods, depending on your interest for the effects of the request:

− abrasion up to a certain degree of wear surface of fabric;

− abrasion to the fabric surface degradation.

The fabrics were subjected to abrasion wear using the Martindale method. The samples were weighed by the fabric to determine the initial mass and then the samples were subjected to friction per 1000 cycles respectively 2000 cycles.

Table 2

The Friction Behaviour of Samples of Fabrics

Speed of rotation: 71.3 rev/min	Initial mass [mg]	Mass after 1000 cycles [mg]	Mass after 2000 cycles [mg]	Loss of mass [mg]
Sample 1	5013.9	5010.9	−	3
Sample 2 (without film)	5198.3	−	5178.1	20.2

3. Results and Discussions

After analysing the behaviour of the two types of samples were found several particularities. In the case of the sample 1, there is a difference between the fabric behaviour at the tensile request the two yarn systems: warp and weft. On the warp direction, strength and elongation at break are higher than the weft direction (Figs. 1 and 2).

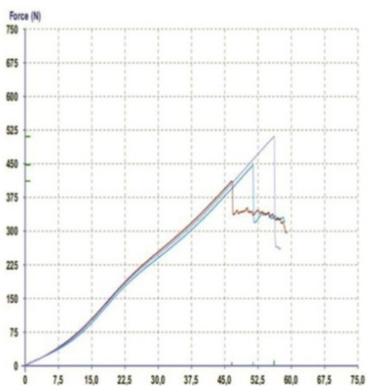

Fig. 1 – The diagrams force - extension on warp direction for sample 1.

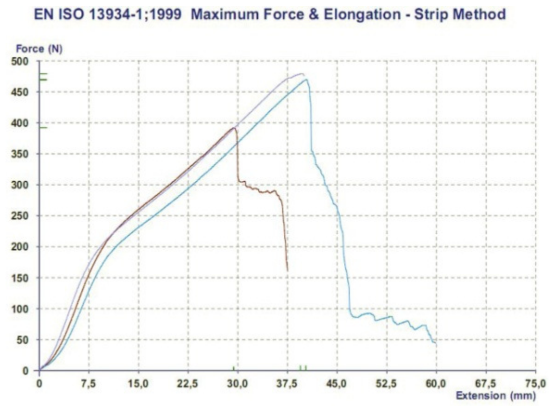

Fig. 2 – The diagrams force - extension on weft direction for sample 1.

This can be explained by the fact that the warp yarns have greater strength and a greater density. In the direction of warp can be seen that a small force of 40 N requests, elongation is relatively high – 7.5 mm, the elasticity of the fabric is great. At the direction of the weft, fabric is more rigid as a force of 180 N elongation request is 7.5 mm. This affects the dimensional stability of the product.

This behaviour is the fabric and the limits of proportionality: 10.65 mm in the direction of the warp and the direction of weft 3.29 mm. Taking into account that in this fabric backpack can be carried in the hand, which means changing the system of yarns that support the main requests, this product is not used for long-distance transport (mountain trails).

In the case of sample 2 you can compare both the two yarn systems, and the two types of samples in the direction of the warp and direction of the weft, weave with and without film. The resistance of the weave in the direction of warp is greater than weft in both for film coated fabric and uncoated fabric case. This is because as in the case of the sample 1, the fact that the warp yarns have greater strength and a greater density (Figs. 3 and 4). Unlike the sample 1 it can be seen that the relative elongation (%) is higher in the weft direction than warp direction. This is influenced by the characteristics of the yarns and fabric structure.

Analysing the samples with film, they have a much greater resistance than the uncoated, and etc. It was the role of coated fabric, to improve the properties of tensional of fabric. Sample 2 is a fabric with a density and a relatively small mass to decrease the weight of the final product. It can be seen that breaking is not suddenly, but the yarn with the yarn. Film resists to breakage, so after a maximum breaking force, weave has a high elongation breaking occurring later.

Fig. 3 − The diagrams force - extension of warp direction for sample 2;
A – with film; B – without film.

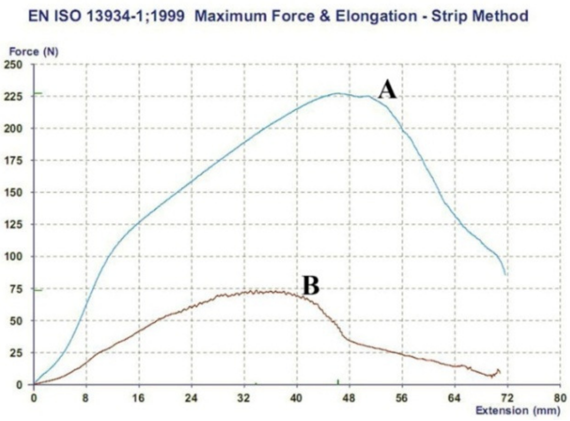

Fig. 4 − The diagrams force - extension of weft direction for sample 2;
A – with film; B – without film.

Performance of fabrics and products made from them can appreciate with resistance to friction wear. Sample 1 had a mass loss of 3 mg table following the request to 1000 cycles of friction. The fabric's appearance has changed, beginning to show the effect of pilling, Table 2.

Sample 2 had a mass loss of 20.2 mg following the request at the 2000 cycles of friction. Pilling effect is more pronounced, and due to the deterioration of the fabric changes its resistance characteristics. With the increase in the number of cycles friction has observed the effect of pilling. The effect of pilling propagates gradually, and the number of neps increases with the increase of the time of friction. The fibres are phased out through the effect of pilling, thus resulting in the loss of weight of the fabric. Materials subject to friction changes appearance to the surface, it gradually decreases the thickness by pilling effect, resulting in a lower surface resistance. During the process of abrasion of the fabric fibres are degraded or removed from the structure and the fabric strength is affected.

4. Conclusions

The paper proposes a study of the physical and mechanical properties of fabrics used in the production of backpacks. The backpacks appeared in the 1920's, before them there was nothing but a bag tied with two belts, an object that became less comfortable as the increased weight. Were studied two types of materials existing on the market, respectively: a black fabric in polyester, which is treated with a coating to increase the resistance of the product (sample 1), and a chequered fabric made of polyester that is attached to the heat sealed film offering resistance and impermeability of the product (sample 2). Following the analysis of mechanical properties of the fabrics it is found that:

− on the warp direction, strength and elongation at break are higher than the weft direction, explained by the fact that the warp yarns have greater strength and a greater density, for the both samples;

− applying a waterproofing for the second wave produces increased of resistance by 83% in the direction of warp, those with 200% in the direction of the weft, while the mass of weave remains low, the fabric can be used for backpacks used for long-distance transport (mountain trails);

− the breaking of the first sample is done immediately after reaching the maximum force, while the diagram for elongation – effort for second has a serrated shape, thanks to the gradual breaking, while the film extends the time of breaking. Because of this backpack can be used in the mid-market for the first sample;

− elongation at break is increased in the case of coated fabric with 40.6% in the warp direction, respective to 37% in the direction of the weft. It was the role of coated fabric, to improve the properties of tensional of fabric;

− behaviour to friction wear of the two fabrics is similar, the loss being between 0.06% and 0.4%, instead it appears the phenomenon of pilling will lead to decreasing the strength of woven fabrics.

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STUDIU ASUPRA ȚESĂTURILOR TEHNICE UTILIZATE PENTRU PRODUCEREA RUCSACILOR

(Rezumat)

Textilele sunt folosite în toate domeniile din sport cum ar fi echipamente pentru sport, încălțăminte şi alte produse pentru sport. Îmbrăcămintea folosită în practicarea diverselor activități sportive sunt realizate din materiale textile care asigură produse rezistente, proprietăți igienice şi estetice. Materialele textile utilizate sunt realizate din lână, bumbac, fibre chimice sau amestecuri. Articolul propune un studiu al proprietăților fizico-mecanice ale materialelor utilizate în producția de rucsaci. Au fost studiate două tipuri de materiale existente pe piață.

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EQUATIONS FOR PROGRAMMING THE TURN OF THE ROLL ON TANGENTIAL WINDINGS WITH CONSTANT RATE-DELIVERED TEXTILES

BY

DANIELA LIUŢE*

"Gheorghe Asachi" Technical University of Iaşi,
Faculty of Textiles & Leather Engineering and Industrial Management

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Abstract. The equations for self – regulation of roll's turning during winding of textiles delivered at constant rate by the drawing and delivery cylinders (warp windings on sizing machines) are presented. These equations establish the analytical functions which self – regulate the roll's turn, as a function of the product's characteristics, of the delivery rate, delivery and winding stresses of the product, the sequential coefficient of stress/elongation ratio, etc. Depending on the winded length, registered on line with an adequate program, the machine's computer may command the decrease of the roll's velocity.

Key words: warp, tangential winding, take up roll, turn, self – regulation.

1. Introduction

Intermediate products and plane textile goods (warps, weavings, etc.) are winded on rolls. For some textile machines (egg. sizing machines) winding stretch is established by modifying the ratio of the roll's winding speed and product delivering speed (*e.g.* warps) by the drawing and delivery roll.

*Corresponding author; *e-mail*: daliute@tex.tuiasi.ro

For the sizing machine (Fig. 1) the drawing and delivery of warp 1 is done by the active roll 2 and two auxiliary rolls. Usually, roll 3 is oscillating and has the supplementary function of measuring and commanding the self-regulation mechanisms of the warp's stretch by reducing the revolution of roll 5 with the increasing of the winding diameter. By using a computer, the command to oscillate is no longer given through the rotation of roll 5. In order to command the velocity of engine 6, a counter 4 is required to determine the winding warp's length or the number of winding rotation. The velocity is modified in relation to the R_x ray of winding on the roll 5.

The paper presents the principle of the technological equations which could be used in such a program. Previous related studies have shown such equations for winding (Liuțe & Racu, 2012; Liuțe & Liuțe, 2009).

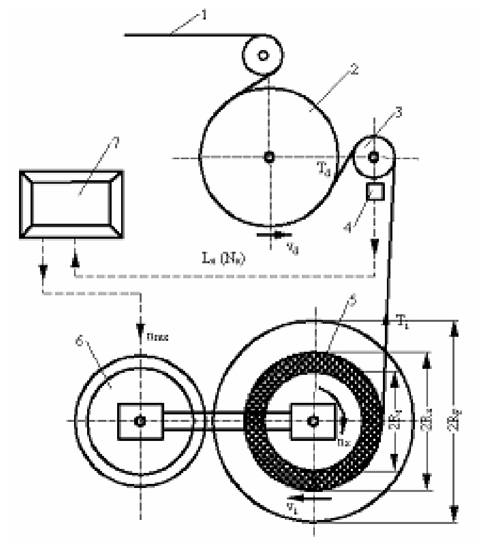

Fig. 1 − Principle of the warp.

2. Establishing the Self-regulating Technological Equations for the Roll's Rotation

The v_d speed of warp delivering mechanism 1 is constant. In relation to this speed, the warp's stretch in the area of the delivering roll 2 has a specific constant value (T_d) that is technologically known. The warp's stretch T at winding on the roll is adjusted at certain values by modifying the winding speed (v) in relation to the delivering speed of the warp (v_d). At the sizing machine, for instance, stretch T must be greater than stretch T_d resulting from $v > v_d$. The difference between the v and v_d speeds generates the stretch T that is a technological requirement for winding.

The increase of the yarn's stretch from value T_d to value T generates a certain sequential elongation of the yarn (ε_{di}) between the delivery rolls and the winding roll. For intervals similar to the elongation's variation and for its relatively small values, the proportionality equation between the stretch and the sequential stretching is:

$$T_i - T_d = K_{ps}\ \varepsilon_{di} \qquad \text{or} \qquad \Delta T_i = K_{sp}\ \varepsilon_{di} \tag{1}$$

where: K_{sp} – the sequential coefficient of proportionality between the sequential increasing of the yarn's elongation and its sequential stretching, [cN/%]; T_i and T_d – the yarn's elongation at the winding point on the roll, respectively the yarn's elongation at the delivery point of the drawing rolls; ΔT_i – the increase of the yarn's elongation at the delivery winding area; ε_{di} – the percentage of the lengthening of the yarn in the delivery winding area.

Cinematically, the elongation ε_{di} is determined by the following equation:

$$\varepsilon_{di} = \frac{v - v_d}{v_d} 100 \tag{2}$$

Therefore:

$$T_i - T_d = K_{sp} \frac{v - v_d}{v_d} 100 \tag{3}$$

Hence, the speed v of the roll winding is given by:

$$v = v_d \left(1 + \frac{T_i - T_d}{100\, K_{ps}} \right) \tag{4}$$

The roll winding speed is cinematically calculated with the following equation:

$$v = 2\pi R_x\, n_x \tag{5}$$

where: R_x – the winding ray which increases constantly; n_x – the roll turn which has to constantly decrease in order to maintain the constant speed v, respectively the elongation T.

By equating the technological speed with the cinematically calculated speed the following equation is obtained:

$$v_d \left(1 + \frac{T_i - T_d}{100\, K_{sp}}\right) = 2\, \pi\, R_x\, n_x \tag{6}$$

The roll turn has to decrease at the same time as the winding radius increases as follows:

$$n_x = \frac{v_d}{2\, \pi\, R_x}\left(1 + \frac{T_i - T_d}{100\, K_{sp}}\right) \tag{7}$$

The yarn's tensions (T) and (T_d) are technologically known and the sequential coefficients of proportionality tension/stretching K_{ps}, [cN/%] can be experimentally determined.

The command of the decrease of the roll's turn (n_x) can be determined by means of the measurement of the radius (R_x), by means of monitoring the winded length of the roll (L_x), or by means of monitoring the winding turns (N_x). Depending on the number of the winding turns, radius R_x is determined using one of the following equations:

− for fabrics with measurable δ

$$R_x = R_{x0} + \delta\, N_x \tag{8}$$

− for warps

$$R_x = R_{x0} + \frac{T_t P_u}{10^5 \rho} N_x \tag{9}$$

where: R_x – stands for the winding ray at one point in time, [cm]; R_{x0} – the initial ray of the roll (the support-tube) (cm); δ – the thickness of a lap winded on a take up roll, [cm]; N_x – the number of winding turns required for radius R_x (if these can be monitored); T_t – the fineness of the winded yarn, [tex]; P_u – the warp setting, [yarns/cm]; ρ – the winding density, [g/cm^3].

The expression of radius R_x depending on length L_x winded on the take up roll is given by the following equations (Liuțe & Liuțe, 2010):

− for fabrics with measurable δ,

$$R_x = \sqrt{R_{x0}^2 + \frac{\delta}{\pi} L_x} \tag{10}$$

− for warps

$$R_x = \sqrt{R_{x0}^2 + \frac{T_t\, P_u}{10^5\, \pi\, \rho} L_x} \tag{11}$$

where: L_x is the length of the fabric winded on the roll, [cm].

The equations necessary for determining the turn of the roll and used by a computer program for the turn self-regulation are:

$$n_x = \frac{v_d}{2\pi\left(R_{x0} + \delta\, N_x\right)}\left(1 + \frac{T_i - T_d}{100\, K_{sp}}\right) \tag{12}$$

$$n_x = \frac{v_d}{2\pi\left(R_{x0} + \frac{T_t\, P_u}{10^5\, \rho} N_x\right)}\left(1 + \frac{T_i - T_d}{100\, K_{sp}}\right) \tag{13}$$

$$n_x = \frac{v_d}{2\pi\sqrt{R_{x0}^2 + \frac{\delta\, L_x}{\pi}}}\left(1 + \frac{T_i - T_d}{100\, K_{sp}}\right) \tag{14}$$

$$n_x = \frac{v_d}{2\pi\sqrt{R_{x0}^2 + \frac{T_t\, P_u}{10^5\, \pi\, \rho} L_x}}\left(1 + \frac{T_i - T_d}{100\, K_{sp}}\right) \tag{15}$$

In all situations, the turn of the roll's engine (n_{mx}) can be determined by Eq. (16).

$$n_{mx} = n_x\, i_{sm} \tag{16}$$

where: i_{sm} − the reduction ratio between the roll and the engine.

3. Experimental Work

3.1. Determination of the Sequential Coefficient of Proportionality Tension/Elongation (K_{sp}) for the Rolling-up Zone

The experimental determination of the coefficient K_{sp} was made using the yarn strength tester. We have used three sizing yarns since we have studied the wrapping by the gumming machine. Table 1 shows the results obtained for three sizing stretched yarns.

Table 1

Tensions, Elongations, Sequential Proportionality Coefficients

Parameters	Determination	Yarn count		
		Nm 24/1 (41.66 tex) 100% cotton	Nm 40/1 (25 tex) 100% cotton	Nm 76/1 (13.15 tex) 65% PES + 35% cotton
Yarn tension at delivery rolls, T_d, [cN]	$T_d = (0.68 - 1.135)T_t$	41	22	13
Yarn tension at take-up roller, T_i, [cN]	$T_i = (1.17 - 1.60)T_t$	67	35	22
Tension growth from delivery rolls to take-up roller, T_{id}, [cN]	$T_{id} = T_i - T_d$	26	13	9
Yarn absolute elongation for tension T_d, a_d, [mm]	Display reading	0.95	0.75	0.7
Yarn relative elongation for tension T_d, [%]		0.19	0.15	0.14
Yarn absolute elongation for tension T_i, [mm]	Display reading	1.6	1.2	1.15
Yarn relative elongation for tension T_i, [%]		0.32	0.24	0.23
Growth of relative elongation of yarn a from delivery rolls to take-up roller, [%]		0.13	0.09	0.09
Sequential proportionality coefficient K_{sp}, [cN/%]		200	144.44	100

The sequential proportionality coefficients have different values for the winding zone, according to yarn properties. The elongation of the stretched yarns is less than the one of normal yarns, especially for very thick yarns. In the case of increased thickness, the sequential proportionality coefficients are also higher (K_{sp} = 200 cN/% for the thickness of a yarn, count Nm 20/1) in comparison to lower thickness (K_{sp} = 100 cN/% for the thickness of a PES + cotton yarn, count Nm 76/1).

3.2. Technical Data and Necessary Steps forTurn of Spindle Self-Regulation

A program for turn of spindle self-regulation based on Eq. (13) or (15), needs as input data the warp properties (T_t, P_u, ρ), the ray of the empty roll ($R_{xo} = R_t$) , the speed of delivery rollers (the slashing velocity), and the technological tensions T_d and T_i .

For a specified warp made at a given time, its parameters are constant. The turn of spindle will be comanded according to these constants and be self-regulated according to one of the following increasing values: the rolling ray R_x, the number of rollings N_x or the rolling length L_x.

For the rolling of slashed warps, the linear density of the slashed yarn is different from the one of the unslashed yarn. It is given by

$$T_{ti} = T_t \frac{100 + I_s - a}{100} \tag{18}$$

where: T_{ti} – the linear density of the stretched yarn, [tex]; T_t – the linear density of the normal yarn, [tex]; I_s – the load of the warp with the sizing at legal regain, [%]; a – growth of warp elongation from delivery rolls to take-up roller, [%].

Usualy the values T_{ti} have to be determined in laboratory. The constant values, the initial and final turn values of the take-up roll are given in Table 2. Fig. 2 shows the decreasing curves corresponding to the turn values of the take-up roll for three different warps. These curves depend on the yarns and warps properties.

Table 2

Constant Parameters Necessary to Determine the Variation of Turn Values of Take-Up Roll

Constructive and Technological parameters	Warp of yarns thickness:		
	41.66 tex 100% cotton	25 tex 100% cotton	13.15 tex 65%PES + 35% cotton
Ray of the empty roll ($R_t = R_{x0}$), [cm]	6	6	6
Speed of warp delivery by the control rolls, v_d, [cm/min]	4.000	5.000	5.000
Linear density of the sized yarn, T_{ti}, [tex]	43.74	26.5	14.07
Warp setting, P_u, [yarn/cm]	18	20	24
Density of winding, ρ, [g/cm^3]	0.42	0.43	0.45
Tension of the yarn in delivery roller zone, T_d, [cN/yarn]	41	22	13
Tension of the yarn at beaming, T_i, [cN/yarn]	67	35	22
Sequential proportionality coefficients, K_{sp}, [cN/%]	200	144.44	100
Initial turn value of the take-up roll, n_{x0}, [rot/min]	106.29	132.81	132.81
Final length of warp, L_f, [m]	1500	1500	1500
Turn of take-up roll n_{xf}, [rot/min] corresponding to a final length L_f = 1500 m	20.93	31.98	40.13
No. of revolutions of the spindle at a given moment, after N_x revolutions (N_x = 1500), n_{xf}, [rot/min]	1500	1500	1500
Final turn value of the take-up roll after 2000 revolutions, n_{xf}, [rot/min]	18.73	32.59	46.19

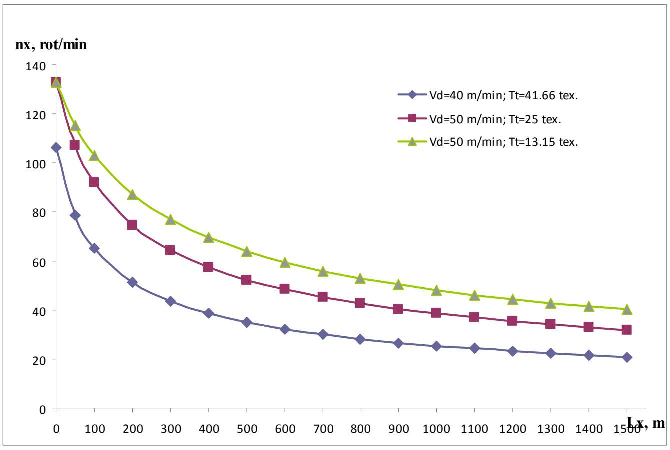

Fig. 2 − Variation of the turn of the take up roll with the warp length.

The algorithm for the calculus of the spindle's self-regulated speed based on the technological equations presented above includes the following steps:

1. Determine the sequential proportionality coefficient (K_{sp}), using a tensile testing machine;
2. Determine the yarn tension at winding T_i and in the previous zone T_d (take-up rolls);
3. Determine the linear density of the sized yarn (T_{ti}), if a sized warp is considered;
4. Define the warp setting (P_u) and the winding density as a function of yarn tension and the pressure of the roll;
5. The turn value (n_x) of the roll is calculated using Eq. (15) or a similar one;
6. Input of all constant values (kinetics, tehnological) corresponding to a given warp (Table 2);
7. Input of L_x, the length winded on the roll;
8. Calculation of n_x, the number of turns of the roll, and of n_{mx}, the revolutions of the engine, as function of L_x and the decrease of these values according to the equations presented in this paper.

4. Conclusions

1. The sequential proportionality coefficients for tension/elongation can be determined using tensile testing machines;
2. Knowing the sequential proportionality coefficients allows us to find out new technological equations for the self-regulation of the rotation of take-up rolls, according to the equations presented in the paper;
3. The technological principle described by the new equations allows the self-regulation of the speed of take-up rolls according to the length of the

winded warp. Therefore commands received from the tensioning roller are no longer needed;

4. As the tensioning roller no longer adjusts the speed, it only guides the warp yarns and its mechanisms are simplified.

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RELAȚII PENTRU PROGRAMAREA TURAȚIEI SULURILOR
LA ÎNFĂŞURĂRI TANGENȚIALE ALE TEXTILELOR
DEBITATE CU VITEZĂ CONSTANTĂ

(Rezumat)

Se prezintă relații care stabilesc funcții analitice după care se poate autoregla turația sulurilor în funcție de caracteristicile produsului, viteza de debitare, tensiunile produsului la debitare şi la înfăşurare, coeficientul secvențial de proporționalitate tensiune/alungire etc. În funcție de lungimea înfăşurată înregistrată on – line şi de un program adecvat, calculatorul maşinii poate comanda scăderea turației sulului, fără utilizarea unor cilindri oscilanți în funcție de tensiunea produsului.

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COMPRESSION AND BENDING STIFFNESS OF FUNCTIONAL WEFT KNITTED FABRICS

BY

CRINA BUHAI and MIRELA BLAGA[*]

“Gheorghe Asachi” Technical University of Iaşi,
Faculty of Textiles & Leather Engineering and Industrial Management

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Abstract. This paper presents an investigation on the compression properties and bending stiffness of weft knitted spacer fabrics. The spacer fabrics were manufactured on Stoll CMS 530 E 6.2 computer controlled flat knitting machine. Sixteen kinds of spacer fabrics have been resulted from the combination between different raw materials and four types of the knitted structures. In order to accomplish the physical and psychological comfort requirement of the users, for the face layer, worn next to the skin, was used a soy protein yarn Nm. 56/3 and as spacer yarns and second layer were used synthetic fibres: polyester Nm 30/3, polyamide Nm 50/3 and polypropylene Nm 16. This yarn configuration was used to maintain the body’s microclimate during physical effort or unfavorable climatic conditions.

The KES FB3-AUTO-A compression tester was used for testing the compression property of the spacer fabrics. The testing method was used according to the instruction manual from Kato Tech Co., Ltd and to determine the bending stiffness was used he textile Flexometer.

The results show that fabric structure, thickness, raw material rigidity and the degree of yarn torsion are some parameters with a high influence on the compression and bending stiffness.

The tested mechanical properties were analyzed in accordance to the fabrics parameters: structure, weight, porosity and fabric thickness. Statistical software

[*]Corresponding author; *e-mail*: mblaga@tex.tuiasi.ro

ANOVA and Statistical Regression were used to evaluate the significance of the structural parameters on the compression and bending stiffness properties.

Key words: compression, resilience, spacer weft knitted fabrics, bending stiffness.

1. Introduction

Weft knitted spacer fabrics found a fast development into a large range of products with applications in all areas of industry.

A great attention has been given to weft-knitted spacer fabrics due to their good transversal compressibility and excellent air permeability. Pereira *et al.* (2007) analyzed the physical-mechanical properties of some warp knitted fabrics designed for knee braces. The study indicates that in terms of dimensional properties, the knitted spacer fabrics have higher volume and lower bulk density than commercial structures. The researchers discovered that spacer fabrics are more suitable for knee braces than the commercial materials due to the fact that they are thinner and have lower weight. They also find out that the warp knitted spacer fabrics have similar breaking load values on course and wale direction, fact that makes the adequate for fabrics that require a uniform compression level.

Bakhtiari *et al*. (2006) analyzed the compression properties of the weft knitted fabrics made from shrinkable and non-shrinkable acrylic fibres. The knitted fabrics were produced with different structures and loop lengths. They find out that the fabrics with knit-tuck structure have higher compression rigidity than the knits with missed structures. Also the 20% shrinkable fibres are highly compressible.

Due to the fact that spacer fabrics are able to absorb kinetic mechanical energy under compression actions, Liu *et al.* (2011), used warp knitted spacer fabrics as a substituent for the polyurethane foams used for cushioning. These fabrics are more suitable for cushioning because of the better moisture transmission, very good compression behavior and similar energy absorption properties with the polyurethane foams.

The good comfort properties of these fabrics recommend them for apparels and medical care (Liu & Hu, 2011). Compression and bending stiffness of the weft knitted spacer fabrics are relevant mechanical properties, especially for functional clothing and cushioning.

Z.-Qun Du *et al*. (2011) studied the bending stiffness of textile fabrics, claiming that aesthetics and handle of textile products mainly depend on bending behavior. They also developed a handle evaluation system based on measuring and characterizing weight, bending, friction and tensile properties of the fabrics.

Ertekin and Marmarali (2012) discovered that the compression resistance of the spacer fabrics produced on circular knitting machines is significantly affected from the spacer yarn type, dial height and surface material.

To summarize, the compression and bending stiffness properties of the spacer fabrics are very important and they are designed according to the processing operations and the end-uses of the knitted fabrics.

2. Materials and Methods

The spacer fabrics have endless options regarding the potential yarns combinations and fabrics structures. Due to the fact that the knitted spacer fabrics are designed for functional clothing, for the face layer worn to the skin, was used a soy protein yarn Nm. 56/3 because of its good comfort properties and skin affinity, and as spacer yarns and second layer were used synthetic fibres: polyester Nm 30/3, polyamide Nm 50/3 and polypropylene Nm 16. This yarn configuration was used to maintain the body's microclimate during physical effort or unfavorable climatic conditions. The spacer fabrics were manufactured using Stoll CMS 530 E 6.2 computer controlled flat knitting machine. Sixteen kinds of spacer fabrics have been resulted from the combination between different raw materials and four types of the knitted structures. Fig. 1 displays the knitting sections of the four spacer structures denoted as S1, S2, S3 and S4.

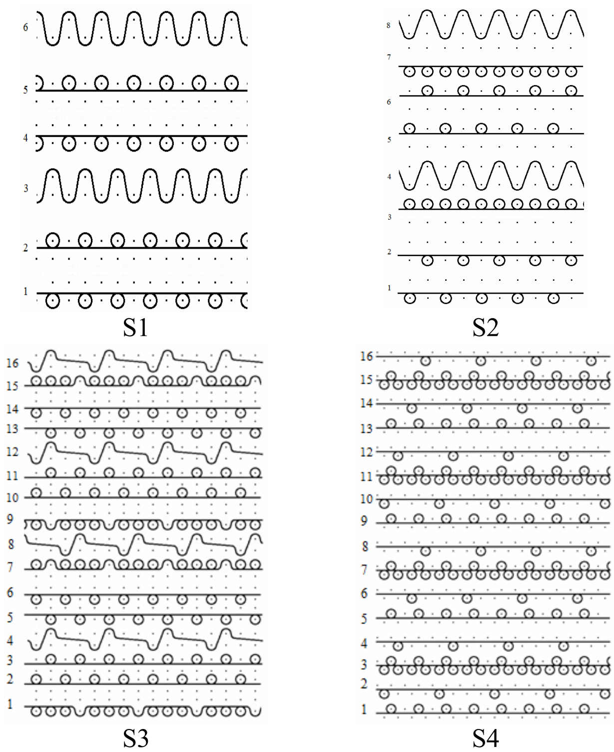

Fig. 1 − Knitting sections of the spacer structures.

The fabrics porosity was calculated with the Eq. 1:

$$P = (1 - m/\rho h)*100, \ \ [\%] \tag{1}$$

where: P – represents the fabric porosity, [%]; m –fabric weight, [g/cm^2]; ρ – density of the fiber, [g/cm^3]; h – fabric thickness, [cm].

Fabric engineering was carried out in order to create an experimental plan, able to performing some comparative analysis. Therefore, the structures S1 and S2 have the same connecting point's ratio but the structure of the outer layers is different. For structure S3 it can be observed in Table 1 that the number of connection points of the spacer yarn is lower, and the outer layers have knit and tucks in their structure. The structure S4 is formed mostly of missed stitches and the link between the two layers is made using a rib structure.

Statistical software was used to evaluate the experimental data and the analysis of variance (ANOVA) was used to evaluate the significance of fabric structural parameters on the comfort properties of the fabrics. To conclude whether the parameters are significant or not, p values were examined. Ergun (1995) has established that if "p" value of one parameter is greater than 0.05, this parameter will not present any influence and it will be ignored.

Table 1
Spacer Fabrics Characteristics

Fabric code	Structure of the spacer fabrics			Fabric density		Weight [g/m^2]	Thickness [mm]	Porosity [%]
	F	B	S	Wales /5cm	Courses /5cm			
S1	Soy	Soy	Soy	33	39	685	3.32	86.41
S1-1	Soy	PES	PES	33	38	542	2.54	85.17
S1-2	Soy	PA	PA	33	37	482	2.41	84.49
S1-3	Soy	PP	PP	33	40	763	4.05	83.61
S2	Soy	Soy	Soy	33	39	546	3.01	88.06
S2-1	Soy	PES	PES	30	38	443	2.27	86.42
S2-2	Soy	PA	PA	32	40	379	2.25	86.91
S2-3	Soy	PP	PP	33	41	685	3.63	83.57
S3	Soy	Soy	Soy	34	52	623	3.42	88.01
S3-1	Soy	PES	PES	34	50	507	2.97	88.13
S3-2	Soy	PA	PA	36	48	459	2.84	87.46
S3-3	Soy	PP	PP	34	54	725	3.87	83.70
S4	Soy	Soy	Soy	42	44	412	2.82	90.38
S4-1	Soy	PES	PES	42	44	376	2.91	91.13
S4-2	Soy	PA	PA	44	46	354	2.75	90.60
S4-3	Soy	PP	PP	42	46	487	3.28	88.39

F – Front layer; B – Back layer; S – Spacer yarn

3. Results and Discussions

3.1. Compression Properties of the Spacer Fabrics

The KES FB3-AUTO-A compression tester was used for testing the compression property of the spacer fabrics. The testing method was used according to the instruction manual from Kato Tech Co., Ltd (Kawabat & Niwa, 1996). Five measurements of each 20 cm x 20 cm size sample were taken under a maximum load of compression of 50 [gf/cm^2] and the average values were reported.

The parameters obtained from the compression hysteresis curves are defined in Table 2.

Table 2

The Compresion Properties of Spacer Fabrics

Fabric code	Linearity of compression	Work of compression [gf*cm/cm^2]	Resilience of compression [%]	Thickness at the maximum load, [mm]
S1	0.389	0.955	35.87	2.38
S1-1	0.521	1.040	35.39	1.75
S1-2	0.558	1.765	33.87	1.42
S1-3	0.772	1.057	29.74	3.47
S2	0.362	0.920	38.20	2.11
S2-1	0.544	1.210	36.10	1.13
S2-2	0.585	1.620	35.40	1.27
S2-3	0.725	1.112	31.22	3.02
S3	0.605	1.830	41.30	2.56
S3-1	0.387	1.210	35.74	2.01
S3-2	0.441	1.720	34.40	2.12
S3-3	0.762	1.206	30.70	3.26
S4	0.473	1.622	45.20	1.62
S4-1	0.524	1.674	42.50	1.70
S4-2	0.595	1.923	41.34	1.48
S4-3	0.622	1.470	33.20	2.61

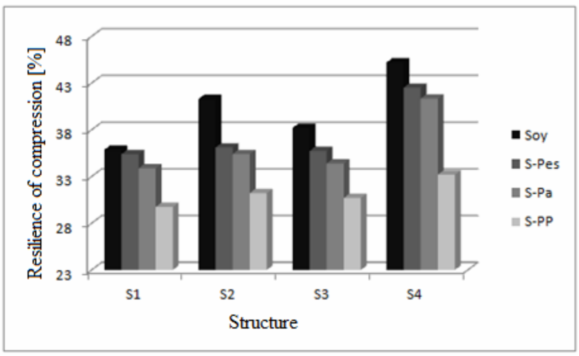

Fig. 2 − Weft knitted spacer fabrics resilience of compression.

Analysing the dates from Table 3, one can observe that, the linearity of compression is increasing with the fabric thickness. The resilience of compression is the percentage energy recovery from the compression deformation in the thickness direction. A higher resilience percentage indicates that the fabric has better recovery property.

From Fig. 2 it can be concluded that the raw material, fabric thickness, density, the arrangement and the connecting distance of the spacer yarn are factors that have a significant influence on the resilience of the spacer fabrics. Thus, structure S4 has the highest resilience and the structure S1 posses the lowest values of the compression resilience. More, the fabrics having both layers made of soy protein yarns have good resilience. By using a synthetic yarn for the reverse layer the resilience will decrease, the lowest values of the recovery it is shown by the fabrics that have the reverse layer made from polypropylene.

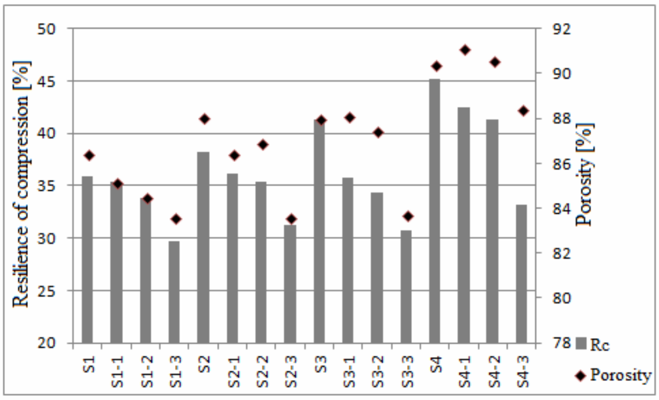

Fig. 3 − The relation of resilience of compression and porosity.

The relation between the resilience of compression and the porosity of spacer fabrics it is listed in Fig. 3. It can be noticed that the resilience is increasing with the porosity, so the higher is the porosity; the better is the fabric recovery from compression. The statistical analysis shows that the porosity has a significant effect on the fabrics resilience (p = 0.00035). Also the ANOVA analysis indicates a significant interaction between the raw material and the fabric resilience (p = 0.014) and between the linearity of compression and raw material (p = 0.0032).

3.2. Bending Stiffness of the Spacer Fabrics

Stiffness is the ability of material to resist at deformation. The bending length was determined with the Textile Flexometer as being the length under which the material will bend under an angle of 41º30' (Niculăiasa, 2000; Harpa

2003). Samples of 150 x 20 mm dimensions have been weighted, and a number of five measurements of the bending length were determined the average being listed in Table 3.

The bending stiffness was calculated using the formula:

$$R = m\left(\frac{L_c}{2}\right)^3, \text{ [cm]} \tag{1}$$

where: R – bending stiffness, [cm]; m – weight, [g]; L_c – bending length, [cm].

Table 3
Bending Stiffness of Spacer Fabrics

Fabric code	Wale direction			Course direction			Fabric bending stiffness [cm]
	Weight [g]	Bending length [cm]	Bending stiffness [cm]	Weight [g]	Bending length [cm]	Bending stiffness [cm]	
S1	2.45	3.75	129.20	2.6	3.53	113.88	121.30
S1-1	1.85	4.20	137.06	2.0	4.01	128.96	132.95
S1-2	1.80	4.26	138.67	1.9	4.10	130.95	134.75
S1-3	2.95	4.36	244.50	2.8	4.14	201.50	221.96
S2	1.75	3.59	80.97	1.8	2.55	29.85	49.16
S2-1	1.65	3.43	66.29	1.7	2.28	20.74	37.08
S2-2	1.35	3.8	74.08	1.6	3.15	50.01	60.87
S2-3	2.50	4.03	163.02	2.4	3.30	84.45	117.33
S3	2.05	3.64	98.87	2.1	3.01	57.27	75.25
S3-1	1.80	3.92	108.01	1.9	3.42	75.67	90.41
S3-2	1.70	4.13	119.32	1.8	3.87	103.93	111.36
S3-3	2.70	4.37	224.55	2.7	3.98	166.44	193.32
S4	1.65	3.33	60.65	1.9	2.47	27.88	41.12
S4-1	1.30	3.47	54.08	1.4	2.70	26.57	37.91
S4-2	1.45	3.62	68.50	1.5	2.45	21.19	38.10
S4-3	2.15	4.08	145.49	2.2	3.44	91.59	115.44

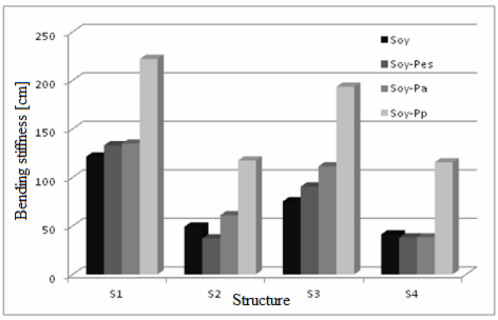

Fig. 4 – The bending stiffness of the weft knitted spacer fabrics.

Fig. 4 outlines the influence of the structure on the bending stiffness of the spacer fabrics. The structure S4 which is formed mostly of miss stitches has the lowest bending stifness, while the structure S1 due to the higher density of the conecting points of the spacer yarn and the density of the outer layers exhibits the highest bending stiffness. The fabrics that have the reverse layer made of polypropilene have the highest values of the bending stiffness due to the yarn rigidity and fabrick thickness.

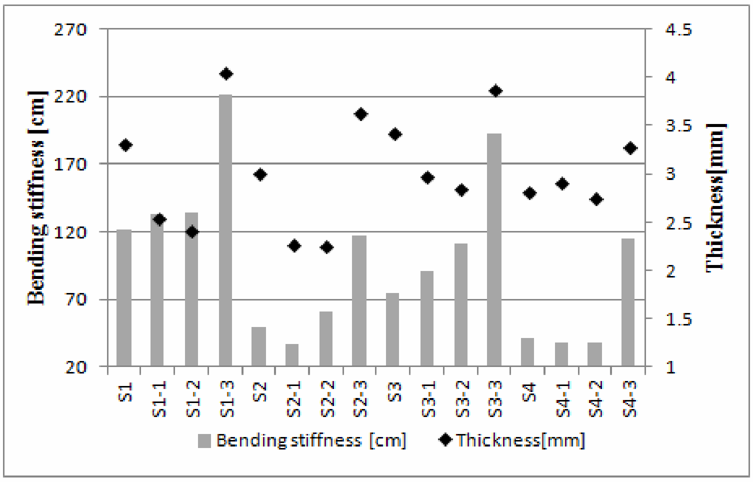

Fig. 5 − The relationship between bending stiffness and fabric thickness.

Fig. 5 outlines the relationship between bending stiffness and fabric thickness, clearly being that with the increasing of thickness the bending stiffness is higher. The statistical analysis confirm the relationship between the banding stiffness and fabric thickness since the p values is lower than 0.05 ($p = 0.007$).

However the fabric thickness is not a defining factor for the bending stiffness, the raw material rigidity and the degree of yarn torsion are also very important factors that have a strong influence on this property.

4. Conclusions

In this study, the compression and bending stiffness of weft knitted spacer fabrics designed for functional clothing were investigated, in relationship with yarn type distribution on the layers and fabrics parameters.

The fabric structure, fabric thickness, raw material rigidity and the degree of yarn torsion are some parameters having a high influence on the bending stiffness. The regression statistics demonstrates the influence of thickness on the analysed mechanical properties.

In case of compression properties of the spacer fabrics, from this study it can be concluded that the raw material, fabric thickness, stitch density and the cross section of the fabrics are significant factors. The fabrics having both layers from soy protein yarns show very good resilience. The resilience properties are decreased by using a synthetic yarn for the reverse layer of the spacer fabrics, the lowest values of the recovery it is shown by the fabrics that have the reverse layer made from polypropylene.

Statistical analysis was performed to determine the influence of porosity on the fabrics resilience of compression. ANOVA analysis indicates a significant interaction between the raw material and the fabric resilience and between the linearity of compression and raw material.

Structural design demonstrated a clear influence on the bending stiffness of the spacer fabrics.

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COMPRESIA ŞI RIGIDITATEA LA ÎNCOVOIERE A TRICOTURILOR DIN BĂTĂTURĂ STRATIFICATE

(Rezumat)

Această lucrare prezintă o cercetare asupra proprietăților de compresie şi rigiditate la încovoiere a tricoturilor din bătătură stratificate. Tricoturile stratificate au fost realizate pe maşina rectilinie electronică de tricotat din bătătură Stoll CMS 530, de finețe E 6.2. Şaisprezece variante de tricoturi stratificate au fost obținute prin combinarea diferitelor tipuri de materii prime şi a patru variante de structuri. În vederea îndeplinirii cerințelor fizice şi psihologice de confort, pentru stratul față, care vine în contact cu pielea s-a utilizat un fir cu proteine din soia de finețe Nm. 56/3, iar ca fire de legatură şi pentru stratul spate s-au folosit fibre sintetice: poliester Nm 30/3, poliamidă Nm 50/3 şi polipropilenă Nm 16. Această aranjare a firelor a fost stabilită pentru a menține microclimatul subvestimentar in timpul efortului fizic sau în condiții climatice nefavorabile.

Pentru a testa proprietățile de compresie ale tricoturilor stratificate s-a folosit aparatul KES FB3-AUTO, în conformitate cu manualul de instrucțiuni al Kato Tech Co, Ltd, iar pentru a determina rigiditatea la incovoiere s-a utilizat Flexometrul textil.

Rezultatele arată că structura tricotului, grosimea, rigiditatea firului şi torsiunea sunt parametrii care au o influență semnificativă asupra proprietăților de compresie şi rigiditate la încovoiere. Proprietățile mecanice testate au fost analizate în corelație cu parametrii de structură, respectiv: structura, masa, porozitatea şi grosimea materialului.

Pentru validarea influenței parametrilor de structură asupra proprietăților de compresie şi rigiditatea la încovoiere a tricoturilor stratificate, s-a efectuat analiza statistică şi regresia statistică ANOVA.

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CONSIDERATIONS REGARDING THE CONTROL OF FVF OF COMPOSITE MATERIALS REINFORCED WITH SANDWICH KNITTED FABRICS

BY

SAVIN DORIN IONESI[1*], ANA VIRCAN[1] and IONUȚ DULGHERIU[2]

“Gheorghe Asachi” Technical University of Iaşi,
[1]Doctoral School of the Faculty of Textiles & Leather Engineering and Industrial Management
[2]Faculty of Textiles & Leather Engineering and Industrial Management

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Abstract. Fibre Reinforced Composites are becoming the most popular materials in sport, automobiles, aerospace or other industries where high strength to low ratio is required. A fibre reinforced composite material is a material that contains fibres which provide strength and stiffness to it. The Fibre Volume Fraction (FVF) of composite materials has been found to manifest significant effects on composites mechanical properties, including failure mode, ultimate strength or impact resistance.

This paper presents the influence of reinforcement system and matrix used over the fibre volume fraction of composite materials. 3D sandwich knitted made by Kevlar, Twaron and Linen yarns were used as reinforcement system. The composite materials were prepared by Vacuum Assisted Resin Transfer Moulding (VARTM) technique using epoxy and polyester resins as matrix. The experimental results shown that the FVF of composites can be controlled by the structure of reinforcement preform and by matrix used.

Key words: composite materials, VARTM, reinforcement systems.

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[*]Corresponding author; *e-mail*: dionesi@tex.tuiasi.ro

1. Introduction

Composite materials concept is not new. This kind of materials can be found in ancient Egypt as clay bricks reinforced with straw. In 1942 the first boat made form laminated composites was produced and bi-dimensional laminated composited are used in high end applications from the early 70`s.

In last century the applications of fibre reinforce composite materials (FRCM) has grown exponentially, becoming the most popular materials in sport, automobiles, aerospace or other industries where high strength to low ratio is required. Their application areas show an extremely promising future in those domains where stress and fatigue of classical materials are considered the dominant mode of failure. Fig. 1 shows the main areas of application of FRCM and their market share reported to 2008 global production.

In European Union, the top consumers of FRCM are Germany, France and Italy due to major automotives and aeronautic industry present in these three countries, as shown in Fig. 2.

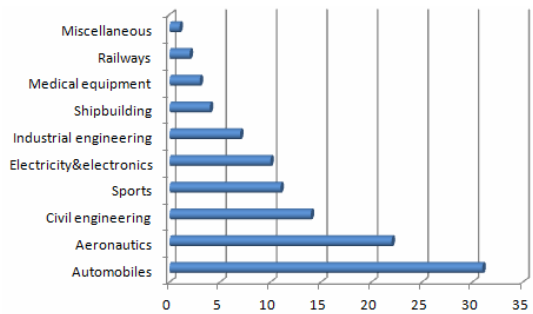

Fig. 1 − Application domains of composite material.

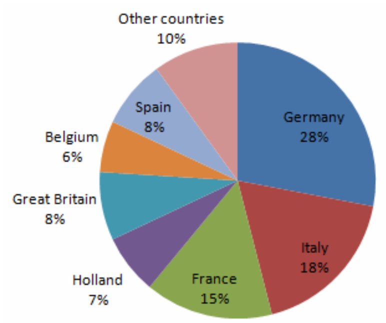

Fig. 2 − FRCM market in European Union.

The researches conducted in last decades were focused on development area in order to manufacture FRCM components with a higher strain/stress ratio than traditional materials (wood, steel) and lower production cost.

Fibre volume fraction (FVF) of FRCM represents the mass of reinforcement material from the total composite mass. Several researchers (Budan, 2011; Rejab, 2008; Wasik, 2005) concluded that FVF have a decisive influence over the mechanical properties of FRCM, especially on impact resistance, rigidity and tensile strength. As a general rule, mechanical properties of FRCM will increase proportionally with the FVF up to a point. If the FVF value is too high (more than 90%) FRCM properties are negatively influenced due to reduced quantity of resin. This situation causes the formation of areas in composite plate with insufficient resin-reinforcement material interface.

2. Materials and Methods

The experimental work focused on the study of influence of reinforcement structure and matrix used over the FVF of FRCM. In order to do this para-aramid (Kevlar and Twaron) and natural technical fibres (Linen) were used. Para-aramid fibres are the choice for any products used to improve mechanical behaviour, but they are rather expensive. Linen is a technical fibre that is cheap and presents acceptable tensile characteristics. The tensile properties of selected fibres are presented in Table 1.

Table 1
Tensile Properties of Selected Fibres

	Kevlar	Twaron	Linen
Densit, [g/cm^3]	1.44	1.44−1.45	1.54
Fiber diameter, [μm]	12	12−14	5−7
Modulus, [GPa]	131	60−120	27
Tenacity, [GPa]	3.6−4.1	2.6	0.54
Elongation, [%]	2.8	2.2-3.6	3

The 3D U sandwich knitted preforms were programmed on a Sirix station and the technological parameters were set for optimum quality. The fabrics were produced using a STOLL CMS 320 TC weft flat knitting machine, gauge 10E. The outer layers were knitted with Kevlar and Twaron yarns (as transversal reinforcement yarns), while Linen and Kevlar yarns were used for the connecting layers, as presented in Table 2.

Table 2
Raw Materials Used for Producing Sandwich Fabrics

<table>
<tr><th rowspan="2">Sample</th><th colspan="2">Outer layers</th><th colspan="2">Connecting layer</th></tr>
<tr><th>Yarn type</th><th>Linear density (tex)</th><th>Yarn type</th><th>Linear density (tex)</th></tr>
<tr><td>1</td><td>Kevlar®</td><td>28</td><td>Kevlar®</td><td>28</td></tr>
<tr><td>2</td><td>Kevlar®</td><td>28</td><td>Linen</td><td>20</td></tr>
<tr><td rowspan="2">3</td><td>Kevlar®</td><td>28</td><td rowspan="2">Kevlar®</td><td rowspan="2">28</td></tr>
<tr><td>Twaron®</td><td>6</td></tr>
<tr><td rowspan="2">4</td><td>Kevlar®</td><td>2</td><td rowspan="2">Linen®</td><td rowspan="2">20</td></tr>
<tr><td>Twaron®</td><td>6</td></tr>
</table>

The composite materials were prepared using VARTM technique and epoxy and polyester resins as matrix. After infusion, the composite materials were cured at room temperature (23°C), the composite with epoxy for 46 h and the one with polyester for 23 h. The epoxy matrix had a mixing ratio of 30% EPIKURE Curing Agent 04908 and 5% Dearing agent BYK A535 while for the polyester resin the mixing contained 1.5% of initiator for unsaturated polyester resin NOROX MCP 75 and 0.08% polyester inhibitor NLC 10.

The final aspect of the knitted preforms is presented in Fig. 3 and the final aspect of FRCM is presented in Fig. 4.

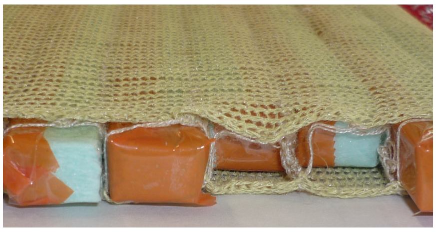

Fig. 3 – Final aspect of U shaped sandwich knitted perform.

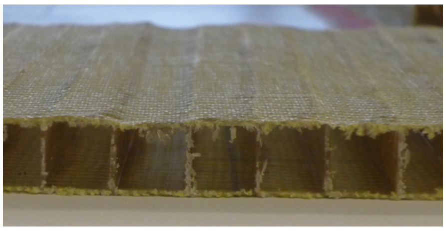

Fig. 4 – Final aspect of FRCM.

FVF of FRCM has been experimentally determined according to the follow relation:

$$F_v = \frac{p_m * W_f}{p_f * W_m + p_m * W_f} \quad (1)$$

where: F_v – fibre volume fraction; W_f – reinforcement material mass; W_m – matrix mass; p_f – reinforcement material density; p_m – matrix density.

3. Results and Discussions

The FVF has been determined for all FRCM manufactured according to the experimental matrix and results are presented in Table 3 and graphically represented in Fig. 5.

Table 3

FVF of Composite Materials

Resin	Reinforcement	Composite mass, [g]	Reinforcement mass, [g]	FVF [%]
Epoxy	Kevlar	13.2	3.9	29
	Kevlar Linen	11.5	3.7	32
	Kevlar Twaron	19.3	6.4	33
	Kevlar Twaron Linen	18.1	6.27	34
Polyester	Kevlar	15.3	3.9	25
	Kevlar Linen	14	3.7	26
	Kevlar Twaron	18.7	6.4	34
	Kevlar Twaron Linen	17.2	6.27	36

It can be remarked that the best FVF ratio has been obtained for composite materials reinforced with Kevlar, Twaron and Linen yarns, for both considered resins.

Another aspect that has to be noticed is that the use of Twaron yarn as transversal yarn has a direct influence on the reinforcement mass. This fact is generally valid for all FRCM manufactured according to the experimental matrix, as illustrated in Figs. 6 and 7.

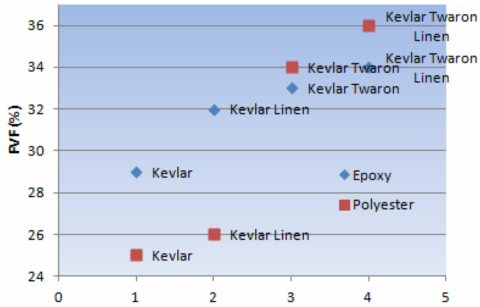

Fig. 5 – FVF of composite materials

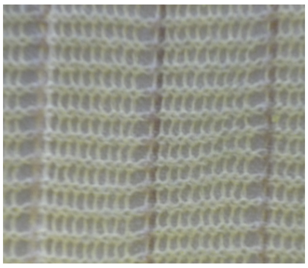

Fig. 6 – Aspect of FRCM without Twaron yarns.

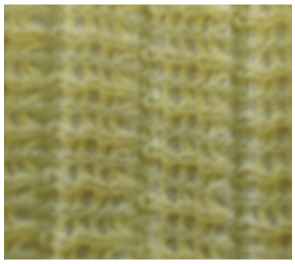

Fig. 7 – Aspect of FRCM with Twaron yarns.

Comparing the FVF ratio that was obtained using the same reinforcement materials but different resins it can be remarked that for epoxy resins the ratio is higher by about 20% for first two reinforcement systems. When the Twaron yarns are used this difference is lower, the FVF ratio been almost equal.

4. Conclusions

Composite materials with sandwich knitted fabrics as reinforcement material and termoset matrix (epoxy and polyester) were successfully developed using VARTM infusion technique.

The best FVF ratio has been obtained for composite materials that used laid-in Twaron yarns in the structure of the outer layers.

In order to improve the FVF of composite materials reinforced with sandwich knitted fabrics the following solutions can be applied:

− use of knitted structures with reinforcement yarns on both directions (weft and warp);

− use of knitted machines equipped with auxiliary needle beds in order to knit the outer and connecting layers on all needles and increase fabric compactness;

− use of split technique when a connecting layer is introduced;

− use of technical yarns with linear density situated in the upper range of the specific interval given by the correlation yarn/machine gauge.

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CONSIDERAȚII PRIVIND CONTROLUL FRACȚIEI VOLUMICE A MATERIALELOR COMPOZITE RANFORSATE CU STRUCTURI SANDWICH TRICOTATE

(Rezumat)

Materialele compozite ranforsate cu structuri fibroase sunt utilizate pe o scară tot mai largă în domenii precum industria automobilelor, aeronautică sau alte industrii în care este necesară rezistență ridicată şi o greutate redusă. Un material compozit ranforsat cu fibre este un material ce foloseşte ca sistem de ranforsare structuri fibroase în vederea obținerii rigidității şi rezistenței specificate. Fracția volumică a materialelor compozite influențează în mod hotărâtor proprietățile mecanice ale acestora, în special modul de rupere, rezistența la impact sau la penetrare.

Lucrarea prezintă influența sistemului de ranforsare şi a matricei utilizate asupra fracției volumice a materialelor compozite ce folosesc structuri sandwich ce au la bază fire de Kevlar, Twaron şi In ca material de ranforsare şi răşini epoxidice şi poliesterice ca matrice. În vederea producerii acestora a fost utilizată tehnologia VARTM. Rezultatele experimentale demonstrează faptul că fracția volumică a materialelor compozite poate fi controlată prin intermediul structurii de ranforsare şi a matricei utilizate.

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TEAM ROLES BALANCE
THEORETICAL CONSIDERATION

BY

SIMONA LUPULEAC and ZENICA-LIVIA LUPULEAC [*]

“Gheorghe Asachi” Technical University of Iaşi,
Faculty of Textiles & Leather Engineering and Industrial Management

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Abstract. During the last years, some theories have been postulated to test the team roles balance effects on team performance. However, the impact of team composition on performance and moderating variables potentially affecting this relationship is still not clearly understood, and research have produced mixed findings. This review proposes some suggestion to improve team balance measurement for increasing team performance. The implications of this review for future research and organizational practices are also discussed.

Key words: team roles, team balance, team performance, team motivation.

1. Introduction

One of the team-related factors that can affect performance is the team roles composition of members (Belbin, 2010a). According to Belbin team roles are useful behaviours which make an effective contribution to team performance which can be grouped according to the type of effect (Belbin, 2010b). Previous research (Aritzeta *et al.*, 2007; Harrison & Klein, 2007; Partington & Harris, 1999; Higgs, 2005; Chong 2007; Villado *et al.*, 2011) did not show strong support for this proposition. This may be because the definition

[*]Corresponding author; *e-mail*: zenylivy@yahoo.com

of what constitutes a balanced team they used is not isomorphic with the qualitative notions Belbin used to define the idea of balanced teams. The mix of team roles is than just sets of skills, knowledge, and competencies; there has to be more than quantitative aspect to be taken into account for team balance. However, given the centrality of the concept of roles balance, it was decided that a more rigorous approach to calculating balance is required.

2. Materials and Methods

This paper try to propose some suggestions to improve team roles balance measurement taking into account Belbin qualitative framework and some information that literature provides.

Meredith Belbin, in his book "Why They Succeed or Fail", 2010 sustain that personality it is a critical factor for team performance and give as some examples. Also Belbin consider two types of team built for different purposes, each to contain five members and give a design format for two five-member teams.

In Sandra Krebs Hirsh and Jane are analyzed 8 personality types using MBTI tool and the way this personality types can be used to improve team performance.

Manning *et al*. (2006) found the relationships between five personality dimensions (using Big Five Theory) and Belbin team role behaviour. For example they found that extroverted individuals tended to have high scores on the following team role scales: Shaper, Resource Investigator and Co-ordinator. It is the view of the authors that the concepts of team role and personality have become inter-twined in Belbin's model of team roles, in that a team role is seen essentially as a cluster of personality characteristics.

Now the big questions are: what team balance is mean; how can we design balanced teams when team size is less than nine; who works best with whom; which of the multitude of teams that can be generated are better?

3. Results and Discussions

This concept of a team role is very psychological in nature (Manning *et al.,* 2006) so we can conclude that team balance calculation need a psychological approach. According to Belbin the degree of 'balance' in a team depends on the extent all nine roles are represented 'naturally'. Belbin's (1993) classification of individuals into their 'natural' and 'secondary' roles applies to relatively small teams of up to six persons. This concept that a person can have more than one personality type is supported also by Krebs & Kise (2006) and others authors.

In the same time we have to consider team task complexity (Higgs, 2005) to choose the roles for a team Considering One of Belbin's notions not incorporated in the team balance scores is the notion of role conflict. This type of conflict can occur on an intrapersonal level and interpersonal level. On an interpersonal level there are combinations of roles that are unlikely. Belbin takes the example of a shaper/team worker combination. Belbin argues that all these cases exemplify someone who can potentially make a valuable contribution to a team but who is unlikely to do so. His natural Team Role will be blocked either by the apparent lack of need for it or by the presence of competing persons. That does not mean that his Team Role will be enacted by another.

The authors try to define the notion of balanced teams in terms of measurable quantities. If we use Blau's index all nine teams have "equal balance". The same it is happens if we are considering a team with 5 different team roles compared to another that has 4 different team roles. The team with 5 team roles it will have a 'better balance' than the 4 one has (with Blau's index).

If we consider any eight of the nine roles and we use Combination Formula (C98) we can build nine different teams (Fig. 1).

- Team 1:TW RI ME IMP PL CO SH SP
- Team 2:TW RI ME IMP PL CO SH CF
- Team 3:TW RI ME IMP PL CO SP CF
- Team 4:TW RI ME IMP PL SH SP CF
- Team 5:TW RI ME IMP CO SH SP CF
- Team 6:TW RI ME PL CO SH SP CF
- Team 7:TW RI IMP PL CO SH SP CF
- Team 8:TW ME IMP PL CO SH SP CF
- Team 9:RI ME IMP PL CO SH SP CF

Fig. 1 – 9 different team with 8 team roles.

Regarding the methods used for measuring team roles balance until now it can be made some improving:

– One of Belbin's notions not incorporated in the team balance scores is the notion of role conflict. Belbin sustain that there are combinations of roles that are unlikely. Belbin argues that this case exemplify someone who can potentially make a valuable contribution to a team but who is unlikely to do so. His Team Role will be blocked either by the apparent lack of need for it or by the presence of competing persons. That does not mean that his Team Role will be enacted by another.

– Team type - team balance depends also on the type of tasks;

– All nine roles has to be represented for team performance (Belbin's Theory, Diversity-Variety and team performance);

– A member can have more than one role in a team (Roles Theory, Personality Theory);

− Team roles categorisation made by some authors;

− Belbin 2010: Into the ark the managers went two by two. There were two types of negotiator (Resource Investigator (RI) and TeamWorker (TW)), manager-worker (Implementer (IMP) and Completer Finisher (CF)), intellectual (Monitor Evaluator (ME) and Plant (PL)), and team leader (Co-ordinator (CO) and Shaper (SH)). These ark members in all the various combinations of characteristics provide the basic material for assuring team performance and motivation;

− Belbin 2010: Belbin argues that typical ineffective team occur where obstacles prevent individuals finding their preferred Team Role. This can be true for any Team Role.

4. Conclusions

Previous research (Partington & Harris, 1999; Higgs, 2005; Chong 2007) did not show strong support for this proposition. This may be because the definition of what constitutes a balanced team they used is not isomorphic with the qualitative notions Belbin used to define the idea of balanced teams.

This concept of a team role is very psychological in nature (Manning *et al.,* 2006), so we can conclude that team balance calculation need and a psychological approach.

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ECHILIBRUL ROLURILOR ÎN ECHIPĂ
Consideraţii teoretice

(Rezumat)

În ultimii ani, unele teorii au fost postulate pentru a testa efectele echilibrului de roluri în echipă asupra performanţei echipei. Cu toate acestea, impactul componenţei echipei asupra performanţei şi a factorilor care pot afecta această relaţie nu este încă clar înţeles, cercetările producând rezultate mixte. Această lucrare propune câteva sugestii pentru a îmbunătăţi măsurarea echilibrului de roluri de echipă în vederea creşterii performanţei echipei. De asemenea, sunt redate implicaţiile acestei lucrări pentru cercetări viitoare şi practici organizaţionale.