STRESS - STRAIN CURVE ANALYSIS OF WOVEN FABRICS MADE FROM COMBED YARNS TYPE WOOL

VÎLCU Adrian[1], HRISTIAN Liliana[2], BORDEIANU Demetra L.[3], VÎLCU Catalin[4]

[1,2,34,] *"Gh.Asachi" Technical University of Iasi, Faculty of Textile, Leather and Industrial Management, Prof. Dr. Doc. Dimitrie Mangeron Str., No. 29, 700050, Iasi, Romania*

Corresponding author: Hristian Liliana, e-mail: hristian@tex.tuiasi.ro

Abstract: *The paper analyses the tensile behaviour of woven fabrics made from 45%Wool + 55%PES used for garments. Analysis of fabric behaviour during wearing has shown that these are submitted to simple and repeated uniaxial or biaxial tensile strains. The level of these strains is often within the elastic limit, rarely going over yielding. Therefore the designer must be able to evaluate the mechanical behaviour of such fabrics in order to control the fabric behaviour in the garment.*
This evaluation is carried out based on the tensile testing, using certain indexes specific to the stress-strain curve. The paper considers an experimental matrix based on woven fabrics of different yarn counts, different or equal yarn count for warp and weft systems and different structures. The fabrics were tested using a testing machine and the results were then compared in order to determine the fabrics' tensile behaviour and the factors of influence that affect it.From the point of view of tensile testing, the woven materials having twill weave are preferable because this type of structure is characterised by higher durability and better yarn stability in the fabric. In practice, the woven material must exhibit an optimum behaviour to repeated strains, flexions and abrasions during wearing process.
The analysis of fabrics tensile properties studied by investigation of stress-strain diagrams reveals that the main factors influencing the tensile strength are: yarns fineness, technological density of those two systems of yarns and the weaving type.

Key words: *fabrics, elasticity modulus, stress-strain diagrams.*

1. INTRODUCTION

The fabric tensile properties depend on the tensile properties of the two yarn systems and the fabric structural parameters (yarn fineness, technological density of the two yarn systems and weaving type). One of the main objectives in designing a fabric is the tensile behaviour. By means of the tensile behaviour one can analyze the fabric behaviour during wearing process, as it shows that these are subjected to simple or repeated uniaxial or biaxial tensile strains. The level of these strains can be close to the ultimate tensile strength or they can have small, insignificant values; that is why the designer must anticipate the behaviour to such strains.

The complexity of reality requires, in statistical surveys, the follow-up of two directions:
- description of a population by a feature or multiple features highlighting;
- comparison between populations [1].

This can be appreciated by determining the indices inferred from the stress-strain diagram, relevant for the peculiarities of the strain process as follows [2], [3]:

– Proportionality, elasticity, yielding and breaking limits;
– Elasticity modulus for warp and weft yarns, calculated with:

$$E_{twarp} = \frac{200 \cdot F_p}{\varepsilon_p \cdot P_{weft} \cdot T_{tex}}, \text{ [N/tex]} \quad (1)$$

$$E_{tweft} = \frac{200 \cdot F_p}{\varepsilon_p \cdot P_{weft} \cdot T_{tex}}, \text{ [N/tex]} \quad (2)$$

where: F_p and ε_p – the force and elongation corresponding to the proportionality limit;

P_{warp} and P_{weft} – the fabric warp and weft density;

T_{tex} – yarn's linear density.

– Work of rupture

$$W_{warp} = f_{warp} \cdot F_{rwarp} \cdot a_{rwarp}, \text{ [daN.m]} \quad \textbf{(3)}$$

$$W_{warp} = f_{warp} \cdot F_{rwarp} \cdot a_{rwarp}, \text{ [daN.m]} \quad \textbf{(4)}$$

where: f_{warp} and f_{weft} – the work factor for warp and weft direction, determined on the stress strain curves;

F_{rwarp} and F_{rweft} – breaking force for warp and weft testing direction;

a_{rwarp} and a_{rweft} – fabric breaking elongation [mm] for warp and weft testing direction

– Specific work of rupture, expressed through the following relations:

$$W_{mwarp} = \frac{W_{warp}}{M \cdot b \cdot l_0}, \text{ [N.m/g]} \quad \textbf{(5)}$$

$$W_{mweft} = \frac{W_{weft}}{M \cdot b \cdot l_0}, \text{ [N.m/g]} \quad \textbf{(6)}$$

$$W_{swarp} = \frac{W_{warp}}{M \cdot b \cdot l_0}, \text{ [N.m/m}^2\text{]} \quad \textbf{(7)}$$

$$W_{sweft} = \frac{W_{weft}}{M \cdot b \cdot l_0}, \text{ [N.m/m}^2\text{]} \quad \textbf{(8)}$$

where: W_{warp} and W_{weft} – work of rupture for warp and weft direction, [N.m]; M – sample mass, [g/m2]; b – sample width, [mm]; l_0 – sample initial length, [mm], [4].

Indicators values for appreciation tensile properties of woven materials can be influenced by the creasing behavior.The creasing of woven materials made from combed yarns type wool used for ready-clothes is an undesired deformation effect with temporary or permanent character, which is caused by a composed strain of bending and compression during utilization, processing or maintenance. It is manifested by the appearance of wrinkles, folds or stripes on the surface of wovens materials, thus diminishing their qualitative appearance and also their practical value.

The quality and durability of textile/fabrics are appreciated by determining the tension properties expressed by indicators, whose variation limits differentiate themselves and depend on:

- basic structural characteristics: geometrical structure and fibrous composition of the component yarns, tie, yarn systems numbers
- structural features derived from basic structures: the degree of waving of the yarns, fabric thickness/per unit of length, area, volume;
- surface features: fabric luster appreciated through the pilling resistance or the number of bundle fibers which are analyzed quantitatively and qualitatively [5];
- processing parameters;
- finishing process parameters.

2. EXPERIMENTAL PART

2.1. MATERIALS AND METHODS

The fabric variants used for tensile testing were determined based on an experimental matrix (see Table 1) that included 3 input variables: yarn count for weft and warp system, yarn count balance between weft and warp system and fabric structure.

Table 1: *Experimental Matrix*

Variant Code	X1	X2		X3
	Yarn count balance	**Nm_{warp}**	**Nm_{weft}**	**Fabric structure**
A1		60/2	60/2	P6/66/6
A2		60/2	60/2	D2/1
A3		60/2	60/2	D2/2
A4		60/2	60/2	plain
A5		52/2	52/2	D2/2

A6	$Nm_{warp}=Nm_{weft}$	52/2	52/2	crepe
A8		52/2	52/2	D2/2
A9		52/2	52/2	D2/12/5
A10		52/2	52/2	D2/1
A12		52/2	52/2	plain
A13		52/2	52/2	P2/22/2
A14		48/2	48/2	D2/2
A16		60/2	60/2	D2/1
A7	$Nm_{warp} \neq Nm_{weft}$	52/2	52/1	D2/1
A11		52/2	30/1	D2/1
A15		64/2	37/1	plain
A17		56/2	37/1	D2/1

The basic parameters (fibre composition, linear density, technological density of the two yarn systems and weave type) have been determined for the finished fabric through classical means and standardized methods.

Processing of yarns from blended fibres is technically and economically justified by their superior workability, usability and durability obtained at convenient costs. The physical- mechanical characteristics are pre-established by choosing the components, and quantitatively by components dosing, such that the yarn corresponds to its destination.

The fibre composition of the warp and weft yarns extracted from the fabric sample has been determined through standardized methods on representative specimens, through microscopic analysis and burning test.

Structural parameters of analysed articles, determined through standardized methods are indicated in Table 2.

Table 2: *Structural parameters of analysed articles*

Variant Code	Fibrous composition	$P_{warp/weft}$ (fire/10cm)		Flotation		Fabric structure
		Warp	Weft	Warp	Weft	
A1	45%Wool70s+55%PES (1645)	330	310	6	6	P 6/6 6/6
A2		310	210	1.5	1.5	D2/1
A3		280	240	2	2	D2/2
A4		235	220	1	1	plain
A5		280	240	2	2	D2/2/
A6		260	250	1.5	1.5	crepe
A8		260	270	1.5	1.5	D2/1
A9		260	235	2	2	D2/2
A10		295	280	2.5	2.5	D 2/1 2/5
A12		265	245	1.5	1.5	D2/1
A13		280	300	1.5	1.5	D2/1
A14		210	180	1	1	plain
A16		265	250	2	2	P 2/2 2/2
A7		280	245	2	2	D2/2
A11		240	270	1	1	plain
A15		320	230	1.5	1.5	D2/1
A17		290	300	1.5	1.5	D2/1

The fabrics were made from 45%wool +55%PES yarns of different counts, as mentioned above. The fabrics were finished with specific technologies. The tensile testing was performed using an H 1K-S UTM Tinius Olsen (Hounsfield) testing machine, having 1 kN load cell. The tests were done accordingly to standard (SR EN ISO 2062, 2002), on both directions – weft and warp [6].

2.2. RESULTS AND DISCUSSIONS

The raw data for each stress-strain curve was saved for further processing. The proportionality field and breaking point was recorded for each curve. Fig. 1, Fig. 2, presents the stress-strain curve of two variants, as examples, one example for a fabric with $Nm_{warp} = Nm_{weft}$ and the other with $Nm_{warp} \neq Nm_{weft}$

The qualitative and quantitative analysis of the stress-strain curves (see Table 3) allows emphasising the following aspects: the variation intervals for tensile limits; the factors that differentiate the stress-strain curves for the studied variants - testing direction; fibrous composition; weaving draw through mean flotation of yarns; technological density of warp respective weft yarns.

The stress-strain curves were used to calculate the indicators for tensile behaviour mentioned above.

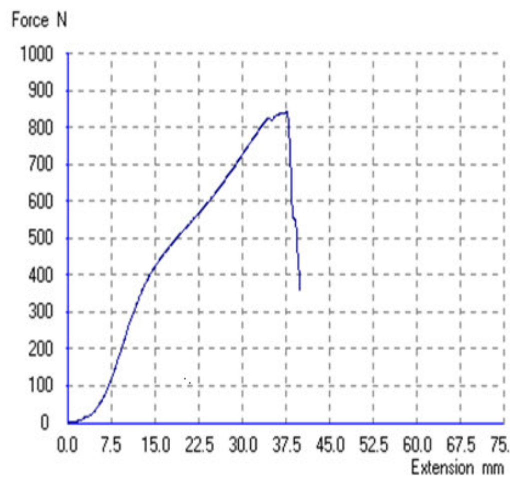

Fig. 1: *Stress-strain curves for woven fabric tested varianta A3 45%wool +55%PES (Nm_{warp} 60/2; Nm_{weft} 60/2) requested the warp direction*

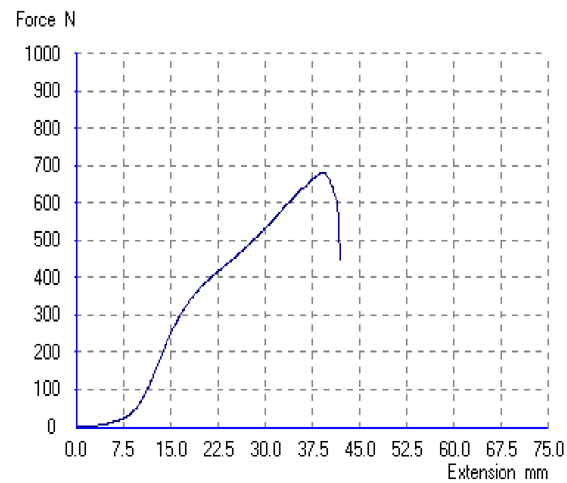

Fig.2: *Stress-strain curves for woven fabric tested varianta A3 45%wool +55%PES (Nm_{warp} 60/2; Nm_{weft} 60/2) requested the weft direction*

Table 3: *The tensile indicators for woven materials made 45%Wool + 55%PES*

Variant Code	F (daN)		ε (%)		E (cN/tex)		f_W	
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft
A1	79.70	90.80	35.35	34.11	182.30	272.29	0.51	0.49
A2	91.20	60.40	46.42	41.39	153.35	187.41	0.50	0.48
A3	84.10	68.20	32.87	29.3	242.77	344.97	0.56	0.48
A4	64.70	62.80	31.31	27.71	222.79	270.15	0.54	0.53
A5	77.40	63.20	34.19	30.34	177.00	223.91	0.51	0.53
A6	66.60	62.90	35.28	32.25	209.22	239.84	0.53	0.52
A8	81.30	67.50	32.79	38.75	214.21	171.96	0.55	0.50
A9	75.90	65.70	36.24	30.9	231.39	253.39	0.54	0.52
A10	92.30	80.40	36.73	31.45	181.32	218.06	0.56	0.52
A12	86.00	76.40	37.44	36.49	202.98	201.33	0.51	0.51
A13	81.10	54.60	47.7	55.8	130.05	161.08	0.54	0.52
A14	77.40	60.10	41.7	39.25	210.86	190.73	0.50	0.48
A16	71.70	66.20	33.15	32.72	284.55	239.36	0.55	0.49
A7	90.00	72.50	36.77	32.11	214.45	215.18	0.54	0.48
A11	61.10	58.50	35.85	36.2	193.67	255.78	0.54	0.51
A15	80.70	53.90	40	32.04	154.32	230.39	0.56	0.54
A17	76.20	62.30	38.1	35.65	196.41	193.58	0.54	0.53

(***Table 3*** *continued*)

Variant Code	W (daN.m)		Wm (daN.m/g)		Ws (daN.m/m^2)	
	Warp	Weft	Warp	Weft	Warp	Weft
A1	1.42	1.53	1.26	1.35	284.80	306.56
A2	2.12	1.20	2.16	1.22	424.96	240.69
A3	1.55	0.95	1.35	0.83	309.86	189.88
A4	1.10	0.92	1.36	1.13	219.98	183.15
A5	1.34	1.02	1.27	0.97	268.55	204.19
A6	1.25	1.05	1.30	1.10	249.06	210.97
A8	1.46	1.30	1.45	1.29	292.61	260.91

A9	1.49	1.06	1.39	0.99	297.37	212.86
A10	1.90	1.31	1.56	1.08	379.70	262.97
A12	1.65	1.43	1.62	1.40	330.95	285.27
A13	2.09	1.58	1.80	1.37	417.79	316.85
A14	1.61	1.13	1.92	1.35	321.53	225.30
A16	1.30	1.05	1.25	1.01	261.00	210.75
A7	1.78	1.12	1.52	0.95	356.11	223.24
A11	1.18	1.08	1.54	1.41	236.57	216.01
A15	1.81	0.93	1.80	0.93	361.54	186.51
A17	1.57	1.17	1.63	1.22	313.37	234.62

The following useful observations can be drawn based on the analysis of the values from Table 2 and on their graphical representation:

- for woven fabrics with **$Nm_{warp} = Nm_{weft}$**

– the maximum breaking strength for warp direction has been recorded for variant **A9**, characteristics: F_{warp} = 92,30 daN, Nm_{warp} 52/2; Nm_{weft} 52/2, P_{warp} = 295 yarns/10cm; P_{weft} = 280 yarns/10cm; warp yarns twist T = 648 twists/m respective twist of weft yarns T = 637 twists/m and compound diagonal bonding $D\frac{2\ \ 2}{1\ \ 5}$. Variant **A1** has the maximum breaking strength for weft direction, F_{weft} = 90,80 daN, Nm_{warp} 60/2; Nm_{weft} 60/2, P_{warp} = 330 yarns/10cm; P_{weft} = 310 yarns/10cm; warp yarns twist T = 747 twists/m respective twist of weft yarns T = 735 twists/m and panama weave $P\frac{6\ \ 6}{6\ \ 6}$.

– the minimum breaking strength for warp direction has been recorded for variant **A4**, F_{warp} = 64,70 daN, Nm_{warp} 60/2; Nm_{weft} 60/2, P_{warp} = 235 yarns/10cm; P_{weft} = 220 yarns/10cm; warp yarns twist T = 712 twists/m; weft yarns twist T = 701 twists/m, plain weave. Variant **A16** has the minimum breaking strength for weft direction, F_{weft} = 53,90 daN, Nm_{wrap} 60/2; Nm_{weft} 60/2, P_{warp} = 320 yarns/10cm; P_{weft} = 230 yarns/10cm; warp yarns twist T = 723 twist/m; weft yarns twist T = 712 twists/m; diagonal bonding $D\frac{2}{1}/$.

- for fabric variants with **$Nm_{warp} \neq Nm_{weft}$**

– the maximum breaking strength for both testing directions has been recorded for variant **A7**, F_{warp} = 81,30 daN, F_{weft} = 67,50 daN Nm_{warp} 52/2; Nm_{weft} 52/1, P_{warp} = 260 yarns/10cm; P_{weft} = 270 yarns/10cm; warp yarns twist T = 648 twists/m and weft yarns twist T=520 twists/m; having diagonal bonding $D\frac{2}{1}/$.

– the minimum breaking strength for warp direction has been recorded for variant **A15,** F_{warp} = 61,10 daN, Nm_{warp} 64/2; Nm_{weft} 37/1, P_{warp} = 240 yarns/10cm; P_{weft} = 270 yarns/10cm; warp yarns twist T = 764 twists/m; weft yarns twist T = 596 twists/m; plain bonding. The minimum breaking strength value for weft direction has been determined for variant **A11**, F_{weft} = 54,60 daN, Nm_{warp} 52/2; Nm_{weft} 30/1, P_{warp} =280 yarns/10cm; P_{weft} = 300 yarns/10cm; warp yarns twist T = 648 twists/m; weft yarns twist T = 637 twists/m; twill weave $D\frac{2}{1}/$.

The plain weave is characterized by the smallest values of the ultimate strength, in the direction of both the warp and the weft yarns, which is justified by the fact that the evolution of the two yarn systems provides a good positional stability of yarns, these having a bigger crimp frequency. In order to point out the influence of the fabric on the tensile properties the studied variants, the bonding was expressed through mean flotation F_{warp} for warp yarns respective mean flotation F_{weft} for weft yarns.

The intersection between a warp yarn and weft yarn is called a bonding point, thus the bonding contains all bonding points having a warp or weft effect along longitudinal or transversal direction. One or more bonding points with the same effect and forming one bonding segment can exist in longitudinal or transversal direction.

3. CONCLUSIONS

Based on the analysis of the tensile behaviour determined for the fabric variants, the following general conclusions can be drawn:

1. The influence factors on tensile strength of woven materials are: yarns fineness, technological density of warp respective weft yarn systems and bonding type. The maximum values have been recorded for fabric variants having compound diagonal bonding, fundamental diagonal bonding and panama bonding due to their bigger yarn flotation (a value of 1.5; 2 or 6). Meanwhile, the minimum values have been observed for variants having plain bonding for which the flotation value is 1.

2. Elasticity modulus is bigger on warp direction owing to the smaller influence of the twist degree. The increasing of the twist degree lead to the increasing of the twist angle and decreasing of the yarn elasticity.

3. Depending on shape of the stress-strain curve, the mechanical work factor can have one from the following values: fw = 0.5 – ideal case; fw < 0.5 case in which both yarn systems manifest a reduced deformation strength; fw > 0.5 case in which both yarn systems manifest an increased deformation strength. From the experimental data results that the mechanical work factor has values over 0.5 for almost all fabric variants.

4. From the point of view of tensile testing, the woven materials having diagonal bonding are preferable because this type of structure is characterised by higher durability and better yarn stability in the fabric. In practice, the woven material must exhibit an optimum behaviour to repeated strains, flexions and abrasions during wearing process.

5. It can establish a fabric hierarchy in term of their behaviour to tensile strength based on the evaluation of the specific mechanical energy consumed to break the specimen. The value of the quality index is influenced by: the nature of the utilized raw material; adopted technological process and parameters of processing; the parameters of geometrical structure at which the product is accomplished; technology and technological finishing parameters applied to the product.

6. The woven fabrics accomplished from yarns type combed wool (blend of 45% Wool+ 55%PES) are characterized by specific structural parameters and specific aspect, as well as by their physical-mechanical properties which satisfy the requirements of a certain area of utilization (external clothing products).

The percentage of chemical fibres blended with wool fibres influences both the development of the technological process and the physical-mechanical characteristics of the fabrics. A factor that must be especially taken into account is the shrinkage, which diminishes as the polyester fibres are introduces.

REFERENCES

[1] Hristian L., Lupu I. G., Bordeianu L. D. and Cramariuc O., *"Study regarding the creasing behavior of fabrics made from combed yarns type wool"*, Annals of the university of Oradea fascicle of textiles, leatherwork, vol. XIII, 2012, No. 2, ISSN 1843 – 813X, pp. 78 – 82.

[2] Hristian L, *„Substantion and Elaboration of a New Testing Methodology of Woven Materials Surface Characteristics with Classical Testing Methods"*, Ph.D Thesis, "Gheorghe Asachi" Technical University, Jassy, 2008.

[3] Neculaiasa M. S., Hristian L., *"Textile metrology",* vol. I, Ed. Performantica, 2004, Iasi.

[4] Hristian L., Lupu I. G. and Cramariuc O., *"Creasing behavior of some woven materials made from combed yarns type wool – an experimental investigation",* International Scientific Conference 19-20 November, Gabrovo, 2010, vol. II, pp. 348-352.

[5] Hristian L., Bordeianu D. L. and Lupu I. G., *"The quantitative and qualitative analysis of woven fabrics type wool surface characteristic using Anova model",* Annals of the university of Oradea Fascicle of Textiles, Leatherwork, vol. VIX, 2013, No. 2, pp. 50-56.

[6] *Standards SR EN ISO 13934-1:2002-Textiles-Tensile properties of fabrics −Determination of maximum force and elongation at maximum force using the strip method.*