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Investigation of tensile resilience properties of stretch denim fabrics

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The aim of this research is to investigate the resilience properties of stretch denim fabrics on the basis of tensile properties and structural parameters. Tensile properties are studied using the KES-F system. It is found that for better tensile recovery stretch denim fabrics should have higher polyester and lower cotton content, lower linear density and density of weft yarns but higher density of warp yarns. Tensile resilience could be determined from the initial region of the tensile curve and by setting specific modulus of elasticity at the yield point strain. Higher specific modulus of elasticity of fabrics with elastane ensures better tensile elastic recovery.

Keywords: Fabric construction, Mechanical properties, Stretch denim, Tensile resilience

1 Introduction

Stretch fabrics are increasingly being used across the whole gamut of clothing applications, such as fashion, sportswear, medical and functional garments[1]. Consumers require that the clothing should satisfy their needs in terms of aesthetic appearance, fit and comfort during usage while the clothing manufacturer requires that the fabric is easy to tailor and that the finished garment has a good appearance. One of the factors which influences clothing appearance is the ability of fabrics to recover from induced wrinkles or to retain a smooth surface appearance after wear and repeated laundering[2,3].

Fabrics during garment wear are required to stretch in accordance with the body movements and after stretching to retain the original shape without any deformation[3]. Therefore, the extension and recovery properties after repeated stretch are very important to the performance and appearance of garments[4].

In order to prevent deformation and to reduce bagging and dimensional changes, the extendable or stretch and high elastic recovery fabrics have been introduced to textile market[3,5]. Elastane fibres are characterized by superior stretch and excellent elastic recovery properties. Elastane fibres are mostly used in conjunction with other fibres to achieve controlled stretch and recovery properties and to protect the elastane from mechanical damage[6,7]. Elastane-blended fabrics have higher extension, immediate recovery, and resiliency than 100% cotton fabrics[8].

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The garment quality, appearance, its tailoring processing and performance are determined by the fabric mechanical and surface properties[2]. The extension or stress applied to woven fabrics during manufacturing, finishing, garment construction and wear is generally within the low-stress region. The KES-F system is a device capable of measuring the low-stress tensile, shear, bending and compression deformations[9] of fabrics. With the information provided by this system it is possible to specify fabric handle-related performance requirements and transactions based on fabric mechanical properties data[10].

The clothing engineers have tried to apply the mechanical parameters to tailoring process control and have also attempted to connect these parameters with suit appearance[11]. It was reported that the ideal fabric satisfies the three conditions, namely good hand, good appearance of suit and mechanical comfort for wear. The mechanical comfort is expressed by a range of fabric mechanical parameters such as tensile and shear properties, as indicated below:

$0.60 \geq LT \geq 0.50$; $78 \geq RT \geq 73$
$5.1 \geq EMT_{warp} \geq 4.3$; $18 \geq EMT_{weft} \geq 7.5$;
$3.0 \geq EMT_{weft}/EMT_{warp} \geq 1.3$;
$0.65 \geq G \geq 0.50$; $1.55 \geq 2HG5 \geq 0.8$.

Fabric tensile and shear properties are mainly used in tailoring process control[12]. Higher value of tensile strain *EMT* provides wearing comfort but creates problems during stitching and steam pressing. Very high values of *EMT* in warp direction generate problems in sewing and pressing due to distortion of fabric[13]. The linearity (*LT*) of tensile curve indicates wearing comfort. Lower values of *LT* give higher fabric extensibility in an initial strain range indicating better comfort, but the fabric dimensional stability decreases[13]. Higher value of *LT* means more elastic recovery of a fabric, so better dimensional stability[12,14].

With the increase of fabrics tensile strain (*EMT*), tensile energy (*WT*) increases too. Higher extensibility means higher tensile energy, while tensile resilience is reduced[15]. Relationship between *EMT*, *WT* and *LT* can be described as follows[16]:

$$EMT = \frac{2 * WT}{LT * F} = \frac{WT}{245 * LT} \quad \ldots (1)$$

The ability of textile fabrics to restore their original shape after removing the external loading is known as fabric resilience. Resilience of textile materials is one of the main exploitation parameters describing the quality of the garment and its stability during all wear period, thus the investigation of resilience properties of textile materials is of great importance.

The tensile resilience (*RT*) indicates recovery after tensile deformation[13]. Tensile resilience depending on tensile recovery and deformation energies influences garment appearance. Lower value of *RT* generally means softer the fabrics. However, too low a value of *RT* negatively influences the garment appearance[7]. A higher value of tensile resilience makes the fabric more elastic[14]. Higher tensile resilience gives higher dimensional stability after deformation[17]. With the increase of tensile strain, resilience decreases, i.e. stability and capability to return to original shape decrease[17,18].

Composition of fabric affects resilience properties. With the increase in polyester content, tensile resilience increases[13]. Elastane improves elastic recovery; the elastane percentage in the core-spun yarn has a strong positive correlation with recovery after stretch ($r = 0.80$)[6]. In this study woven fabrics containing elastane yarn along the weft direction were investigated. Ching-Iuan *et al.*[19] and Ozdil[3] established that the elastic recovery increases when draw ratio of spandex increases.

Denim is perhaps the most used item of clothing and is the only fabric which has been produced in such large quantities[20]. Conventionally, denim is a heavy twill fabric made from 100 % cotton with indigo-dyed warp yarn and undyed weft yarn. Through modern technology, denims have been improved in quality and provide a satisfactory level of comfort and durability to consumers[21]. Nowadays denim fabrics are produced mostly with elastane to improve not only comfort but also recovery. Hence, the aim of this research is to investigate resilience of stretch denim fabrics on the basis of fabric tensile properties and structural parameters.

2 Materials and Methods

Tests were performed with five stretch denim fabrics (Table 1). Area density was determined in accordance with LST ISO 3801:1998 standard, fabric density in accordance with LST EN 1049-2:1998 standard, and linear density in accordance with ISO 7211/5-1984 standard. Thickness was measured at a pressure of 50 Pa using the KES-F automatic system. Fractional cover factor *C* represents the ratio of surface area covered by yarns to the total fabric surface area. It is related to the thread density (*n*) and the diameter of the thread (*d*), and was calculated as $n \cdot d$ [22]. If calculated cover factor *C* is ≥ 1 then it should be always accepted as 1.

Tensile properties were defined by the KES-F automatic tensile system (Table 2). The specimens were stretched till force of 490 N/m was reached and

Table 1 — Structural characteristics of tested fabrics

Sample code	Composition, %	Weave	Thickness (*T*), mm	Area density (*W*), g/m²	Linear density (*LD*), tex		Density (*n*) 1/cm		Cover factor (*C*)	
					Warp	Weft	Warp	Weft	Warp	Weft
M1	98 CO, 2 EL	Twill 3/1	0.97	357	67.5	70.0	34	20	1.00	0.84
M2	65 CO, 33 PES, 2 EL	Twill 2/1	0.80	232	45.0	25.0	40	20	1.00	0.50
M3	78 CO, 20 PES, 2 EL	Twill 2/1	0.95	369	105	45.0	28	18	1.00	0.61
M4	97 CO, 3 EL	Twill 2/1	1.15	369	65.0	55.0	30	25	1.00	0.94
M5	78 CO, 20 PES, 2 EL	Twill 3/1	0.69	230	20.0	27.5	65	35	1.00	0.93

CO – Cotton; PES – Polyester; EL – Elastane.

Table 2 — Mechanical characteristics of tested fabrics

Sample code	*EMT*, %		*WT*, Nm/m^2		*LT*			*RT*, %		
	Warp	Weft	Warp	Weft	Warp	Weft	Average	Warp	Weft	Average
M1	**11.4**	15.30	23.91	27.71	0.858	0.740	**0.799**	38.86	46.62	**42.74**
M2	4.28	15.10	8.96	23.17	0.855	0.625	**0.740**	47.70	55.96	**51.83**
M3	**8.38**	14.10	21.15	20.25	1.030	0.647	**0.838**	38.70	56.08	**47.39**
M4	**36.0**	**25.50**	64.07	47.60	0.741	0.745	**0.743**	44.93	46.37	**45.65**
M5	**3.57**	**34.90**	8.00	58.11	0.915	0.680	**0.797**	43.38	49.67	**46.52**

Bold values shows that they are outside mechanical comfort zone for suiting[11].

after that the specimen was relaxed. The width of the specimen was 200 mm and the distance between clamps was 50 mm. Speed of extension was 0.2 mm/s. From the tensile load-strain curve (Fig. 1), tensile strain *EMT* (%), tensile energy *WT* (Nm/m^2), linearity *LT* (-), tensile resilience *RT* (%) and residual strain ε_r (%) were determined. Tensile resilience *RT* (%) is the % ratio of the energy retained in the textile material in unloading/loading[16]. *WT* is tensile energy or work done in tensile deformation represented by the area under the load-strain curve and *WT'* is the area under textile material load-strain curve in recovery (unloading) process.

Smaller area of hysteresis curve represents the higher resilience *RT*. The hysteresis (energy losses) during tensioning is due to the restriction of fibre movement by interfibre friction and the viscoelastic properties of the fibres[2,9].

Tensile linearity *LT* describes the extent of nonlinearity of the stress-strain curve[9] and is derived from the tensile curve (Fig. 1) as *WT*/*WOT*, where *WOT* is the area of triangle *OAB*. The recovery of textile materials is expressed as a ratio of elastic strain to the total strain[23,24].

Residual strain ε_r is derived from the tensile curve as a strain which remains after the recovery process (Fig. 1), while the ratio of the elastic strain to the total strain was calculated as a degree of elasticity *DE*:

$$DE = \frac{EMT - \varepsilon_r}{EMT} \cdot 100\% \quad \ldots (2)$$

In order to compare different fabrics, specific stress should be calculated as the tensile force divided by the linear density *LD*. While specific stress divided by a strain at a yield point EMT_{Yield} represents specific modulus of elasticity *M*:

$$M = \frac{F_{Yield}}{EMT_{Yield}} / LD \quad \ldots (3)$$

where F_{Yield} is the tensile force at the yield point strain. Yield point strain is related to elastic limit when extension of the material is considered to be elastic and will revert to its original length when the force is removed. The degree of stretch was defined manually by stretching 100 mm sample on the ruler while wrinkles do not arise. No additional force was used. Test was done five times in each direction to ensure the reliability of results. Later the degree of stretch *DS* (%) was calculated by subtracting the initial length (100 mm) from the extended length *EL* (mm) and then dividing the result by the initial length or simply by subtracting 100 mm from the extended length[1]:

$$DS\,(\%) = [\{EL\,(\text{mm}) - 100\}*100\%]/100 = EL\,(\text{mm}) - 100 \quad \ldots (4)$$

Five specimens were used for each investigation. Coefficients of variation did not exceed 6 %.

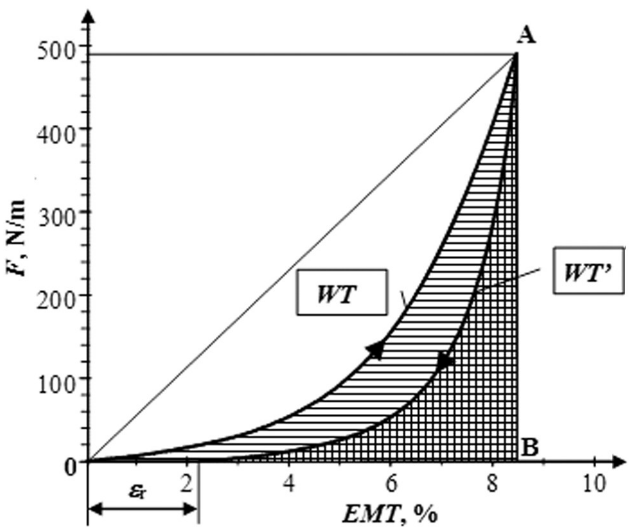

Fig. 1 — Tensile load – strain curve by KES-F

3 Results and Discussion

In this research, stretch woven denim fabrics which ensure good stretch properties and wearing comfort have been investigated. However, tailorability and good recovery properties are even more important.

$EMT \geq 9$ % in warp direction causes difficulties with fabric in overfeed operations and in cutting process[2], $EMT \geq 8$ % in weft direction causes spreading problems in cutting process, while $EMT \geq 11$ % causes fabric distortion after sewing[11]. Two tested fabrics (M1 and M4) have too high *EMT* in warp direction, while very high *EMT* in warp direction of fabric M4 (36 %) could generate problems due to distortion of fabric during sewing. This fabric distinguishes from other tested fabrics (Fig. 2) because it alone has elastane in both warp and weft directions. Other tested fabrics have elastane only in weft direction. This is the reason to separate tested fabrics into two groups, namely 1st group – without elastane (M1 – M3 and M5 in warp direction) and 2nd group – with elastane (M1 – M5 in weft direction and M4 in warp direction).

It is known that the fabrics with higher polyester content have lower extensibility[13]. With the increase in proportion of synthetic component in the core, tensile resilience (*RT*) increases[14]. Our results agree with the results of other researchers[13,14], eg. fabric M2 has the highest polyester content, the lowest *EMT,* and also the highest tensile resilience *RT* (Table 2). Also, the tendency that the amount of cotton has positive relation with tensile strain (*EMT*) is observed, but only for 1st group ($r = 0.83$).

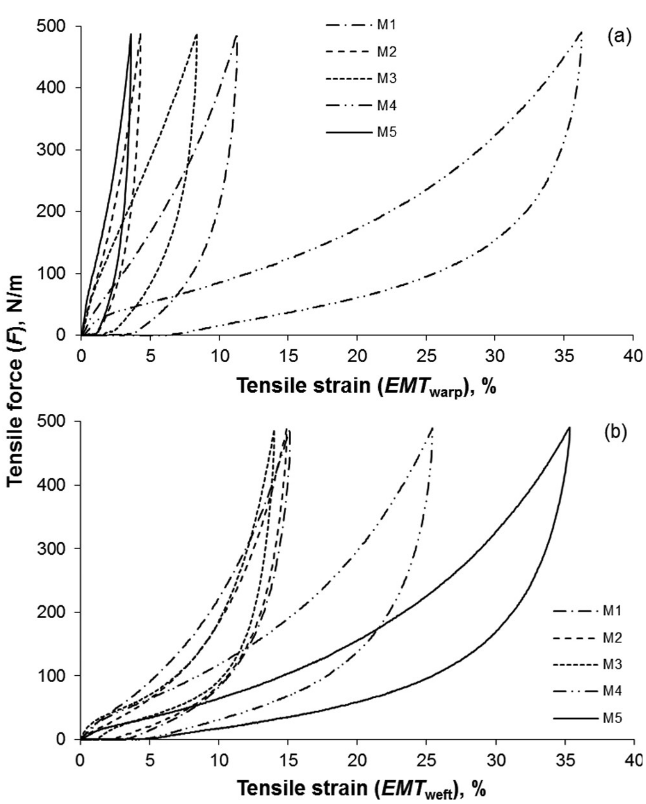

Fig. 2 — Tensile hysteresis curves of tested stretch denim fabrics defined by KES-F system

Linear relationship between *EMT* and *RT* for tested fabrics is found to be negative and the coefficient of correlation between them is -0.82 for 1st group and -0.61 for 2nd group. This result is similar to that obtained by other researcher[25] who analyzed 20 cotton denim fabrics. Relationship is negative because for higher fabric extension the recovery process will take a longer time and therefore less energy is recovered.

Stretch denim fabrics with high *EMT* could have low resilience (*RT*) and this could ensure comfort but may lead to dimensional distortion or bagging of fabric in garment. To ensure not only good stretch properties but also good recovery after stretch, high *EMT* and *RT*, but small residual strain ε_r should be achieved. This depends on fabric composition and structure and is analyzed in this research.

It is defined that density has a strong influence on *EMT* for 2nd group ($r = 0.96$): with the increase of density tensile strain increases too. This result agrees with that of other researcher[8] who stated that with the increase of density in weft direction for any fabric type, a rise of *EMT* will be observed. For 1st group (no elastane) negative coefficient of correlation -0.72 is observed, which means that the density in warp direction should be lower to ensure higher tensile strain. It is not expected to see a relationship between *LD* and *EMT*. Relationship between yarn linear density and *EMT* for 2nd group is not established while for 1st group coefficient of correlation of 0.69 is obtained.

Thread density (n) and yarn linear density (*LD*) together are related to fabric tightness. Linear relationship exists between cover factor C and product of n and *LD* ($r = 0.83$). Cover factor in warp direction cannot be used because of tight structure and $C = 1$, therefore the parameter $n{\cdot}LD$ is one of alternatives for tightness investigation. There is a medium positive linear relationship found between $n{\cdot}LD$ and *EMT* ($r = 0.72$ for 1st, and $r = 0.57$ for 2nd group).

Stretch properties of tested denim fabrics could be analyzed using coefficient *DS* (Table 3) which represents degree of stretch. It is observed that *DS* has a strong linear relationship with *EMT* [Fig. 3(a)] for both groups, as shown below:

$$EMT = 2.05*DS-1.61 \quad \dots (5)$$

This could be used for *EMT* calculation ($r = 0.94$). This is useful because *DS* is defined using a simple

Table 3 — Stretch and recovery results of tested fabrics

Sample code	Degree of stretch (*DS*), %		Residual strain (ε_r), %		Degree of elasticity (*DE*), %		Yield point strain (EMT_{Yield}), %		Specific modulus of elasticity (*M*)	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
M1	5	7	2.06	2.99	81.9	80.5	0.70	1.05	0.68	0.34
M2	4	10	0.77	2.00	82.0	86.8	0.60	0.95	2.19	0.59
M3	5	8	1.47	0.96	82.5	93.2	0.75	0.55	0.85	0.89
M4	14	16	5.83	4.17	83.8	83.6	1.25	1.40	0.33	0.39
M5	3	18	0.68	4.20	81.0	88.0	0.48	1.30	7.08	0.50

test method while for *EMT* evaluation expensive KES-F system is required. Equation (5) could be used only for stretch denim fabrics, while for other groups of fabrics additional testing should be done.

Tensile energy (*WT*) and tensile curve linearity (*LT*) are related to fabric extensibility also. The greater the area under tensile curve, the more energy is used to achieve the same tensile load, i.e. such material is more stretchable, and vice versa. *EMT* and *WT* are highly correlated (r = 0.98) and this result is in accordance with the findings of other researcher[25]. When *LT* is small, fabric extensibility in the initial strain range is high, and this gives comfort in wearing. *LT* is inversely proportional to *EMT*, i.e. the lower the *EMT* at the same tensile load, the higher is the *LT* and therefore the higher stability of textile material is obtained which returns to its original dimensions after unloading and keeps its own original shape and form[26]. To ensure lower *LT*, the fabric structure should be less tight (correlation between *LT* and $n{\cdot}LD$ is r = 0.84 for both groups), the same for *WT* (r = 0.83 and r = 0.66 for separate groups), while Morino & Matsudaira[27] stated that *LT* and *WT* were not influenced by crossing-over firmness factor *CFF*. Our results coincide with those of Hu[9] who stated that *WT* will increase with the rise in weft densities, indicating that more work is needed to extend the fabric.

It is observed that fabric M2 which has the highest polyester content shows the smallest *LT* value. This result does not coincide with the findings of Nayak *et al*[13], who stated that *LT* is higher for the fabrics with higher polyester content. This discrepancy could be because of elastane usage, which changes curvature of tensile curve. Pramanik and Patil[14] stated that 100% cotton fabric has the highest *LT*, and as the amount of cotton is reduced, the *LT* value is decreased. This trend is also observed by us since fabric M2, which has the smallest amount of cotton shows the smallest *LT*.

Tensile resilience is related to the recovery from tensile deformation, and also to the tailorability and

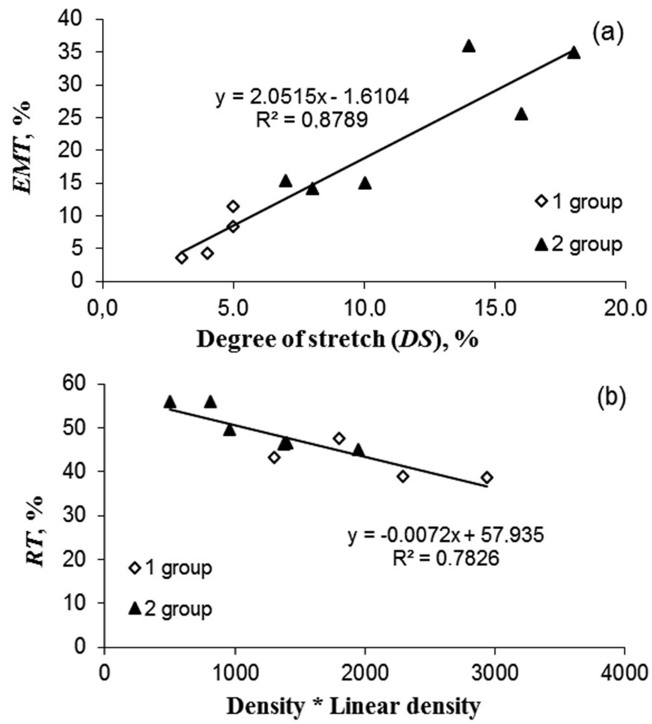

Fig. 3 — Relationship between degree of stretch (*DS*) and tensile strain (*EMT*) (a), and between tensile resilience (*RT*) and multiplied density with linear density (b), for all tested stretch denim fabrics

shape retention. If *RT* is lower than 55 %, the difficulties in steam-press operations are predicted, and distortion of fabric must be carefully avoided[2,12]. All tested stretch denim fabrics have low *RT* (Table 2), so they are less elastic in their tensile property[12]. The smallest value of *RT* in warp direction is for fabric M3, which has the highest linear density *LD* in warp direction (Table 1). The coefficient of correlation between *RT* and *LD,* separately for 1st and 2nd groups, is moderate (r = -0.67 and -0.72 respectively), which means that as linear density increases, tensile resilience decreases.

Geršak[15] stated that fabrics with extremely low density of warp and weft yarns and high mass exhibit lower *RT*. This trend is also observed in our research, but only for the 1st group of fabrics. Fabric M3 which has the smallest density of warp yarns and the highest area density has the smallest value of *RT* in warp direction. While result for the 2nd group which contains elastane is contrary. Fabric M3 in weft direction has the smallest yarn density, but the highest *RT*. This could be due to elastane incorporated into weft direction which changes recovery behavior of fabrics as compared to fabrics without elastane.

3.1 Effect of Tightness of Fabric Structure on Resiliency

Nayak *et al.*[13] and Chan *et al.*[10] stated that *RT* values are higher for the fabric with tighter construction because of the crimp removal which leads to a better recovery in a tight fabric. They analyzed different woven fabrics without elastane. In our research no significant relationship between density and *RT* is obtained (r = 0.44 for 1st and r = -0.51 for 2nd group), but good relationship between *RT* and $n \cdot LD$ is achieved [Fig. 3(b)]. So, more tight structure (higher value of multiplied densities) reduces resilience. Our results agree with that of Morino and Matsudaira[27] that *RT* is influenced by parameter of weave structure, crossing-over firmness factor *CFF*, with coefficient of correlation -0.685. They analyzed 10 cotton/polyester fabrics. In our research, cover factor *C* in weft direction has strong negative relationship (r = -0.91) with *RT*.

Analyzing initial tensile force – strain curves (Fig. 4), it could be seen that there are significant differences between the tensile behavior of fabrics with and without elastane. If fabrics in warp direction without elastane have clearly expressed linear elastic region, then fabrics in weft direction and with elastane have different curvatures of tensile curves. The straight region represents deformations which are completely recoverable and this extends to the yield point. Increasing the load beyond the yield point results in the movement of fibres in the core of the yarn and this causes time-dependent deformation.

Elastic region is analyzed using specific modulus of elasticity (*M*) at the yield point strain (EMT_{Yield}) (Table 3). It is defined that *RT* has a strong positive linear relationship with *M* for 2nd group (r = 0.89), higher *M* values of fabrics with elastane ensure better tensile elastic recovery. However, for 1st group no strong relationship is achieved (r = 0.40). *M* is closely related to EMT_{Yield}; the higher the EMT_{Yield}, the smaller is the *M* (r = -0.94 for 1st and -0.84 for 2nd group). For all tested stretch denim fabrics, power equation is defined [Fig. 5(a)].

It is linear negative relationship between *M* and $n \cdot LD$ (r = -0.84 and r = -0.72 for separate groups) and also between *M* and *C* in weft direction (r = -0.67), so more tight structure reduces specific modulus of elasticity as in the case of tensile resilience [Fig. 3(b)].

EMT_{Yield} has a strong positive relationship with *EMT* for all tested fabrics (r = 0.87) but the higher *EMT* causes the higher residual strain ε_r (r = 0.94), which means worse tensile resilience *RT* [Fig. 5(b)]. EMT_{Yield} and *RT* show negative linear relationship also (r = -0.65 for 1st group and r = -0.78 for 2nd group).

Smaller ε_r causes higher *RT* and also higher degree of elasticity *DE* (Table 3). Residual strain (ε_r) of tested fabrics is higher if structure is tighter (r = 0.80 for 1st group and r = 0.69 for 2nd group). For the same composition of fabric but with the increase of density, area density and thickness, the resilience *RT* increases and residual strain decreases, i.e. fabric maintains original shape better[18]. This applies only to the 1st group of tested fabrics (no elastane), because with the increase of density, ε_r decreases (r = -0.69), while for the 2nd group, it increases (r = 0.79). Analyzing the effects of *LD* and *n* on ε_r separately, it is clear that lower value of ε_r would be obtained using lower *LD* of

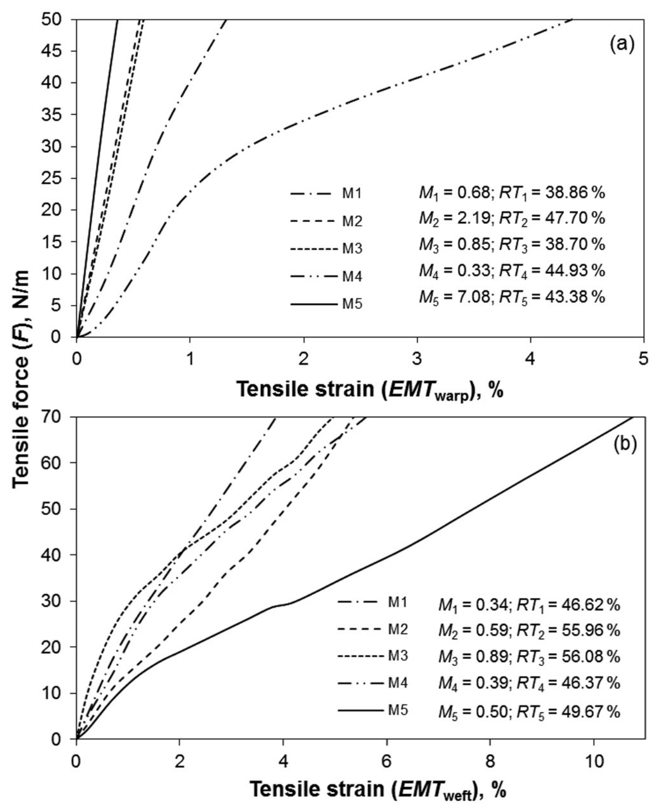

Fig. 4 — Initial region of tensile force – strain curves of tested stretch denim fabrics

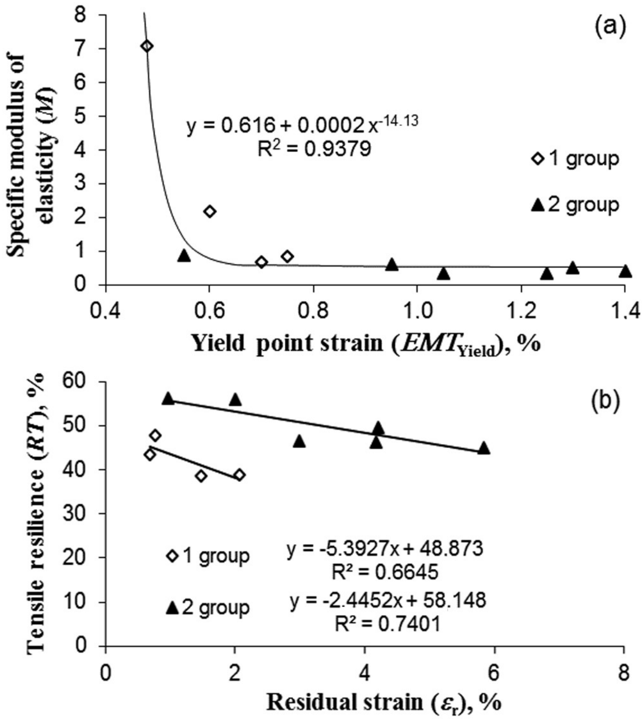

Fig. 5 — Relationship between specific modulus of elasticity (*M*) and tensile resilience (*RT*) for all tested fabrics (a), and linear relationship between residual strain (ε_r) and tensile resilience (*RT*) (b)

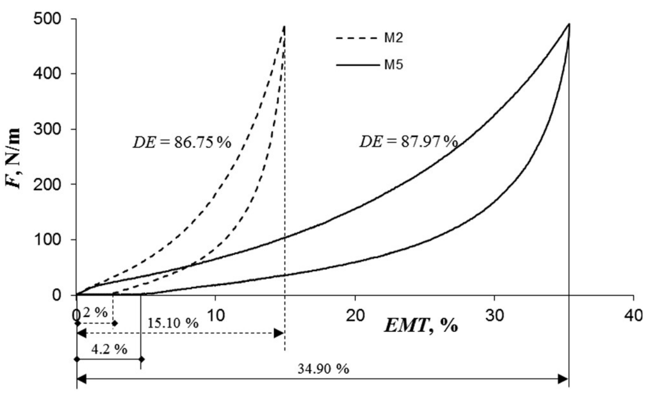

Fig. 6 — Tensile hysteresis curves and degree of elasticity (*DE*) of two tested fabrics M2 and M5 in weft direction

warp and weft yarns, higher density (*n*) of warp and lower of weft yarns.

It is defined that *DE* has strong linear negative relationship (r = -0.93) with *M* for 1st group, whereas for 2nd group the nature of relationship is changed (r = 0.94), so the higher the *M*, the higher is *DE* if elastane is used, but this result is opposite if elastane is not used. The slope of latter is small, so the influence upon *DE* is more significant if elastane is used. If EMT_{Yield} is higher, *DE* is higher too (r = 0.92) if elastane is not used, but it is lower (r = -0.65) if elastane is used.

DE depends not only on ε_r but also on tensile strain *EMT* at the tensile force of 490 N/m, so it is clear that only residual strain cannot be used for defining the resilience, because the most important is percentage of recovery after stretching to the whole tensile strain. We can see that ε_r values of fabrics M2 and M5 in weft direction (Fig. 6) are different by nearly a factor of two, while their *DE* is almost the same.

Degree of elasticity (*DE*) is related to tensile resilience (*RT*). The higher the *DE*, the higher is the *RT*. This relationship is stronger for 2nd group (r = 0.79), which contains elastane. The smallest *DE* and *RT* are for fabric M1which has the highest percentage of cotton and the highest linear density of weft yarns (Table 1).

4 Conclusion

In this study it is found that to ensure better tensile recovery properties, stretch denim fabrics should have higher polyester and lower cotton content, lower linear density and density of weft yarns but higher density of warp yarns. To ensure higher tensile resilience, degree of elasticity and also lower residual strain, fabric structure should be less tight.

Tightness of fabrics could be investigated using density (*n*) multiplied by linear density (*LD*), because there exists strong linear relationship (r = 0.83) between cover factor (*C*) and $n \cdot LD$.

Residual strain alone cannot be used for recovery investigation, because the most important is percentage of return after stretching to the whole elongation. For this reason, degree of elasticity should be calculated. Degree of elasticity (*DE*) is related to tensile resilience *RT* (r = 0.76), i.e the higher the *DE*, the higher is the *RT*.

Tensile resilience could be analyzed using initial region of tensile curve and by setting specific modulus of elasticity (*M*) at the yield point strain. The lower the EMT_{Yield}, the higher is the *M*. This relation could be described by a power function for all tested stretch denim fabrics. If EMT_{Yield} is higher, *DE* is higher too (r = 0.92) if elastane is not used, but it is lower (r = -0.65) if elastane is used.

The higher the specific modulus of elasticity (*M*), the higher is the degree of elasticity (*DE*), if elastane is used, but lower if elastane is not used. So, higher *M* of fabrics with elastane ensures better tensile elastic recovery.

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