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The Effect of Bonded Seams upon Spatial Behaviour of Knitted Materials Systems

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Spatial behaviour of knitted materials with bonded seams under biaxial tensile loading is analysed in this work. The objects of the research were plain jersey and rib 1×1 polyester knitted materials with elastane (93 % PES, 7 % EL). Two thermoplastic polyurethane (PU) films different in thickness (75 µm and 150 µm) were used. For each sample of knitted material and thermoplastic film five types of samples with bonded seams (10 mm in length) were prepared by changing the orientation of knitted materials pieces, i. e. parallel/parallel, parallel/bias, parallel/perpendicular, bias/bias and bias/perpendicular. The effect of thermoplastic films type and the effect of knitted materials orientation in seam was analysed on the basis of biaxial punching characteristics – maximal punching force P (N) and maximal punching height H (mm). The changes of tested specimens strength and deformation were compared before and after their cyclical fatigue loading (50 cycles of punching force P = 50 N). The obtained results have shown that changes before and after cyclical fatigue loading are mostly determined by the type of thermoplastic film, but not effected by the orientation of knitted materials pieces in bonded seam.

Keywords: knitted material, bonded seams, punching, cyclical fatigue loading, thermoplastic film.

1. INTRODUCTION

Bonded and welded seams always were the critical link in the chain of waterproof protection. Nowadays, together with customized printing, it plays an important role in aesthetic evolution of outwear. Seam bonding method uses thermoplatic films for bonding two fabrics together. During this process heat and pressure activate adhesive layer. The film melts and penetrates into the fabrics by creating a bond between two layers. The second method involves welding of two fabrics by using ultrasonic machinery. The advantages of bonded seams are that they can improve the look and performance of garments, providing added value in terms of form, fit, feel and function. Bonded seam is flat, slimmer and less abrasive. Seam bonded garments provided smooth, seamless appearance, enhanced wearer comfort, lighter weight products, waterproofness [1 – 3].

A variety of adhesives [4 – 6] are used in textile industry for bonding layers of materials or separate fibres [6, 7 – 10], also as protective layer in such products as carpets, synthetic leather (laminated, coated) [2, 4, 11, 12] and specific applications of decorative finishing [3]. Polyurethane adhesives are considered one of the high-performance products offered to textile industry because of their excellence in adhesive properties, heat resistance, chemical resistance, and fast curing properties [4]. Company Bemis produces the range of thermoplastic adhesives that are eco-friendly and free of solvents. They are made of five polymer types: polyurethane, polyamide, polyester, polyolefin and vinyl [3, 13]. Sewfree® is a soft, highly elastic, specially formulated polyurethane thermoplastic film designed for fabrics. Thermoplastic films, which are used for textile layers bonding, have additional layer of silicone paper. Therefore the process of two stage bonding must be applied [13 – 15].

Nowadays the variety of investigation methods is used to analyse and to simulate deformational behaviour of flexible polymer materials and textiles during their performance in real conditions. One of them is biaxial deformation performed by punching, during which critical stresses concentrate at the top or near the punch. Thus specimen rupture occurs close to its centre [16 – 19].

The main aim of this investigation was to determine the effect of bonding and the orientation of knitted materials pieces in bonded seams upon deformational behaviour of knitted materials systems under biaxial tension before and after cyclical fatigue loading.

2. MATERIALS AND METHODS

Tests were performed with two types of knitted materials having the same fibre composition, but different in knitting patterns, i. e. plain jersey and rib. They were produced at Lithuania State Research Institute Center for Physical Sciences and Technology. Plain jersey samples were knitted on a single jersey circular knitting machine "JEPY" 18E. Rib samples were knitted on a double jersey circular knitting machine "CMO4A" 15E using two spun yarns (20 tex) and one elastane yarn (4.4 tex). The thickness of investigated knitted materials was defined according to standard ISO 5084:2000 (Table 1).

Two types of Bemis thermoplastic films from polyurethane (PU), which differ in thickness and modulus (Table 2), were selected for the investigations taking into the account the recommendations of manufacturer, i. e. both Sewfree® thermoplastic films can adhere to a wide range of textile materials. B1 film is described as "good" and B2 film is described as "excellent" for the applications

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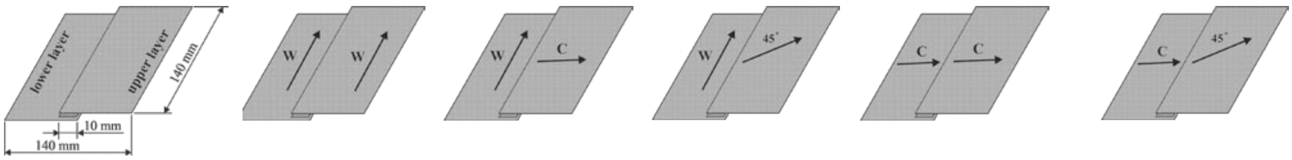
Table 1. The characteristics of the investigated knitted materials

Material symbol	Material content	Knitting pattern	Density		Area density, g/m^2	Thickness, mm	Anisotropy coefficient	
			course dir. P_c, cm^{-1}	wale dir. P_w, cm^{-1}			at breaking force, K_F	at breaking elongation, K_ε
K1	93 % PES, 7 % EL	plain jersey	16.0	28.0	284	1.16	0.80	0.93
K2		rib 1 × 1	25.0	23.0	340	1.32	0.51	0.47

Table 2. The characteristics of Bemis thermoplastic films

Symbol	Content	Glue line temperature range	Softening point	Nominal thickness, μm	Weight, g/m^2	Modulus*, N
B1	Polyurethane (PU)	130 °C – 140 °C	75 °C	75	93	6.7
B2			83 C	150	186	17.8

* Modulus: force required to pull a 25.4 mm wide sample at the specified gauge to 100 %.



a b

Fig. 1. Principle scheme of knitted materials pieces bonding with Bemis thermoplastic film (a); schemes of pieces orientation in bonded overlaped seams (b)

with polyester fabrics [3, 13]. Five types of samples with bonded overlapped seams (10 mm in width) were prepared from both knitted materials and both thermoplastic films by changing the orientation of knitted material pieces: parallel/ parallel (WW), parallel/perpendicular (WC), parallel/bias (W45), perpendicular/perpendicular (CC) and perpendicular/bias (C45), where W – wale direction, C – course direction (Fig. 1). Specimen bonding was performed at two stages using the pressure of 0.3 N/mm^2 (3 Bar) with pressing machine GTK DEA 25R:

- thermoplastic film of 10 mm width was transferred onto lower piece of knitted material by applying 110 °C temperature for 5 s pressing duration silicon paper was peeled of after 5 minutes;
- the upper piece of knitted material was put on the lower piece and was bonded by applying 140 °C temperature for 30 s pressing duration.

Bonding conditions were chosen according to the recommendations of producer and the results of earlier investigations [3, 13 – 15]. All specimens before testing were kept in standard atmosphere conditions (φ = 65 % ±4 %, T = 20 °C ±2 °C) for 24 hours according to standard ISO 139:2005.

Uniaxial tension of non-bonded knitted materials was performed with a standard tensile testing machine Tinius Olsen H10K according to the requirements of standard EN ISO 13934-1. Testing conditions were as follows: specimen length – 50 mm, specimen width – 50 mm, pretension – 1 N/5 cm, tension rate – 100 mm/min. Breaking force F (N) and breaking elongation ε (%) were recorded from typical tension curves. The number of specimens for one sample was 10, the variation coefficient did not exceed 7 %.

Punching was performed with a special device created at Kaunas University of Technology, which was attached to standard tensile testing machine Tinius Olsen H10K [18, 19]. Specimen radius was R = 28.2 mm and punch radius was r = 9.5 mm (Figure 2). During punching such parameters as maximal punching force P (N) and maximal punching height H (mm) were recorded at the velocity of 100 mm/min. Punching of all specimens was performed before and after their cyclical fatigue loading the conditions of which was – 50 cycles up to of punching force P_{cyc} = 50 N, which corresponds to actual low intensity loads during garment wear. The velocity of cyclical fatigue loading was 500 mm/min (Figure 3). The number of specimens for one sample was 5, the variation coefficient did not exceed 7 %.

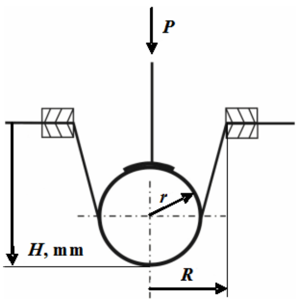


Fig. 2. Principal scheme of specimen punching

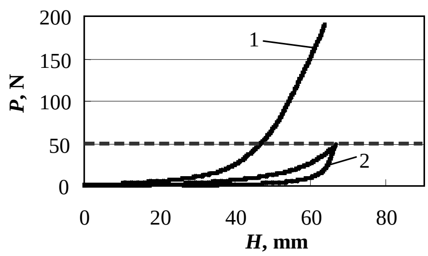
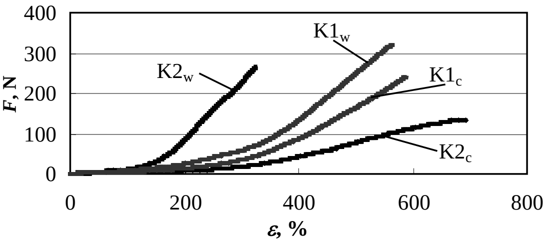


Fig. 3. Principal curves of specimen punching, where 1 – typical curve of maximal punching, 2 – typical curve of cyclical fatigue loading up to 50 N

3. RESULTS AND DISCUSSION

Figure 4 shows typical uniaxial tension curves of non-bonded knitted materials K1 and K2. It is evident that there is no significant difference in the behaviour of knitted material K1 (plain jersey pattern) in course and wale



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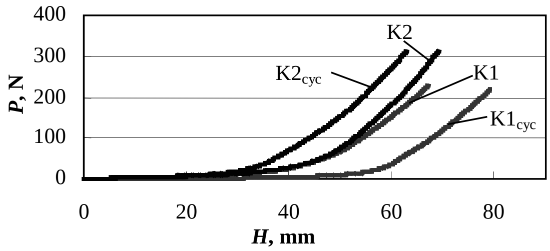

b

Fig. 4. Typical uniaxial tension curves, where subscript c – course direction; subscript w – wale direction

Fig. 5. Typical punching curves of non-bonded knitted materials (K1 and K2) before and after cyclical fatigue loading ($K1_{cyc}$ and $K2_{cyc}$)

directions. Meantime the behaviour of knitted material K2 (rib 1 × 1) in course and wale directions differs significantly. Thus, K1 sample can be characterised as less anisotropic because its breaking force *F* (N) and breaking elongation *ε* (%) in respect to wale and course directions differ only by 18 % and 7 %, respectively (Fig. 4). Knitted material K2 is characterised by higher anisotropy, because breaking force in wale direction is higher by 50 % compared to the breaking force in course direction and the elongation in this direction is less more than twice compared to course direction.

The opposite results were obtained in the case of biaxial punching: maximal punching force *P* of low anisotropic material K1 is lower by 38 % compared to maximal punching force of material K2, but maximal punching height *H* became similar, i. e. the deformational behaviour of both samples assimilates (Fig. 5). It can be explained by the fact that stresses in plain jersey K1 knitted material distributes in the directions of two generating lines (course and wale directions) almost equally and their intensity decreases (Fig. 5), compared to the results of uniaxial tension (Fig. 4). Whereas in the case of high anisotropic material K2 (rib 1 × 1) the main loading falls upon less deformable and stiffer wale direction (Fig. 4) by leaving stretchable course direction less loaded [16 – 20].

Deformational behaviour of both investigated materials after their cyclical fatigue loading is different. Maximal punching height *H* of low anisotropic knitted material $K1_{cyc}$ increases by 18 %, but punching height *H* of high anisotropic knitted material $K2_{cyc}$ decreases by 9 %. Maximal punching forces *P* of both investigated materials after their cyclical fatigue loading have not changed, i. e. low wearing loads do not have any significant effect upon strength characteristics of investigated materials [20].

Analysis of deformational behaviour of all five types of knitted materials samples with bonded seams before cyclical fatigue loading have shown that their maximal punching height *H* is higher (Fig. 6, a and b), compared to maximal punching heights of non-bonded knitted materials K1 and K2. Punching height *H* in the case of knitted materials K1 (low anisotropy) samples with bonded systems formed with thermoplastic film B1 are higher from 14 % to 27 % and with twice thicker film B2 – up to 20 % compared to punching height of non-bonded knitted material K1. Meantime deformability of high anisotropic knitted materials K2 samples with bonded seams was lower in the case of thermoplastic film B1 – up to 14 % and in the case of B2 film – from 6 % to 15 %. The opposite results were obtained for the deformability of samples with bonded systems after cyclical fatigue loading. Maximal punching height H_{cyc} of low anisotropy knitted materials K1 samples with bonded systems formed with B1 film decreased from 18 % to 26 %, compared to punching height of non-bonded knitted material K1. The decrease of punching height H_{cyc} of K1 samples with bonded systems formed with B2 film was insignificant and varied around 7 %. In the case of high anisotropic knitted materials K2 samples with bonded systems formed with B1 film the decrease of deformability was also insignificant, i. e. up to 13 %, but it was interesting to notice that deformability of the same knitted materials samples with bonded systems formed with twice thicker thermoplastic film B2 have increased from 21 % to 28 %.

Analysis of the effect of cyclical fatigue loading upon the deformability of bonded systems have shown that for both investigated knitted materials K1 and K2 samples with bonded seams punching height decreased between 15 % and 26 % in the case when thinner thermoplastic film B1 of lower modulus was applied (Fig. 6, a and b), but in the case when twice thicker film B2 of 2.5 times higher modulus was used the effect of cyclical fatigue loading upon bonded systems spatial deformability was less significant.

Punching height H_{cyc} of low anisotropic materials bonded system K1B2 C45 increases up to 17 %, but of K1B2 W45 decreases by 10 %. The increase of punching height H_{cyc} in the case of high anisotropic material K2 is insignificant, e. g. up to 8 % for bonded system K2B2 CC.

It was observed that punching strength of low anisotropic materials K1 samples with bonded seams formed with thermoplastic film B1 was higher from 40 % to 59 %, with film B2 – from 21 % to 68 %, compared to the strength of non-bonded knitted material K1 (Fig. 7, a and b). Meantime punching strength *P* of high anisotropic knitted materials K2 samples with bonded seams formed with B1 film increased by 47 %, with B2 film – by 32 %. Analysis of the effect of cyclical fatigue loading upon punching strength of samples with bonded seams have shown that for both investigated knitted materials K1 and K2 strength changes are insignificant or very close (Fig. 7, a and b). In the case of low anisotropic knitted materials K1 samples with bonded seams formed with thermoplastic film B1 the most significant changes were observed for K1B1CC sample punching force *P* of which decreased by 21 %. Meantime the strength of bonded samples K1B2WW and K1B2W45decresed by 11 % and 16 % when the film B2 of 2.5 times higher modulus was applied, but the strength of K1B2C45 bonded sample increased by 17 %. In the case of high anisotropic materials K2 samples with bonded seams

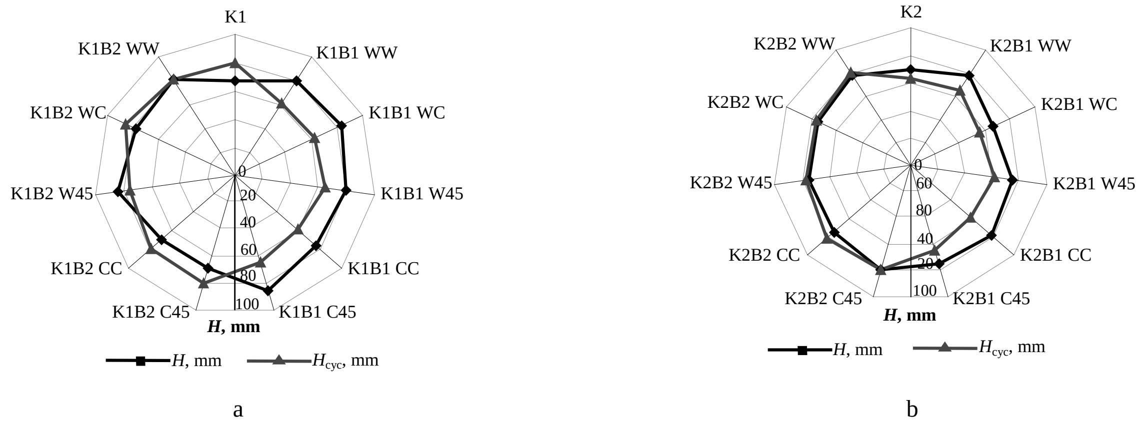

Fig. 6. The changes of punching height *H* of investigated knitted materials K1 (a), K2 (b) and their bonded samples before (*H*, mm) and after cyclical fatigue loading (H_{cyc}, mm)

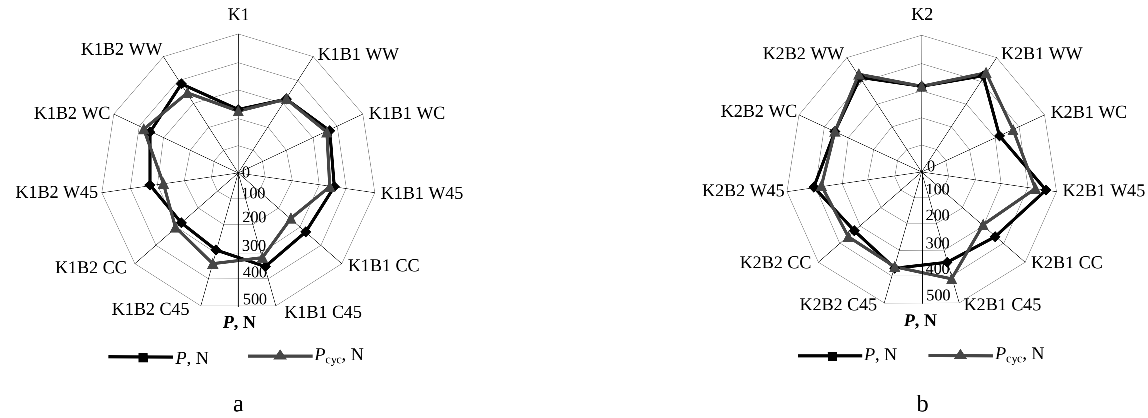

Fig. 7. The changes of punching force *P* of investigated knitted materials K1 (a), K2 (b) and their bonded samples before (*P*, N) and after cyclical fatigue loading (P_{cyc}, N)

formed with lower modulus film B1 the most significant strength changes are characteristic for K2B1W45 and K2B1C45 samples punching force *P* of which increased by 18 %. Whereas punching force *P* of K2B1CC sample with bonded seam decreases by 16 %. When thermoplastic film B2 is applied the most significant strength changes fall upon K2B2CC sample with bonded seam punching force *P* of which increases by 10 %.

It must be noted that breaking of all tested samples with bonded seams during punching appeared not at the place of bonding but close to it. Breaking line in all samples was parallel for the breaking seam and was located on less deformable knitted materials piece, i. g. for WC and W45 samples – on knitted materials pieces which were orientated in wale (W) direction; for C45 sample – on bias (45°) orientated piece. Thus the orientattion of knitted materials pieces in bonded samples did not have any significant effect neither for the breaking character, nor for breaking characteristics (punching force *P* and punching height *H*) of tested samples.

Analysis of the effect of thermoplastic films B1 and B2 upon strength and spatial deformational behaviour of bonded samples with seams is performed on the basis of samples which were made of two pieces oriented in the same direction, i. e. longitudinal WW (wale/wale) and transverse CC (course/course) directions (Figs. 8 and 9). In the case of low anisotropic knitted materials K1 sample (K1B1WW), which was formed by bonding longitudinally orientated pieces with B1 thermoplastic film deformational behaviour, i. e. punching height *H* after their cyclical fatigue loading decreases by 23 %, while strength remains almost unchanged (Fig. 8). The opposite result was obtained when thermoplastic film B2 was used. In this case punching height of K1B2WW sample remains unchanged, but punching strength decreases by 11 % (Fig. 8). The same results were obtained for high anisotropic knitted material K2, i. e. deformation decreases by 18 %, but strength remains unchanged for the sample with B1 film (K2B1WW). In the case of thermoplastic film B2 – sample K2B2WW deformational behaviour and strength remains almost unchanged.

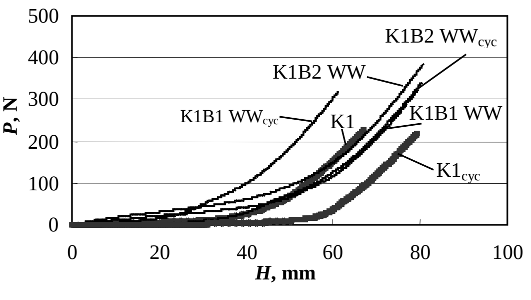

Fig. 8. The changes of punching force *P* of investigated knitted material K1 and its bonded samples with equally (WW) oriented knitted material strips before and after cyclical fatigue loading (subscript cyc)

The assumption can be made that the application of thinner thermoplastic film B1 of lower modulus for bonding longitudinally (WW) oriented pieces does not make any difference compared to the behaviour of non-bonded knitted material, i. e. characteristics of spatial deformation change, but the strength remain almost unchanged. Whereas in the case of twice thicker thermoplastic film B2 the changes of punching height and force values are insignificant. It was noticed that in the case of transverse oriented (CC) pieces in bonded seams, both punching characteristics (punching height *H* and punching force *P*) change after cyclical fatigue loading. In the case of low anisotropic knitted materials K1 sample, which was formed by bonding transverse orientated pieces with B1 thermoplastic film deformational behaviour, i. e. punching height *H* after its cyclical fatigue loading decreases by 23 %, while punching force decreases by 21 % (Fig. 9).

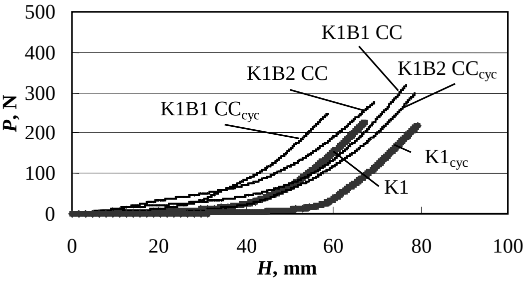

Fig. 9. The changes of punching force *P* of investigated knitted material K1 and its bonded samples with equally (CC) oriented knitted material strips before and after cyclical fatigue loading (subscript cyc)

The results for the sample with B2 film were as follows: 8 % and 10 %, respectively. Summarizing it can be said that systems bonded with B1 thermoplastic film which is characterised by lower modulus are experiencing bigger deformations compared to systems made with B2 film.

4. CONCLUSIONS

The conclusion can be made that the quality of bonded samples with overlapped seams during garment wear depend upon knitted materials anisotropy level and tensile characteristics of thermoplastic films. Whereas the orientation of knitted materials pieces in bonded seams does not have any significant effect.

It was defined that cyclical fatigue loading of 50 cycles up to punching force of 50 N shows the effect upon the behaviour of samples with bonded seams when thermoplastic film of lower tensile modulus B1 is applied – deformational properties change, but strength parameters remain almost unchanged. Meantime the influence of stiffer (higher tensile modulus) film B2 is less significant.

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