Ana Ramona Ciobanu[1], Luminita Ciobanu[1], Catalin Dumitras[2], Bogdan Sârghie[1]

[1]Department of Knitting and Clothing Engineering,
E-mail: ciobanu.luminita66@gmail.com

[2]Department of Machine Tools Design,
„Gheorghe Asachi" Technical University of Iasi
Mangeron 67, Iasi 700050, Rumunia

Comparative Analysis of the Bursting Strength of Knitted Sandwich Fabrics

DOI: 10.5604/12303666.1191432

Abstract
This study presents the mechanical properties of weft knitted sandwich fabrics (bursting strength) and the effect of the raw materials used. Two types of fabrics, with and without reinforcing yarns, were analysed. To determine the influence of the raw material type, a combination of three structure variants were obtained by changing the position in the structure architecture of two types of raw material: Kevlar® and linen yarns. Each of these variants was studied at three levels of density, given by the position of the quality cam, in order to determine the influence of this parameter. Tests were organised in two stages: the first concerned the bursting behaviour of single layer fabrics, and the second considered the study of more layers of sandwich fabrics with different orientation. Satisfactory results were obtained after this study regarding the possibility of replacing the high-performance yarns with natural ones.

Key words: *mechanical properties, weft knitted sandwich fabrics, reinforcing yarns, high-performance, natural yarns.*

Introduction

Together with weaving, braiding and non-weaving, knitting is an important method used to produce textile fabrics. The properties of knitted materials can be tailored, within certain limits, according to the application. A high degree of elasticity, high formability, good mechanical strength, and complex product geometry can be obtained by using the proper raw materials, adequate knitting architecture, knitting process parameter and different knitting techniques [1, 2, 3].

When considering their behaviour, the mechanical properties of knitted fabrics are one of the most important characteristics that must be evaluated. During usage, the fabrics are exposed to different types of strains in different directions. An important type of strain is bursting (pressure applied on the fabric surface). The hyper elasticity of knitted fabrics requires the use of the ball bursting test when measuring the fabric strength.

The analysis of bursting behaviour represents a first step in studying the way a low velocity impact affects knitted fabrics used in mechanical protection. A survey of literature showed that there are numerous studies concerning low, high and hyper velocity impacts [4, 5, 6]. With regard to knitted fabrics, there are fewer references considering the fabrics as part of a composite – either covered with films or used as a reinforcement in plastic matrix [7].

The paper considers an experimental study of the bursting strength of knitted sandwich fabrics connected by yarns, representing an initial stage of a larger study concerning optimisation of the bursting behaviour of knitted sandwich fabrics. It is intended for the identification of the most significant factors of influence with reference to the bursting strength and trends specific to each variable considered for the experiment. The resulting data will then be used for setting up an optimisation model based on the central composite design.

The selection of the knitted structure (sandwich fabrics) is justified by the following:
- The fabric has two independent layers,connected by yarns and with and without in-laid yarns that improve the mechanical behaviour, while maintaining its specific flexibility.
- The structure proved to be balanced, presenting similar mechanical characteristics course wise and wale wise [8, 9].

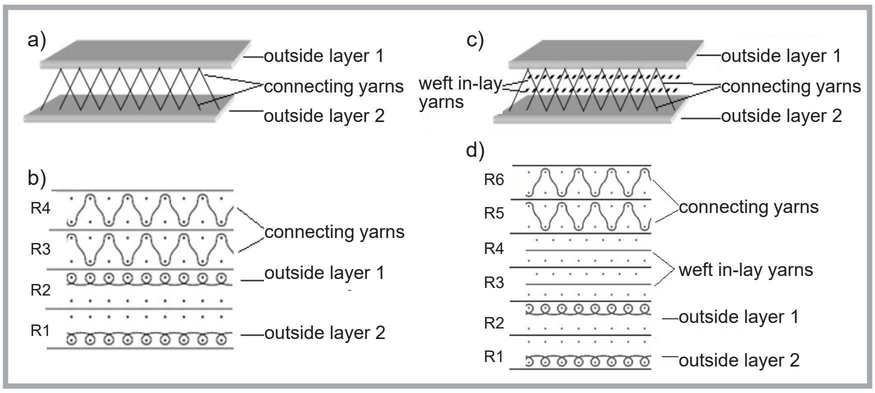

***Figure 1.** Principle of creating sandwich knitted fabrics sandwich knitted structure: a) technical representation, b) knitting sequence, c) reinforced with weft in-lay yarns - technical representation, d) knitting sequence.*

***Table 1.** Fabric variants according to the position of raw material in the structure architecture.*

Raw materials	Position of the yarn type in the structure architecture	Variant code
Kevlar®	Outside layers 1 & 2 and connecting yarns from Kevlar® (***Figure 1.a, 1.b***)	SK
Kevlar®	Outside layers 1 & 2, connecting yarns and weft in-lay yarns from Kevlar® (***Figure 1.c, 1.d***)	SB-K
Kevlar® with linen	Outside layers 1 & 2 from Kevlar®, connecting yarns and weft reinforced yarns from linen (***Figure 1.c, 1.d***)	SB-I

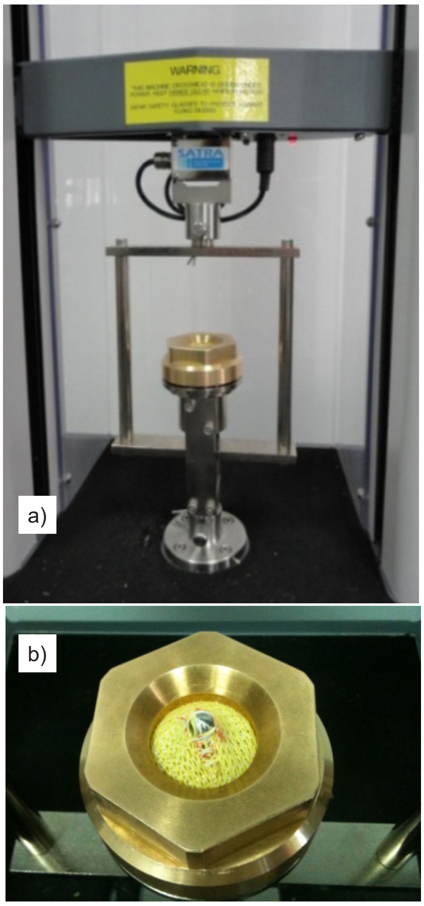

Figure 2. Satra machine STM 466: a) STM 466 LH bursting device, b) aspect of sample after breaking.

- The fabric allows a better control of properties through raw material and technological parameters.

Considering the fabric destination - mechanical protection - the experimental matrix is built with the following input variables: raw materials, position of the stitch quality cam (reflecting fabric density) and test speed (velocity).

Three experimental variants were obtained by changing the position in the structure architecture of two types of raw material: Kevlar® and linen yarns. The use of Kevlar yarns is justified by the need to enhance the mechanical strength, while linen yarns are an alternative for reducing production costs and maintaining fabric performance.

Each of these variants were produced using three levels for the position of the quality cam (NP = 12.0, 13.5, and 15.0), using an electronic knitting machine, CMS 530 Stoll, gauge 6.2 E. After relaxation, the samples were tested for bursting strength and the experimental data was interpreted and discussed.

Materials and methods

An experimental matrix was designed for studying the mechanical behaviour of the knitted fabrics (bursting strength). The following input variables were selected for the matrix:

- Structure – two types of sandwich fabrics (with and without reinforcing yarns), see ***Figures 1.a*** to ***1.d***;
- Raw material – Kevlar and linen yarns (Italy, respectively Portugal) used in preset positions in the fabric architecture (see ***Table 1***);
- Stitch density (determined by the position of the quality cam) – three levels of fabric density were selected, according to the specific knittability interval for sandwich fabrics (NP=12.0, NP= 13.5, NP= 15.0).

Samples were produced on an electronic flat knitting machine - Stoll, CMS 530 E 6.2 (Germany). The position of the yarns used in the structure architecture was varied according to ***Table 1***.

The physical and mechanical (tensile) characteristics of the yarns used for the current study are presented in ***Table 2***. The yarn count was determined according to EN ISO 2060 [10] using a skein gauge apparatus (SDL Atlas, UK), while the tensile characteristics were determined according to ASTM D 2256 [11]. The yarn diameter was measured using a microscope (IOR, Romania). An interval was determined for the diameter of each yarn, as the yarns present irregularities, and the average values are included in ***Table 2***. As expected, the linen yarn was more irregular, its interval for the diameter being larger than that for the Kevlar yarn – the diameter was measured within (0.34 - 0.44) mm for the linen yarn and (0.39 - 0.45) mm for the Kevlar yarn.

Table 2. *Mechanical characteristics of raw material.*

Yarn type/ Characteristics	Linear density, tex	Diameter, mm	Straight yarn test					Loop yarn test				
			Tenacity, cN/tex	Breaking force, cN		Elongation at break, mm		Tenacity, cN/tex	Breaking force, cN		Elongation at break, mm	
				Average	CV, %	Average	CV, %		Average	CV, %	Average	CV, %
Kevlar®	72	0.42	107.5	7739	5.75	14.7	6.95	99.2	7144	7.23	9.9	8.14
Linen	72	0.39	17.1	1228	14.2	7.9	12.45	15.8	1143	16.5	6.0	13.2

Table 3. *Dimensional properties of the knitted fabrics.*

Type of structure	NP	Courses, per 10 cm	Wales, per 10 cm	Loop length, mm				Mass, g/m²		Thickness, mm	
		F, B	F, B	Stitch		Connect. loop		Average	CV, %	Average	CV, %
				Average	CV, %	Average	CV, %				
Single Jersey	12.0	58	68	6.8	2.85	-		182.7	4.08	1.21	6.54
	13.5	54	52	8.2	4.15	-		160.1	3.13	1.01	3.83
	15.0	50	40	9.6	3.83	-		138.0	3.76	0.94	4.31
SK	12.0	48	76	6.2	2.54			735.0	1.74	3.46	3.22
	13.5	48	48	7.7	3.02			551.8	2.45	3.32	2.86
	15.0	48	36	9.3	3.97			450.3	2.77	2.81	4.72
SB-K	12.0	48	76	6.2	2.69			889.4	1.28	3.50	3.28
	13.5	48	50	7.8	4.24	5.3	4.15	616.0	2.95	3.41	3.51
	15.0	48	38	9.3	3.89			520.5	2.32	3.31	5.12
SB-I	12.0	48	76	6.1	4.56			880.7	1.15	3.22	3.73
	13.5	48	50	7.7	5.57			612.7	2.56	2.77	4.23
	15.0	48	38	9.3	4.83			519.0	2.53	2.48	5.46

After the samples were produced, the fabrics were relaxed in a dry environment. The structural parameters presented in ***Table 3*** were determined according to EN 14971 [12], EN 14970 [13], EN 12127 [14], respectively ASTM D 1777 [15]. Single jersey fabrics were included for comparison purposes, in order to emphasise the influence of the structure on dimensional properties.

The bursting strength was determined with ball bursting tests performed on a Satra STM 466 testing machine (UK), equipped with an LH bursting device (***Figure 2***). The samples were tested according to ASTM D3787 – 07 [16], adapted to equipment specifics.

Circular samples of 30 mm diameter were positioned in the circular clamps and fixed manually with a screw. The impactor with hemispherically shaped head struck the material with a rising movement. A total of 3 tests were carried out for each experimental variant.

The tests were organised in two stages – one concerned the bursting behaviour of single layer fabrics, and the second considered the study of more layers of sandwich fabrics with different orientation (see ***Figure 3***). The second tests were designed to identify if a different orientation of the samples in a package could influence the bursting strength. For this last stage, only the fabrics with the highest compactness were selected (corresponding to NP = 12.0).

All single layer variants were tested using 4 levels of velocity: 100, 300, 500 and 1000 mm/min. The experimental variants with 3 layers of fabrics were tested only at 1000 mm/min velocity.

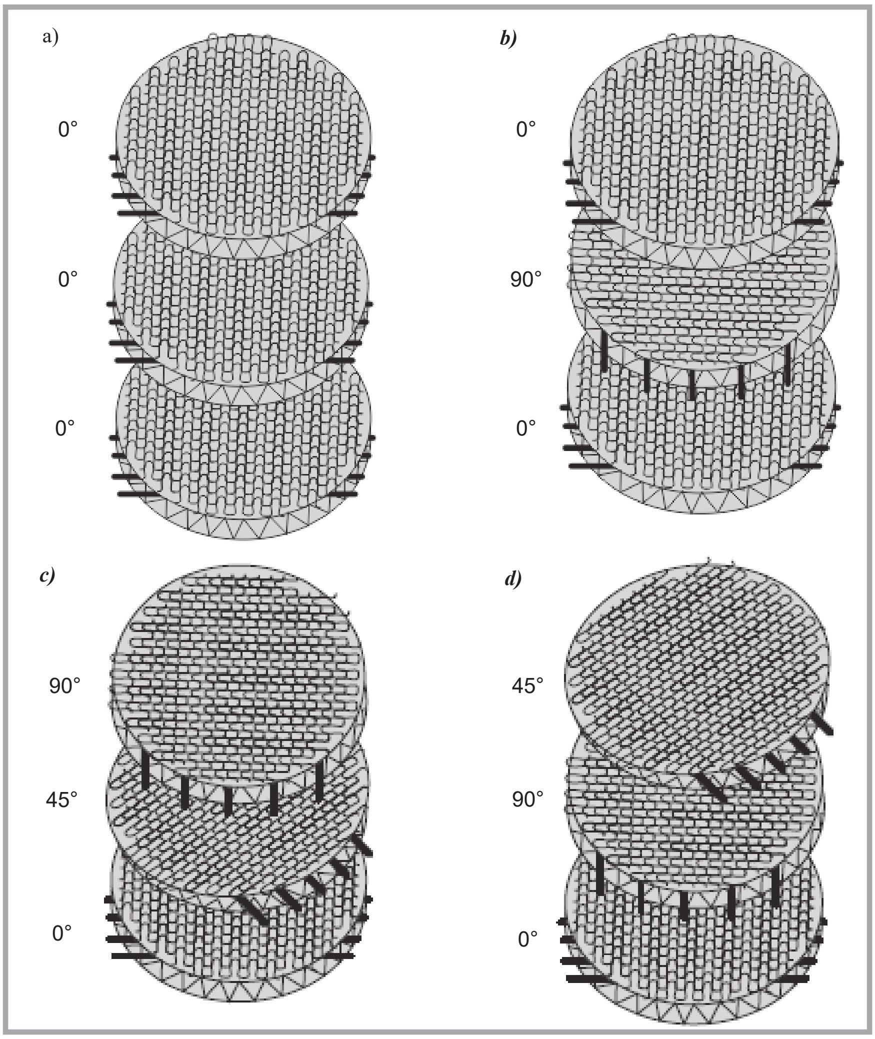

Figure 3. *Different orientation of layers course wise in the second testing set; a) case 1: layer orientation angle 0°-0°-0°; b) case 2: layer orientation angle 0°-90°-0°; c) case 3: layer orientation angle 0°-45°-90°; d) case 4: layer orientation angle 0°-90°-45°.*

Results and discussions

The structural parameters of all fabric variants are presented in ***Table 3***. The statistical data indicate that the knitting process ensured the desired uniformity of all samples and their structural parameters – the coefficients of variation for stitch length, fabric mass and thickness are under 5% for most fabric variants.

The connecting yarns play a double role for the structure: they hold the two layers together, preventing movement against each other, and also they balance the structure. As the outer layers were produced using Kevlar for all experimental variants, the horizontal stitch density is identical for all structure variants (SK, SBK and SBI), at all levels of compactness (quality cam NP values). The vertical stitch density has similar values for the three variant structures for the same level of compactness.

The mass per unit area and thickness of the knitted fabrics are influenced by the type of raw material used. The structures that contain linen yarns show an increased thickness, more than those that have only Kevlar® yarns in their structure, while the mass of the samples is similar. Due to the higher bending rigidity of linen yarns, the thickness of the SKI variants is 6 - 15% higher than those of the fabrics that contain Kevlar® yarns.

The thickness of the sandwich fabrics is also strongly influenced by the presence of the in-laid yarns, the distance between the two independent layers and the stitch density. When compared to single jersey fabrics, the thickness of the sandwich structures increases 2.5 to 3 times. Looser fabrics (lower stitch density) have lower thickness.

Tables 4 to ***6*** present experimental values for the bursting strength, including the average value, standard deviation and coefficient of variation. The statistical data indicate that all the samples had relatively uniform behaviour, with the variation of experimental results being mostly between 1% and 10%, where the highest values for the coefficient of variation reached 15%. The presence of in-laid yarns, especially linen yarns, increases the variability of the results a bit. The coefficient of variation for the breaking force was lower than thatfor the deflection. The coefficient also increased with the test velocity.

The results of the single layer tests show that the bursting strength decreases with

Table 4. *Experimental values for the bursting strength of SB fabrics.*

Quality cam	Velocity, mm/min	Force, N			Deflection, mm		
		Average	St. Dev.	CV, %	Average	St. Dev.	CV, %
NP = 12.0	100	840.7	9.17	1.09	12.06	0.04	0.28
	300	607.4	40.88	6.73	11.54	0.24	2.05
	500	591.0	42.59	7.21	13.46	0.41	3.03
	1000	416.0	37.52	9.02	11.06	0.38	3.44
NP = 13.5	100	705.7	27.79	3.94	11.96	0.14	1.20
	300	544.6	29.38	5.40	11.35	0.30	2.69
	500	503.0	16.09	3.20	10.93	0.43	3.98
	1000	371.7	35.68	9.60	10.01	0.29	2.90
NP = 15.0	100	684.7	19.29	2.82	11.03	0.98	8.85
	300	471.9	38.31	8.12	12.28	1.65	13.44
	500	479.1	51.71	10.79	12.84	0.40	3.09
	1000	303.3	32.38	10.68	12.05	0.52	4.32

Table 5. *Experimental values for the bursting strength of SBK fabrics*

Quality cam	Velocity, mm/min	Force (N)			Deflection (mm)		
		Average	St. Dev.	CV (%)	Average	St. Dev.	CV (%)
NP = 12.0	100	787.3	104.73	13.30	11.02	0.47	4.31
	300	787.4	18.69	2.37	11.09	0.28	2.55
	500	795.6	57.83	7.27	14.32	0.48	3.33
	1000	533.9	26.84	5.03	12.48	0.34	2.72
NP = 13.5	100	705.8	16.16	2.29	9.89	0.28	2.80
	300	618.9	94.84	15.32	10.84	1.57	14.44
	500	451.9	34.66	7.67	12.66	0.08	0.60
	1000	452.9	46.51	10.27	10.52	0.61	5.80
NP = 15.0	100	664.0	41.07	6.18	12.16	0.21	1.78
	300	591.9	136.70	23.10	12.40	0.55	4.45
	500	579.6	53.28	9.19	13.37	1.25	9.34
	1000	373.6	43.57	11.66	10.46	0.83	7.93

Table 6. *Experimental values for the bursting strength of SBI fabrics*

Quality cam	Velocity, mm/min	Force, N			Deflection, mm		
		Average	St. Dev.	CV, %	Average	St. Dev.	CV, %
NP = 12.0	100	726.4	69.97	9.63	12.10	0.47	3.95
	300	736.2	96.92	13.16	12.21	0.24	1.99
	500	662.0	50.40	7.61	13.00	0.51	3.92
	1000	576.0	65.83	11.43	11.34	0.31	2.73
NP = 13.5	100	658.2	92.12	14.00	11.07	0.30	2.68
	300	597.9	30.55	5.11	12.97	2.12	16.33
	500	603.6	25.32	4.20	13.04	0.28	2.11
	1000	427.7	36.98	8.65	10.27	0.41	3.99
NP = 15.0	100	692.2	53.91	7.79	12.24	0.29	2.36
	300	525.2	30.06	5.72	11.86	0.58	4.89
	500	524.8	41.04	7.82	12.62	0.70	5.55
	1000	344.7	29.68	8.61	12.72	0.33	2.59

an increase in the impactor's operating velocity. The duration of impactor penetration into the material decreases with an increase in the operating speed, similar for all three variants studied, as shown in ***Figure 4***. The graphic for SK variants is covered by the other two variants. The highest decrease in test duration was recorded for the first two velocities – the test time decreased around 3 times. From 300 to 1000 mm/min, the test duration is again reduced to half, less than 1 second.

The force necessary to penetrate the knitted fabric decreases with an increase in the impactor velocity and decrease in material stiffness (corresponding to lower fabric densities). The graphics presented in ***Figures 5, 6*** and ***7*** show that the bursting force is influenced primarily by the test velocity and then by fabric density.

The differences in bursting strength between the first and last level of velocity are caused by the fact that the fabrics have less and less time to absorb the strain, and therefore the breaking force decreases significantly. A higher fabric density (NP = 12.0) improves the strength for all variants.

For the first velocity level, the fabric variants made exclusively of Kevlar yarns present better strength than those with linen (see ***Figure 8***). For the other 3 velocity levels, the bursting strength of SK variants is the lowest (see ***Figures 9*** to ***11***), which emphasises the positive effect of the in-lay yarns at higher test velocities. The presence of weft in-lay yarns in the knitted structure (variants SBK and SBI) improves fabric behaviour and reduces the differences in strength caused by the test velocity.

Linen yarns do not affect the fabric behaviour, except for the first test velocity. This shows that the use of linen yarns in sandwich fabrics made of Kevlar leads to positive results, especially for higher test velocities and higher fabric density. For maximum densities, the fabrics with linen increase their strength in relation to those only with Kevlar (SBK) with an increase in the test velocity, until they exhibit similar and even superior behaviour. When analysing the deflection determined for bursting, illustrated in ***Figures 12*** to ***14***, a degree of erratic behaviour was determined, caused by the redistribution of yarns within the fabric geometry, which varies up to a point. There was a certain slippage of the impactor on the surface of the samples caused by the low friction coefficient yarn-metal.

Deflection depends strongly on:
- test velocity – in general, the value of deflection increases with the test velocity, up to 500 mm/min, but at 1000 mm/min, the deflection decreases considerably, similar or below the initial level. This suggests that at higher velocities (low impact) the deflection should be further reduced.
- fabric density – the samples present similar behaviour for NP = 12.0 & NP = 13.5 and distinct behaviour for NP = 15.0. Higher compactness (density) is to be desired when considering such fabrics for mechanical protection.
- raw material (presence of linen yarns) - The presence of linen yarns does not have a negative influence on deflection.

In the case of multiple layers, the idea was that the positioning under different angles would bring an improvement in bursting strength, especially for the fab-

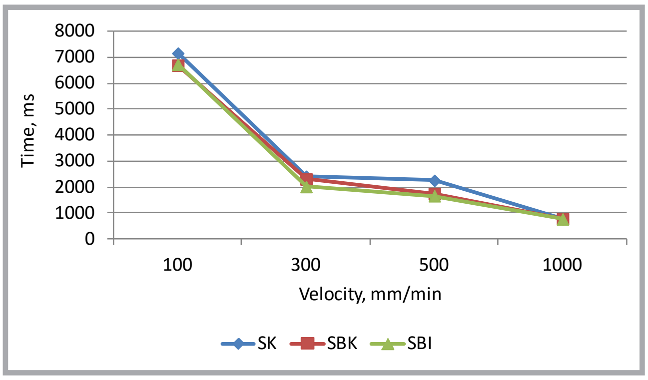

***Figure 4.** Influence of operating velocities of the impactor on the bursting time. Attention: The charts shown in **Figures** 4-14 present only trends and not functions.*

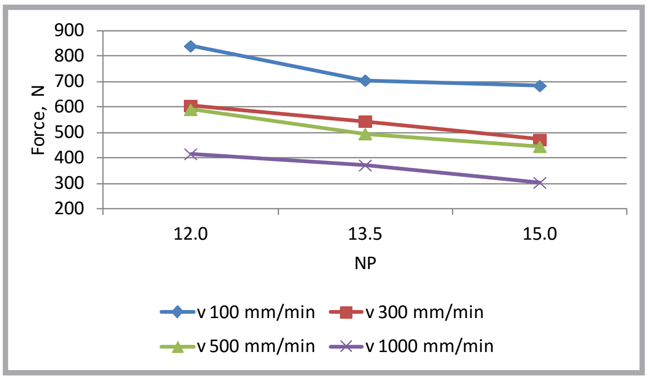

***Figure 5.** Influence of the fabric density on the bursting strength for the SK fabric variant at different operating velocities.*

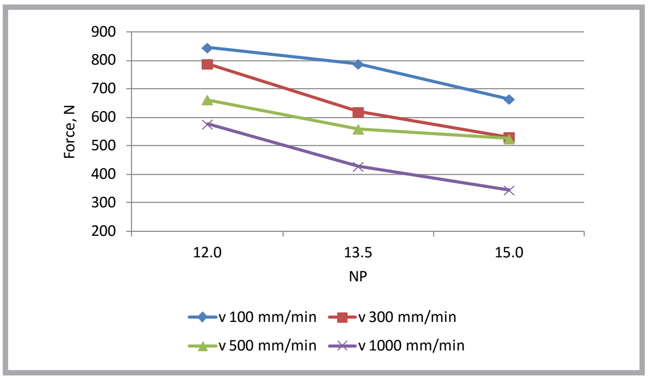

***Figure 6.** Influence of the fabric density on the bursting strength for the SBK fabric variant at different operating velocities.*

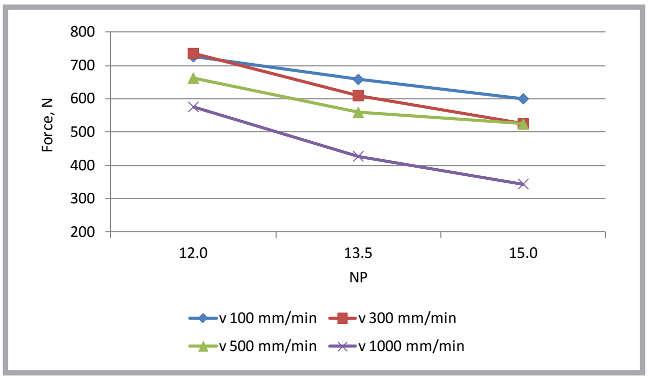

***Figure 7.** Influence of the fabric density on the bursting strength for the SBI fabric variant at different operating velocities.*

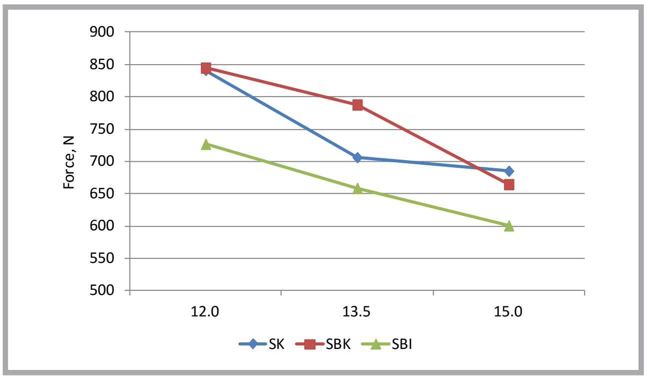

***Figure 8.** Bursting strength of the knitted variants at 100 mm/min operating velocity.*

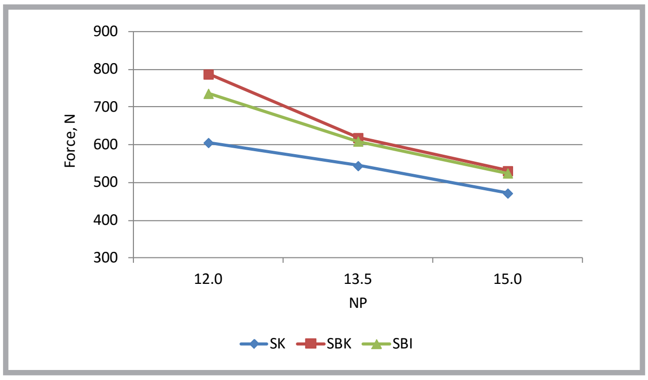

***Figure 9.** Bursting strength of the knitted variants at 300 mm/min operating velocity.*

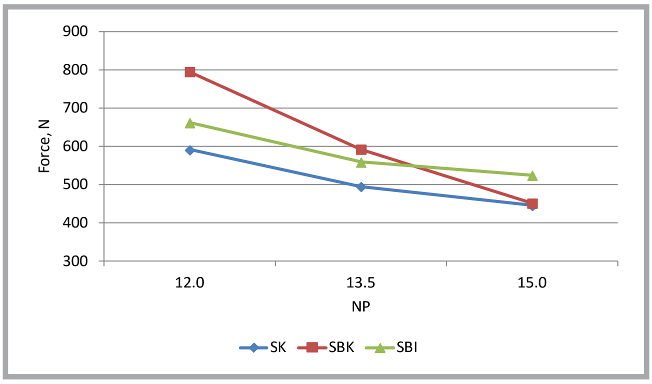

***Figure 10.** Bursting strength of the knitted variants at 500 mm/min operating velocity.*

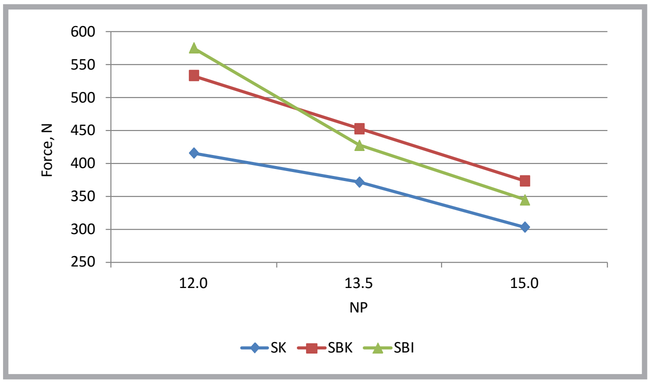

***Figure 11.** Bursting strength of the knitted variants at 1000 mm/min operating velocity.*

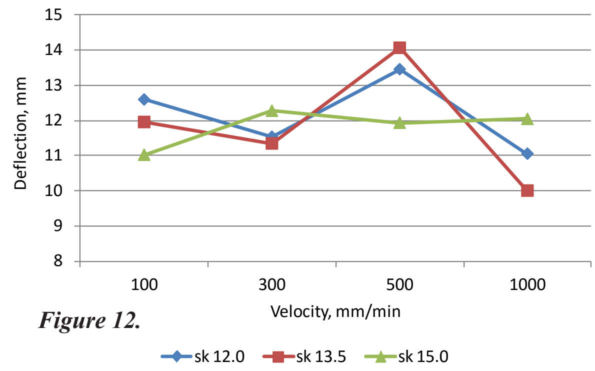

Figure 12.

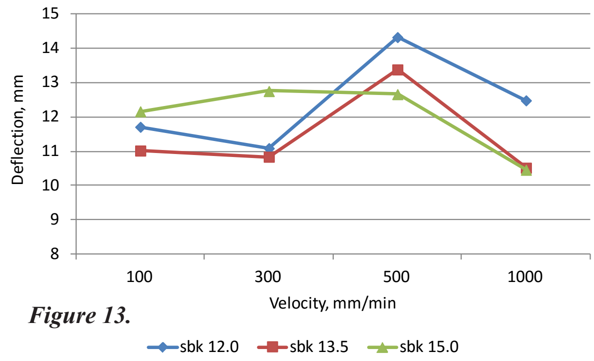

Figure 13.

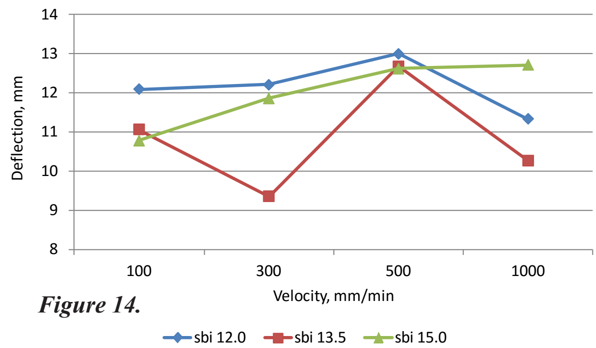

Figure 14.

Figure 12. *Variation in bursting deflection with the testing velocity for SK variants.*

Figure 13. *Variation in bursting deflection with the testing velocity for SBK variants.*

Figure 14. *Variation in bursting deflection with the testing velocity for SBI variants.*

Table 7. *Experimental values for the bursting strength of three layer variants.*

Orientation	0-0-0			0-90-0			0-45-90			0-90-45		
Var.	Average	Stand. Dev.	CV, %	Average	Stand. Dev.	CV, %	Average	Stand. Dev	CV, %	Average	Stand. Dev	CV, %
SK	1540.2	153.4	9.96	1900	212.6	11.19	1441.1	203.5	14.12	1110.6	172.5	15.53
SBK	1985.3	129.7	6.53	1308	163.4	12.49	1876.9	235.7	12.56	1912.0	138.9	7.26
SBI	2013.8	180.3	8.95	1742	123.4	7.08	1925.7	189.6	9.85	1974.6	226.1	11.45

rics with in-lay yarns. The different orientation of the layers was supposed to create an array that would allow the fabrics to accept higher strains. ***Table 7*** and ***Figure 15*** show the bursting strength determined for multiple layers for the three fabric variants. In this case, the values calculated for the coefficient of variation are placed in a higher interval in comparison to those determined for the single layer tests. An explanation could be given by the fact that the layers slide against each other during the test, and therefore their behaviour is different.

Comparing the results obtained for 3 layers with the same orientation (variant 0°-0°-0°) to those for a single layer, the bursting strength increases approximately three times for all fabric variants. This means that the presence of multiple layers significantly and proportionally improves the bursting strength of the fabrics. The strength of the SK variants is much lower than those with in-lay yarns (SBK and SBI), regardless of the nature of these yarns, showing the influence of the fabric structure.

Nevertheless the results suggest that the orientation of the fabric layers has no influence on the fabric bursting strength. Different orientations for the three layers bring about an insignificant variation in strength.

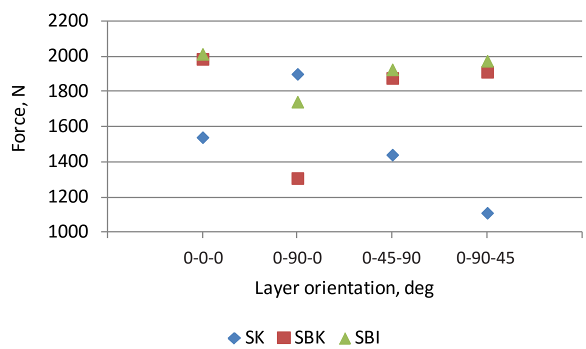

Figure 15. *Influence of layer orientation on the bursting strength.*

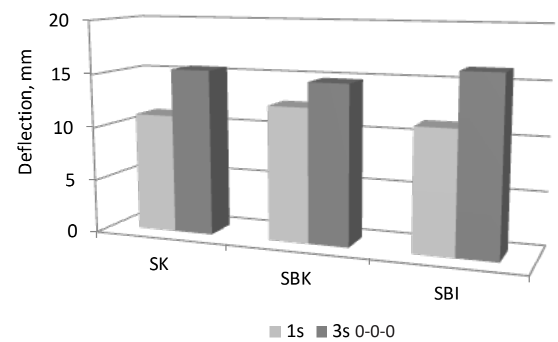

Figure 16. *Variation in bursting deflection with the number of layers (1 layer vs. 3 layers) for all structural variants.*

The variation in deflection for 3 layers was studied for the 0^0-0^0-0^0 orientation variant in comparison to the single variant, for the maximum density (NP=12.0) and test velocity of 1000 mm/min. The values are presented in ***Figure 16***.

The use of the three layers leads to an increase in deflection, varying between 14.78 and 16.25 mm, while the variation interval for single layers is 11.06 - 12.48 mm. From the graphic illustration of this variation, one can see that the presence of linen produces the highest increase in deflection (+43.3%), while for the sandwich fabric SK, the increase is similar (+39.8%). However, the presence of Kevlar as in-laid yarns limits the increase in deflection significantly (+11.8%).

It can be stated that layer orientation does not improve the mechanical behaviour in a significant manner. The layers work independently, not together, and therefore the energy is not better distributed among the different directions and does not increase the bursting strength.

Conclusions

The study considered two types of structures – sandwich and sandwich with in-lay yarns, made with Kevlar and linen. By modifying the type of connecting and in-lay yarns as well as the stitch density, nine experimental variants resulted, which were tested to determine the bursting strength. The tests also took into consideration the testing velocity (4 levels). The following conclusions can be drawn from the experimental data.

The experimental results show that linen yarn can be considered an alternative for replacing high-performance yarns. The optimum position for linen yarns in a sandwich structure is as connecting and in-lay yarns. Such fabrics maintain their mechanical properties in comparison to sandwich fabrics made exclusively of Kevlar. The presence of linen modifies the behaviour of sandwich fabrics under strain for lower test velocities (up to 500 mm/min), but it does not affect the material's strength. The values for strength and deflection are similar to those for Kevlar materials, and therefore it be concluded that linen is a good replacement for such high performance fibres in this type of application, in order to cut production costs.

Bursting strength was influenced by:

- Stitch density – most compact fabrics (NP = 12.0) presented better strength for all cases due to the fact that these fabrics are characterised by a smaller stitch length and higher rigidity
- Test velocity – the strength decreases with the test velocity, as the fabric no longer has the time to respond to the strain.
- As expected, the presence of in-lay yarns improved the bursting strength, the increased values being similar for both types of yarns (Kevlar and linen). The variants with linen connecting and in-lay yarns exhibit higher strength for higher velocities, while for lower velocities the fabrics made of Kevlar yarns presented better strength.

The values of deflection varied in a limited interval (11.06 - 12.48 mm), showing that all variants elongated in a similar manner.

In order to see if the layer orientation influences the bursting strength when using more layers, an experiment with three fabric variants (SK, SBK and SBI) was set up. The test used three layers, orientated in 4 sequences. The presence of more layers increases the bursting strength three times, suggesting that, for mechanical applications, such fabrics are better used multilayered. When compared to the deflection at the bursting point registered for single layers, the deflection for three layers (orientation 0°-0°-0°) increased significantly for variants SK and SBI (up to 43.3%), while the presence of Kevlar in-laid yarns limited this increase to almost 12%.

The experimental results show that the layers do not work together, and therefore the layer orientation does not help to improve the bursting strength of the materials.

Future work will consider optimisation of the bursting strength of knitted sandwich fabrics (multiple layers). Such fabrics should also be tested for higher velocities, which could show the dynamic behaviour of such materials and their capacity for energy absorption.

Acknowledgements

This paper was realized with the support of the EURODOC "Doctoral Scholarships for research performance at European level" project, financed by the European Social Fund and Romanian Government.

References

1. Bruer M S, Nancy P and Gary S. Three-Dimensionally Knit Spacer Fabrics: a Review of Production Techniques and Applications. Journal of Textile and Apparel. *Technology and Management* 2005; 4, 4 (available: http://www.tx.ncsu.edu/jtatm/volume4issue4/Articles/Bruer/Bruer_full_149_05.pdf, downloaded March, 29, 2012).
2. Zhang Y, Huang Z-M and Ramakrishna S. Tensile Behaviour of Multilayer Knitted Fabric Composites with Different Stacking Configuration. *Applied Composite Materials. Publisher Springer Netherlands* 2001, 8, 4: 279–295.
3. Cebulla H, Diesel O and Offerman P. Fully fashioned biaxial weft knitted fabrics. *Autex Research Journal*, 2002, 2, 1 (available http://www.autexrj.com/cms/zalaczone_pliki/2d.pdf, downloaded March, 21, 2012).
4. Stempień Z. Effect of Velocity of the Structure-dependent Tension Wave Propagation on Ballistic Performance of Aramid Woven Fabrics. *Fibres and Textiles in Eastern Europe* 2011; 19, 4(87): 74-80.
5. Ching TW, Tan VBC, *Modelling Ballistic Impact on Woven fabrics with LS-DYNA, in Computational Methods*, editors Liu, GR et al., Springer, 2006, pp. 1879-1884.
6. Nilakantan G. et al. On the finite element analysis of woven fabric impact using multiscale modeling techniques. *International Journal of Solids and Structures* 2010; 47, 17: 2300-2315, DOI: 10.1016/j.ijsolstr.2010.04.029.
7. Naveen V, Padaki R, Alagirusamy Deopurs BL, Sugun B S and Fangueiro R. Low velocity impact behavior of textile reinforced composites. *Indian Journal of Fibre and Textile Research* 2008; 33: 189-202.
8. Ciobanu A R, Fangueiro R, Ciobanu L and Budulan C. Specific mechanical properties for composite knitted reinforcements with natural fibers. *Proceedings of the 16th International Conference Modern Technologies, Quality and Innovation* 2012; 1, 201-204.
9. Ciobanu A R, Fangueiro R, Ciobanu L and Budulan C. Tensile properties of weft knitted sandwich fabrics with natural fibres. *Proceedings of the 46th International Congress IFKT, Knitting around the world* 2012; pp. 851- 856.
10. ISO 2060 Textiles – Yarn from packages – Determination of linear density (mass per unit length) by the skein method
11. ASTM D 2256 Standard test method for tensile properties of yarns.
12. EN 14971 (2006-04) Textiles – Knitted fabrics – Determination of stitches per unit length and unit area.
13. BS EN 14970:2006 Textiles. Knitted fabrics. Determination of stitch length and yarn linear density in weft knitted fabrics
14. EN 12127 Textiles – Fabrics – Determination of mass per unit area using small samples.
15. ASTM D 1777 - 96 (2002) Standard method for thickness of textile materials
16. ASTM D 3787 – 07 Standard Test Method for Bursting Strength of Textiles-Constant-Rate-of-Traverse (CRT) Ball Burst Test.

Received 18.01.2013 Reviewed 15.05.2015