ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 12, No. 1. 2006

Influence of Layer Orientation upon Textile Systems Tensile Properties. Part 1. Investigation of Tensile Strain and Resilience

Kristina DAPKŪNIENĖ*, Eugenija STRAZDIENĖ

Department of Clothing and Polymer Product Technology, Kaunas University of Technology, Studentu 56, LT-51424 Kaunas, Lithuania

Received 09 March 2005; accepted 05 January 2006

Bilayer textile systems composed of outer fabric and interlining were investigated in this work. The aim was to investigate tensile properties such as tensile strain ε and resilience *RT* using KES-F (Kawabata Evaluation System for Fabrics) automatic tensile/shear system at garment wearing level loads. Tests were performed with four woven outer fabrics and two interlinings (warp knitted and non-woven). Three types of fused textile systems were prepared by changing orientation of fusible interlinings, i.e. parallel, bias and perpendicular to outer fabric warp direction. Tensile properties of fused systems were investigated in longitudinal and transverse directions (in respect to outer fabrics warp direction) and on the basis of obtained results recommendations were given to achieve the desirable mechanical reaction of fused textile system. Influence of layers' orientation upon textile systems mechanical behaviour, i.e. tensile strain ε and resilience *RT* at low tensile loads is significant for fused systems which are tensioned in transverse direction and insignificant for systems tensioned in longitudinal direction in respect to outer fabrics' warp direction.

Keywords: fused textile system, layer orientation, tensile strain, KES-F system.

1. INTRODUCTION

Fabrics are typical porous media and can be treated as mixtures of fibres and air, having no clearly defined boundary and thus being different from a classical continuum. They are not homogenous and are well known for their property-direction dependence or property anisotropy [1, 2]. Behaviour of woven fabrics is not linear, their experimental anisotropy curves are not smooth [2 – 4]. Characterisation of woven fabrics is performed by three test responses, i.e. tensile behaviour in warp and weft directions and, also, shear performance [1, 3, 5].

Primary function of fabrics used for foundation garments is to provide support for underlying body still being comfortable to wear [3]. If the fabric is strained not enough, the garment will not be able to provide required support. Interlining fabrics are used to support outer fabrics, as well as, to create and maintain the beautiful three-dimensional shape and drape of a garment [6]. With the increasing popularity of lightweight fabrics, the optimal combination of interlining and woven outer fabric is becoming critical for garment quality. Meantime the problem of selecting most suitable fusible interlining for a specific outer fabric is still not solved.

In fact, bonding of fusible interlining produces a "new" fabric in which the interlining properties are added to those of outer fabric [6]. The fitness of fusible interlining to the outer fabric is very important for wearing performance. Functions of fusible interlining in garments can be summarized as the ease of garment manufacturing due to stability of shell fabric, endowment of volume due to good formability and silhouette and shape retention of garment due to cyclic dry cleaning [7]. Fused garment parts should have sufficient bond strength to withstand subsequent wearing and laundering, must pass good handle and drape and can not experience any excessive shrinkage or distortion. Besides they should be free of problems such as moiré effects, surface distortion, glazing, shading and flattening of pile fabrics [8].

As far as the handle and drape of garment are concerned, the mechanical properties of fabric or fused fabric assemblies play a determining role [6]. Also, fabric mechanical properties are of critical importance determining quality, appearance, and performance of fabrics and garments [9].

Meantime tensile properties of fabrics are defined on the basis of recorded breaking strength. On the other hand, the level of stress during normal garment use is much lower [1]. Thus tensile properties should be determined by means of instruments, which measure the reaction of fabric to small deformations. Kirk and Ibrahim [10] defined "available fabric stretch". They published results, which showed that fabric extension during body movement reached only 40 % of maximal fabric deformation obtained at extension force of 350 N/m. Fabric tensile behaviour is assumed to be linear, and then the stress would be approximately 140 N/m.

The KES-F (Kawabata Evaluation System for Fabrics) system has been developed for objective evaluation of textiles hand properties [4, 11]. Tensile, bending, shear, lateral compression and surface characteristics are clearly identified as being important in the "measurement" of fabric handle [9]. In addition such properties as fabric thickness and mass per unit area are also determined [12]. In contrast to standard tensile tests, testing performed by KES-F system is non-destructive and fabric normally returns to its original shape, because it is subjected to small garment wearing level deformations, i.e. applied tensile force is 490 N/m [13].

The aim of this research was to investigate the effect of layers' orientation upon textile systems mechanical

*Corresponding author. Tel.: +370-37-300205; fax: +370-37-353989.
E-mail address: *Kristina.Dapkuniene@stud.ktu.lt* (K. Dapkūnienė)

behaviour at low tensile loads applied by KES-F system. Such fused textile system's mechanical parameters as tensile strain and resilience were investigated and on the basis of obtained results recommendations were given to achieve the desirable mechanical reaction of fused textile system.

2. MATERIALS AND METHODS

Bilayer textile systems, composed of woven outer fabrics and interlinings, were investigated. Tests were performed with four reinforced broken twill woven outer fabrics (Table 1) and two interlinings, i.e. warp knitted interlining TR1 and non-woven interlining P1 (Table 2 and Fig. 1).

Table 1. Characteristics of woven outer fabrics

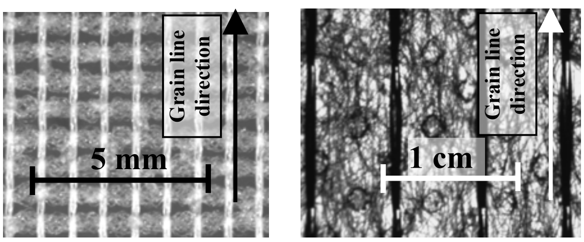
Code	Composition of yarns, %	Area density, g/m²	Thickness*, mm	Density, 1/dm		Linear density, tex
				Warp	Weft	
ST8	80 wool, 20 PA	245.9	1.16	95	87	Warp 121 Weft 117
ST10	80 wool, 20 PA	244.8	1.01	104	102	Warp 98 Weft 115
SM	50 wool, 50 AC	221.8	1.55	162	120	Warp 63 Weft 72
R	80 wool, 20 PES	397.7	2.28	165	129	Warp 116 Weft 118

*thickness measured by KES-F at pressure of 49 Pa;
PA – polyamide, AC – acetate, PES – polyester

Table 2. Characteristics of interlinings

Code	Composition, %	Area density, g/m²	Thickness*, mm	Density		Adhesive, dots/cm²
				Course /cm	Wale /cm	
TR1 (warp knitted)	100 PES	39.1	0.40	14	13	25
P1 (non-woven)	100 PES	40.9	0.56	–	–	17

* thickness measured by KES-F at pressure of 49 Pa.



a b

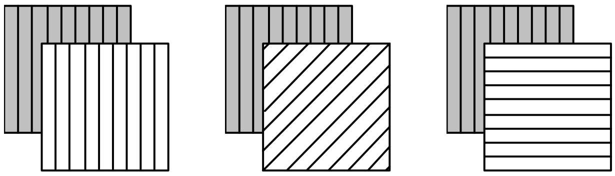
Fig. 1. View of interlinings: a – warp knitted interlining TR1; b – non-woven interlining P1

Fused textile systems were formed by MAYER pressing machine at 145 °C temperature and 0.04 MPa pressure; pressing duration 20 sec.

Three types of fused systems with different orientation of fusible interlining were prepared for the investigations:

1. grain line of fusible interlining was parallel to outer fabric warp direction (Fig. 2, a) – system Par;
2. grain line of fusible interlining oriented at 45° in respect to outer fabric warp direction (Fig. 2, b) – system B;
3. grain line of fusible interlining was perpendicular to outer fabric warp direction (Fig. 2, c) – system Per.

Fused systems were stretched in longitudinal (long.) and transverse (trans.) directions (in respect to outer fabrics warp direction) and tensile properties were defined.



Par **B** **Per**

a b c

Fig. 2. Types of fused textile systems: a – outer fabric warp and interlining grain line directions are the same; b – interlining is at 45° in respect to outer fabric warp direction; c – interlining grain line direction is perpendicular to outer fabric warp direction. – woven outer fabric and its warp direction; – interlining and its grain line direction

Tensile properties were defined by KES-F (Kawabata Evaluation System for Fabrics) automatic tensile/shear system at garment wearing level loads. The specimen was stretched at a constant displacement rate till force of F_m = 490 N/m (500 gf/cm) [13, 14] was reached and after the specimen was relaxed. The width of the specimen was 200 mm the distance between clamps was 50 mm. Velocity of tension was 0.2 mm/sec. From the tensile load – strain curve (Fig. 3) tensile strain ε, % and tensile resilience RT, % were determined.

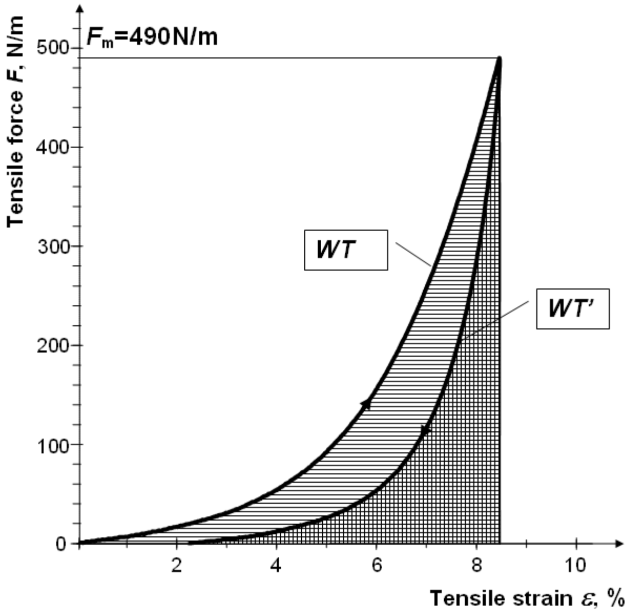


Fig. 3. Tensile load-strain curve in KES-F system

Resilience RT is the ratio of the energy retained in the textile material in loading/unloading cycle and is defined as [13]:

$$RT = \frac{WT'}{WT} 100\,\%\,, \tag{1}$$

where *WT* is the tensile energy per unit area defined as the area under textile material load-strain curve and *WT'* is the tensile energy per unit area in recovering process, respectively (Fig. 3).

3. RESULTS AND DISCUSSION

Desirable stiffness and strength of fused textile system can be achieved by choosing suitable orientation of its layers [15]. Thus, bias orientated fusible interlinings in respect to warp direction of outer woven fabrics are used to maintain the desirable shape of a garment. Stiffness of fused systems should be optimum, because too small, as well as, too high values of stiffness decrease formability, i.e. quality of finished clothing [8].

By Ning *at all* [5], some woven fabrics are stronger in warp direction, while some of them have maximal tensile strength in weft direction, but no maximal tensile strength is achieved in bias directions (15°, 30°, 45°, 60°, 75°) for any woven fabrics. Tensile strength in warp direction is normally higher, since the density of warp yarns is higher in this direction. Meantime, woven fabric breaking strain is highest in the direction of around 45°, where the fabric initial tensile modulus is at its minimum value, meaning that fabric is most stretchable. This is known to be true for most woven fabrics.

Tensile strain

In this research tensile strains of tested textile materials at the tensile value of 490 N/m [13, 14] obtained by KES-F tensile and shear tester are presented in Table 3. The difference between tensile strains ε of tested fusible interlinings in grain line direction (later – in longitudinal direction) is in the range of deviation (±0.26 %). Also it must be noted that perpendicular to grain line direction (later – transverse direction) interlining P1 hasn't reached tensile force of 490 N/m, i.e. strains in this direction exceeded the allowable limits of KES-F equipment.

Table 3. Tensile strains ε, % of tested textile materials

Tension direction	Woven outer fabrics				Interlinings	
	ST8	ST10	SM	R	P1	TR1
Long.*	3.13	3.28	7.17	4.51	1.71	1.76
Trans.*	12.30	16.17	13.65	9.56	–**	34.2

*Long. and Trans. for woven fabrics means warp and weft directions, respectively; **value is not given, because tested material hasn't reached tensile force of 490 N/m

Testing have also revealed that maximal tensile strains ε in fused textile systems (Table 4) with both interlinings (TR1 and P1) is obtained, when fused systems Par (interlinings are orientated parallel to outer fabrics warp direction) are tensioned in transverse direction, because in weft direction outer fabrics and in transverse direction interlinings individually have highest tensile strains (Table 3).

Also it is clear, that high tensile strain ε of fusible interlining in transverse direction can increase tensile strain of the whole textile system, but this increase is more significant for fused systems tensioned in longitudinal direction (Per in long.) than for systems tensioned in transverse direction (Par in trans.). Woven fabrics in weft direction and interlinings in transverse direction are tough and difference between tensile strains ε is 2.12 – 3.58 times, therefore in fused system in some cases tensile strain increases, in some cases decreases (Table 3 and 4). Woven fabrics in warp direction are stiff and interlinings in transverse direction tough (system Per in long.), difference between tensile strains ε is 4.77 – 10.93, and tensile strain of whole system increases up to 1.3 (ST8+P1) times.

Table 4. Tensile strains ε, % in tested systems

Components of textile system		Tension direction	Fused textile system		
Outer fabric	Inter-lining		Par	B	Per
ST8	P1	Long.	2.03	3.39	4.04
		Trans.	12.2	6.79	1.90
	TR1	Long.	2.59	3.70	3.93
		Trans.	13.2	8.97	3.03
ST10	P1	Long.	2.02	3.19	3.66
		Trans.	13.15	6.63	2.02
	TR1	Long.	2.55	3.43	3.72
		Trans.	13.1	9.11	2.99
SM	P1	Long.	2.57	5.36	7.20
		Trans.	13.4	7.48	2.01
	TR1	Long.	3.30	6.68	7.33
		Trans.	13.85	9.91	3.09
R	P1	Long.	2.48	4.31	5.42
		Trans.	11.3	7.07	2.33
	TR1	Long.	3.30	5.04	5.40
		Trans.	10.9	8.80	3.55

Minimal tensile strains ε are obtained when interlining's grain line in fused systems is oriented in respect to tension direction (systems Par in long. and Per in trans.), because in grain line direction both interlinings are stiff and thus decrease tensile strain ε of the whole fused system: by 1.2 (ST8+TR1) – 2.8 (SM+P1) times when system Par is tensioned in longitudinal direction and by 2.7 (R+TR1) – 8.0 (ST10+P1) times when system Per is tensioned in transverse direction. This phenomenon is evidently illustrated in Figure 4 and Figure 5 for R+TR1 fused system.

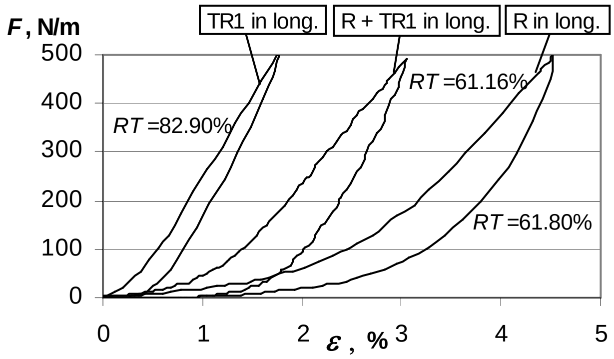


Fig. 4. Tensile strains ε, % and resiliencies *RT*, % in fused system Par (R+TR1) and its components, tensioned in longitudinal direction

Interlining oriented at 45° in fused systems tensioned in transverse direction (B in trans.) decreases tensile strain ε of system by 1.09 (R+TR1) – 2.44 (ST10+P1) times, while tensile strain of this system tensioned in longitudinal direction (B in long.) changes unequal: in some cases increases in some cases decreases. Thus, for achieving the stable system, tensioned in transverse direction, interlining should be oriented in bias or transverse direction.

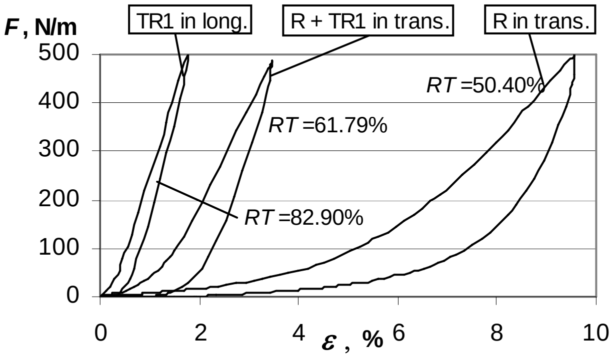


Fig. 5. Tensile strains ε, % and resiliencies *RT*, % in fused system Per (R+TR1) tensioned in transverse direction and its components

Tensile strain ε in fused textile systems tensioned in longitudinal direction after changing orientation of interlining from parallel to bias and then to perpendicular direction (Par → B → Per), increases 1.46 (ST10+TR1) – 2.8 (SM+P1) times. But in the cases when the same fused systems are tensioned in transverse direction (Per → B → Par), tensile strain increases even 3.07 (R+TR1) – 6.67 (SM+P1) times (Table 3). So we can see that orientation of interlining is much more significant for fused systems tensioned in transverse direction than in longitudinal direction.

Tensile strains ε of fused systems with warp knitted interlining TR1 are up to 1.6 (ST8 Per in trans.) times higher than with non-woven interlining P1. For fused systems with orientation of interlining in stiff grain line direction (Par in long., Per in trans.), selection of fusible interlining – warp knitted or non-woven, have the highest influence upon systems tensile strain: ε with TR1 is 1.26 – 1.6 times higher than with P1 (Fig. 6). Also high difference is obtained for fused systems tensioned in transverse direction with bias orientation of interlining: ε with TR1 is 1.24 (with R) – 1.37 (with ST10) times higher than with P1.

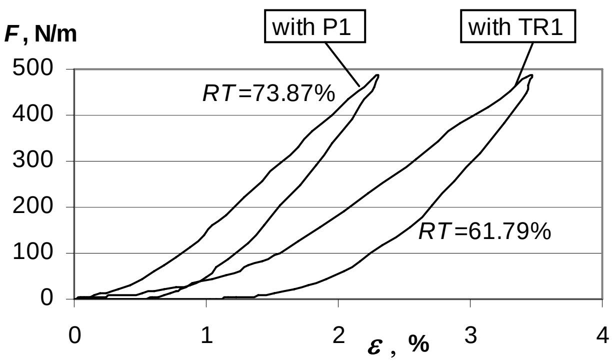


Fig. 6. Fused system Per with outer fabric R tensioned in transverse direction

Difference between tensile strains ε in fused systems with transverse orientation of interlinings P1 and TR1 (Par in trans., Per in long.) is negligible, because in transverse direction interlinings have high tensile strains and influent tensile strain of fused system insignificant (Fig. 7), so it is not important which interlining (P1 or TR1) is chosen for fusing.

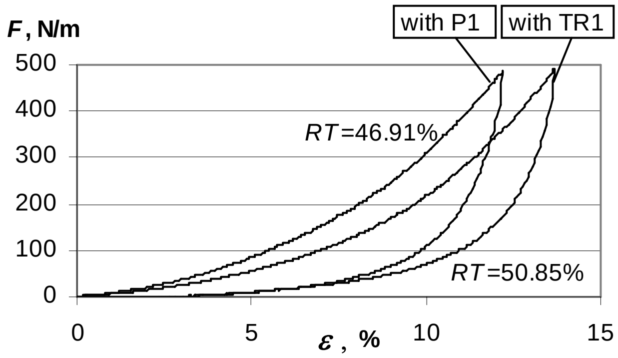


Fig. 7. Fused system Par with outer fabric R tensioned in transverse direction

Resilience

The higher is the resilience *RT*, the higher is the stability of fused system and after unloading it returns to its original dimensions, i.e. doesn't reach plastic deformation and keeps its own original shape and form. Also, the smaller the area of hysteresis is the higher the resilience *RT* is (Fig. 8).

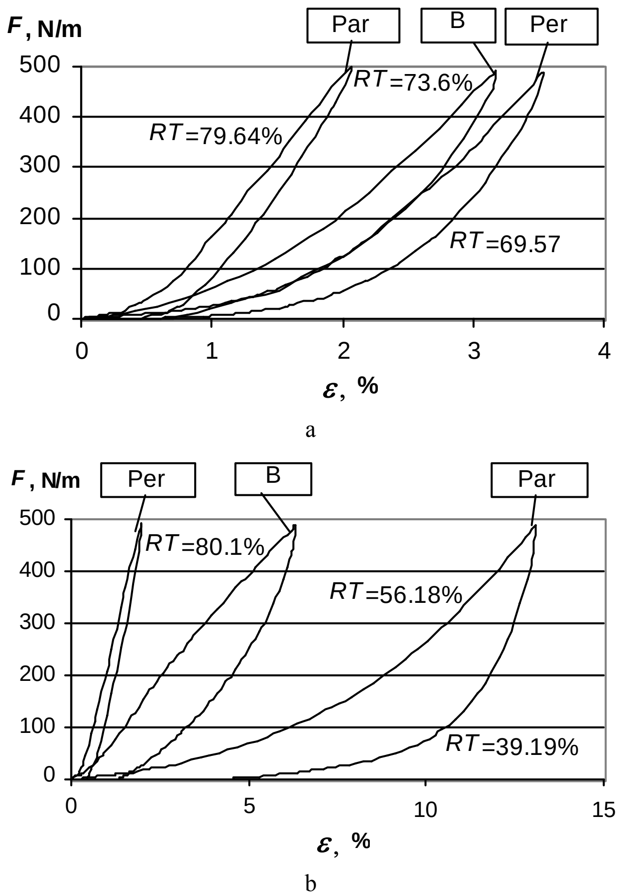


Fig. 8. Resilience *RT*, % in fused systems with outer fabric ST10 and interlining P1: a – tensioned in longitudinal direction; b – tensioned in transverse direction

Resilience *RT* of individual interlinings in longitudinal direction differs in the range of deviation (±5.16 for P1 and ±2.58 for TR1) (Table 5). Resiliencies *RT* of fused systems with longitudinal orientation of interlining (Par in long., Per in trans.) P1 are 1.12 (SM Par in long.) – 1.2 (R Per in trans.) times higher (Fig. 6) than with interlining TR1 (Table 6).

Table 5. Tensile resiliencies *RT*, % of tested materials

Tension direction	Woven outer fabrics				Interlinings	
	ST8	ST10	SM	R	P1	TR1
Long.	67.02	69.87	57.38	61.80	85.20	82.90
Trans.	45.05	40.38	46.00	50.40	–*	29.70

*Long. and Trans. for woven fabrics means warp and weft directions, respectively; **value is not given, because tested material hasn't reached tensile force of 490 N/m

Table 6. Tensile resiliencies *RT*, % of tested systems

Components of textile system		Tension direction	Code of textile system		
Outer fabric	Interlining		Par	B	Per
ST8	P1	Long.	77.01	70.43	64.67
		Trans.	38.75	54.81	80.92
	TR1	Long.	66.18	66.26	66.53
		Trans.	44.57	53.49	67.84
ST10	P1	Long.	79.64	73.60	69.57
		Trans.	39.19	56.18	80.11
	TR1	Long.	69.63	70.23	70.49
		Trans.	45.44	54.54	69.68
SM	P1	Long.	74.36	62.48	54.20
		Trans.	40.19	52.40	79.69
	TR1	Long.	66.68	57.72	57.05
		Trans.	45.37	52.25	68.27
R	P1	Long.	70.29	65.74	58.14
		Trans.	46.91	54.42	73.87
	TR1	Long.	61.16	58.06	58.99
		Trans.	50.85	54.57	61.79

Seeking to increase resilience *RT* of fused system in transverse direction, system Per must be used, because then resilience enlarges even 1.23 (R+TR1) – 1.98 (ST10+P1) times (Table 6, Fig. 5). If interlining is orientated in bias direction (system B), resilience enlarges up to 1.4 (ST10+P1) times, if orientated in transverse direction (Par in trans.) – interlining P1 declines the resilience down to 1.22 (SM+P1) times, while the effect of interlining TR1 orientation is insignificant.

For fused textile systems, tensioned in longitudinal direction, influence of interlinings' orientation upon resiliencies *RT* is less significant (especially for systems with interlining TR1) than for systems tensioned in transverse direction, because in warp direction outer fabrics individually are stiff and characterised by high resiliencies (Table 5).

Besides, systems Par with longitudinal orientation of interlining (Par in long.) P1 have the resilience *RT* about 1.14 times higher than with interlining TR1 (Table 6), though the difference between *RT* of interlinings in grain line direction is in the range of deviation.

Orientation of interlining P1 in bias direction decreases *RT* of systems tensioned in longitudinal direction down to 1.19 (with SM) times, while orientation in transverse direction decreases resilience of system down to 1.15 (with SM) times. Meantime interlining TR1 influences resilience of the systems insignificantly.

Interlining in transverse direction has low resilience and declines resilience of systems Par tensioned in transverse direction down to 1.16 (ST8+P1) times (Table 6), meantime influent the resilience of systems Per tensioned in longitudinal direction insignificantly, because here deciding influence have resilience of outer fabric in warp direction as opposed to resilience of interlining in transverse direction.

It was observed, that up to tensile load of 490 N/m linear inverse dependency exists between resilience *RT* and tensile strain ε, which can be described by linear equation $y = a + bx$ with the coefficient of determination r^2 varying in the range between 0.928 and 0.985 (Table 7).

Table 7. Dependency between RT and ε in fused systems

Components of textile system		Coefficient of determination r^2	$RT = a + b\varepsilon$	
Outer fabric	Interlining		a	b
ST8	P1	0.965	84.13	–3.92
	TR1	0.985	73.98	–2.23
ST10	P1	0.968	85.08	–3.66
	TR1	0.985	77.76	–2.48
SM	P1	0.945	82.45	–3.43
	TR1	0.982	73.30	–2.09
R	P1	0.928	77.72	–2.98
	TR1	0.971	65.67	–1.33

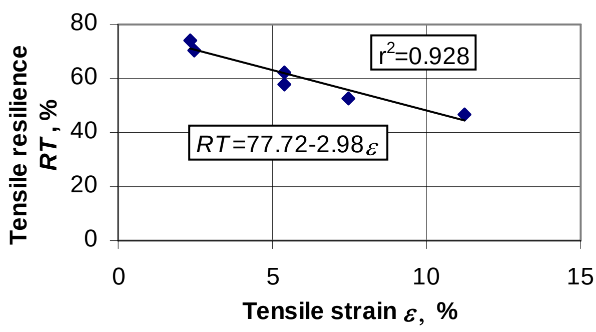


Fig. 9. Dependency between resilience *RT*, % and tensile strain ε, % in fused textile system with outer fabric R and non-woven interlining P1

So, up till tensile force of 490 N/m resilience of fused system can be predicted from tensile strain linearly, i.e. with the increase of tensile strain ε in fused textile system, resilience *RT* decreases by linear relationship (Fig. 9).

CONCLUSIONS

The bilayer textile system was used to investigate the layer orientation upon tensile strain ε and resilience RT values using KES-F system at 490 N/m tensile loads.

The investigation results have shown that the stiffest fused system with low tensile strain ε and high resilience RT is system Par tensioned in longitudinal direction and systems Per tensioned in transverse direction, while the easily stretched are fused systems Par and B, tensioned in transverse direction.

If fusible interlining in fused textile system is oriented in longitudinal direction, it decreases tensile strain and increases resilience of the fused system in such a way: if system is tensioned in longitudinal direction, tensile strain decreases 1.2 – 2.8 times, resilience increases up to 1.3 times, if is tensioned in transverse direction, tensile strain decreases even 2.7 – 8.0 times and resilience increases up to 1.23 – 1.98 times.

Orientation of interlining in bias (45°) direction in fused textile systems, tensioned in transverse direction, decreases tensile strain 1.09 – 2.44 times and increases resilience up to 1.4 times, in systems, tensioned in longitudinal direction, increases resilience insignificant, just up to 1.09 times and tensile strain unequal and insignificant. Thus, for achieving the stable system, tensioned in transverse direction, or don't change characteristics of fused systems tensioned in longitudinal direction, interlining can be oriented in bias direction.

Transverse orientation of fusible interlining is recommended for achieving the stretchable fused system, because it increases tensile strain of system up to 1.3 times and decreases resilience down to 1.15 times.

Orientation of non-woven interlining P1 in its stiff grain line direction enlarges resilience RT of fused system about 1.14 times more than warp knitted interlining TR1 and decreases tensile strain down to 1.6 times more than interlining TR1. For transverse orientation of interlining in fused system it is better to use interlining TR1, because it enlarges resilience up to 1.15 times more than P1 in this direction.

For bias orientation of interlining better use non-woven interlining P1 – then resilience of fused system is up to 1.13 higher and tensile strain is up to 1.37 times lower than with warp knitted interlining TR1.

Dependency between resilience RT and tensile strain ε of tested fused systems can be described by linear equation $RT = a + b\varepsilon$ with the coefficient of determination r^2 varying in the range between 0.928 and 0.985. So, at low wear level deformation loads, i.e. 490 N/m, values of fused systems resiliencies can be predicted on the basis of tensile strains linearly.

Acknowledgements

This paper was finalized in the context of project ITSAPT (Intelligent Textile Structures – Application, Production and Testing), No. G1MA-CT-2002-04060 from 5'Th Frame Programme EU. Coordinator: Technical university of Liberec – Textile Faculty and Research Centre "Textile".

REFERENCES

1. **Bassett, R. J., Postle, R., Pan, N.** Experimental Methods for Measuring Fabric Mechanical Properties: A Review and Analysis *Textile Res. J.* 69 (11) 1999: pp. 866 – 875.
2. **Matthews, F. L., Davies, G. A. O., Hitching, D., Souts, C.** Finite Element Modeling of Composite Materials and Structures. Boca Raton (etc.): CRC Press, 2003: 214 p.
3. **McCartney, J., Hinds, B. K., Kelly, D.** Modelling of Anisotropic Performance Fabrics *Journal of Materials Processing Technology* 159 (2) 2005: pp. 181 – 190.
4. **Cassidy, C., Lomov, S. V.** Anisotropy of Fabrics and Fusible Interlinings *International Journal of Clothing Sciences and Technology* 10 (6) 1998: pp. 379 – 390.
5. **Pan, Ning, Yoon, Mee-Young.** Structural Anisotropy, Failure Criterion and Shear Strength of Woven Fabrics *Textile Res. J.* 66 (4) 1996: pp. 238 – 244
6. **Fan, J., Leeuwner, W., Hunter, L.** Compatibility of Outer and Fusible Interlining Fabrics in Tailored Garments. Part I: Desirable Range of Mechanical Properties of Fused Composites *Textile Res. J.* 67 (2) 1997: pp. 137 – 142.
7. **Kim, S. J., Kim, K. H., Lee, D. H., Bae, G. H.** Suitability of Non-woven Fusible Interlining to the Thin Worsted Fabrics *International Journal of Clothing Science and Technology* 10 (3/4) 1998: pp. 273 – 282.
8. **Fan, J., Leeuwner, W., Hunter, L.** Compatibility of Outer and Fusible Interlining Fabrics in Tailored Garments. Part II: Relationship between Mechanical Properties of Fused Composites and Those of Outer and Fusible Interlining Fabrics *Textile Res. J.* 67 (3) 1997: pp. 194 – 197.
9. **Postle, R.** Fabric Objective Measurement Technology: 1. Historical and Background Development *Textiles Asia* 5.7 (7) 1989: pp. 64 – 66.
10. **Kirk, W., Ibrahim, S. M.** Fundamental Relationships of Fabric Extensibility to Anthropomorphic Requirements and Garment Performance *Textile Res. J.* 36, 37 1966.
11. **Harlock, S. C.** Fabric Objective Measurement Technology: 2. Principles of Measurement *Textiles Asia* 5.7 (7) 1989: pp. 66 – 71.
12. **Curiskis, J. I.** Fabric Objective Measurement Technology: 5. Production Control in Textile Manufacture *Textiles Asia* 6.7 (10) 1989: pp. 42 – 59.
13. **Kawabata, Sueo.** The Standardization and Analysis of Hand Evaluation. Second Edition. The Hand Evaluation and Standardization Committee: The Textile Machinery Society of Japan, 1980: 100 p.
14. **Lomov, S. V., Verpoest, I., Barburski, M., Laperre, J.** Carbon Composites based on Multiaxial Multiply Stitched Preforms. Part 2. KES-F Characterization of the Deformability of the Preforms at Low Loads *Composites* A 34 2003: pp. 359 – 370.
15. Textile Structural Composites. Edited by **Tsu-Wei Chou** and **Frank K. Ko**. Moscow: Mir, 1991: 432 p. (in Rusian).