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RESEARCH REGARDING UNIAXIAL TENSILE STRENGTH OF NYLON WOVEN FABRICS, COATED AND UNCOATED WITH SILICONE

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ABSTRACT. Properties of woven fabrics used to make airbag cushions are influenced by a lot of factors: the nature of raw materials, woven fabric geometry and density, technological parameters of the weaving operation and finishing. The main purpose of this research paper is to find the values of three mechanical parameters – tensile strain, tensile stress and specific modulus – according to the type of samples and test direction on the testing stand. To obtain woven fabric samples were used polyamide 6-6 polyfilament yarns (nylon), silicone coated and uncoated fabric. Testing procedure and samples preparation were done following the standard EN ISO 13934-1:1999. Test results and graphs show that, we have a good uniformity of the geometry for the analyzed fabrics.

1 Introduction

Every time a new product is being designed, specialists are interested in producing components with appropriate shapes and properties to leverage the functional role throughout the planned lifetime at a convenient price. The general term „properties” has a different meaning for each engineer or specialist working with engineering materials.

Mechanical properties illustrate how the material responds to applied mechanical stresses. The most important mechanical features used in engineering calculations are tear resistance, flow limit, hardness, tenacity, elongation and tear breakage that define the ductility of the material. Sometimes, in specific cases, impact resistance, fatigue strength by long-term alternating stress and wear resistance are determined. Determining the mechanical characteristics allows estimating the in-service behavior of the products by quantifying the opposite resistance to their testing and processing [4-5, 29-30].

To determine the behavior of composite materials based on macroscopic fabrics (given the need to input material data into numerical simulation programs), there are several types of mechanical tests such as the uniaxial stretch test, the equiaxial stretch test, Bias test and shear test [2, 8-9, 31-32].

The oldest method of material behavior testing is the uniaxial stretch test. The specimen is fixed at both ends and deformed at a constant speed (or not) on a traction test machine

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until it is broken. The applied force is measured with a force cap and the deformation by an extensometer.

2 Methodology

To carry out the research, we used the experimental stand designed to avoid yarn crushing, the traction, compression and buckling test machine, Instron 5587 - Figure 1.

The data obtained can be plotted directly in the force-displacement coordinates. In many situations they are converted into stress-strain coordinates. In the case of the uniaxial stretch test of silicone coated or uncoated we have chosen to collect the data in the form of force-elongation pairs because the specimens of the type mentioned above do not have a constant section, the number of warp or weft yarns being slightly different from one case to another [2].

The experimental program for determining the mechanical properties of polyamide 6.6 silicone-coated and uncoated fabrics is based on the following:

Samples of five specimens - Figure 2 - were taken (according to standard EN ISO 13934-1: 1999) for each type of fabric, uncoated and coated on three directions: warp direction, weft direction and cut at an angle of 45^0 [6,8].

The specimens are rectangular, with a width of 50 mm.

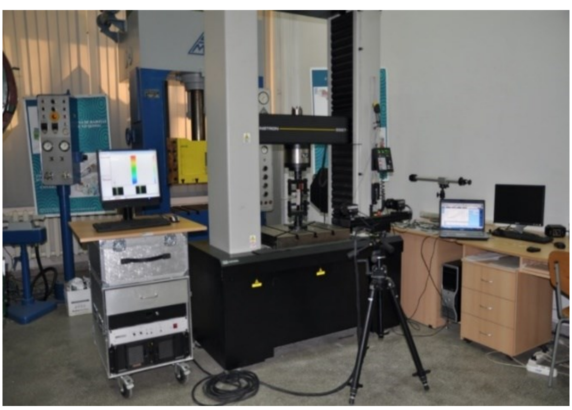

Fig. 1. Instron 5587 test machine with Aramis optical measuring system [2].

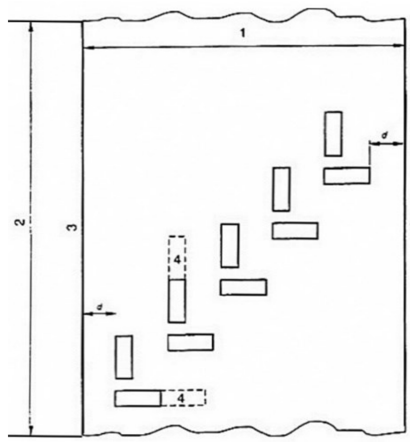

Fig. 2. Sample location on woven fabric [3]: 1-fabric width, 2-fabric length, 3-fabric edge, 4-additional length for wet tests, if required, d=150mm - length addition for wet tests.

A test method was developed in the own language of Instron type testing machine - Bluehill 2. At this stage the type of test (tensile), material data (the shape of the specimen, the specimen width, the distance between the jaws of the machine: 100 mm), machine speed, machine acquisition rate (10 points / second), output file type (ASCII or DIF - Data Interchange Format) and type of output data to be collected were set.

• Test speed: 100 mm/min;
• Specimen width: 50 mm;
• Before performing experiments, samples were kept in the laboratory at a constant temperature of 24°C and relative humidity of 50 ± 5%.

Table 1. Samples' characteristics

Characteristics	Coated woven fabric		Uncoated woven fabric	
	Result	Unit	Result	Unit
Yarn type (warp and weft)	Nylon polyfilament yarn	96 filaments	Nylon polyfilament yarn	96 filaments
Yarn fineness (warp and weft)	555	dtex	700	dtex
Silicon type	DC 3600	-	-	-
Woven structure	Plain weave	-	Plain weave	-
Yarn count warp	202	yarns / 10 cm	160	yarns / 10 cm
Yarn count weft	200	yarns / 10 cm	160	yarns / 10 cm
Weight	263,5	g/m^2	241,5	g/m^2
Thickness	0,301	mm	0,297	mm

The output data were: maximum force [N] and elongation [mm] corresponding to maximum force. We chose the two outputs to the detriment of breaking strength and elongation at break because the moment when the machine detects the break is the one in which the tensile force drops suddenly by 10-20%. This is beneficial for metal specimens or composite layered materials. The composite material with impregnated textile support behaves differently from these types of materials because the polyamide threads break successively, and the force decreases smoothly throughout the test process [9-10]. This leads to the impossibility of determining the breakage of the specimen by the machine and implicitly makes determining the breaking force and elongation at break impossible. Also, the machine software calculates and automatically generates the values for the modulus of elasticity (Young's modulus) and the specific modulus of the tested specimens. In addition to the previously specified data, the primary test data (the coordinates of the characteristic curve in the force [N] - displacement [mm] or [%]) were saved. These data are in the form of pairs of points in the coordinates listed above in the file of each ASCII analysis.

3 Testing stand

The machine used for tests is an Instron, model 5587 – Figure 3.

Fig. 3. The machine used for uniaxial traction, compression and buckling test, Instron 5587[2]

Technical characteristics of the equipment:

- the maximum loading force in steady state: 300 kN

• it is equipped with a force cell with a linearity of +/- 0.25% and repeatability +/- 0.25% for readings in the range 0.4-100% of capacity.
• working area: 1200 mm;
• distance between columns: 800 mm;
• the traverse drive system: electromechanical;
• adjustable test speed in the range of 0.001 - 500 mm / min;
• displacement measuring system mounted on the electric motor;
• computer interface and the condition of the data acquisition card;
• extensometer series 2630-113, for measuring static deformation, distance between markers: 50 mm;
• extensometer Data Acquisition Plate;

The machine is equipped with the Bluehill 2 software used for command and control of the machine and processing results. The Bluehill 2 program allows the following actions: automatic sensor calibration, generating predefined and user-generated reports, system monitoring, viewing results in real time, the possibility of determining the conventional and real characteristic curves and the plasticity characteristics. Tensile testing, compression and buckling machine, model Instron 5587 is equipped with a single calibrated extensometer with a length of 50 mm, with the possibility of mounting according to the longitudinal direction of the sample [2].

4 Initial calculations for determining the specific module of textile samples

Table 2. Specific parameters

No.	Parameter	Formula	U/M	Observations
1	Specific modulus	$M_s = \frac{E}{\gamma}$	m	γ = specific weight
2	Specific weight	$\gamma = \rho \cdot g$	N/m^3	g = 9,8 m/s^2
3	Density of woven fabric	$\rho = \frac{m}{V} = \frac{m}{L \cdot l \cdot g}$	kg/m^3	[26, 27, 28]
4	Young's modulus	$E = \frac{\sigma}{\varepsilon}$	N/m^2	[26, 27, 28]
5	Relative elongation	$\varepsilon = \frac{\Delta l}{l_0}$	m	[26, 27, 28]
6	Cross-section area of fabric	$A_s = No._{yarns} \times A_{yarn}$	mm^2	A_s = cross-section area of fabric $No._{yarns}$ = number of yarns from cross section A_{yarn} = cross-section area of the yarn
7	Cross-section area of the yarn	$A_{yarn} = \frac{\pi d^2}{4}$	mm^2	
8	Yarn diameter	$d_u = \frac{C}{\sqrt{N_{m\,u}}} = A \cdot \sqrt{T_{tex\,u}} = B \cdot \sqrt{T_{den\,u}}$ $d_b = \frac{C}{\sqrt{N_{m\,b}}} = A \cdot \sqrt{T_{tex\,b}} = B \cdot \sqrt{T_{den\,b}}$	mm	The yarn diameters are used for creating the geometric model, adopting the thicknesses and simulating the fabric aspect. A, B, C are constants that depend on the character of the staple, on the structure of the yarns and their manu-facturing technology [1].

In this case, the tested fabric is based on the plain-woven fabric – Figure 4.

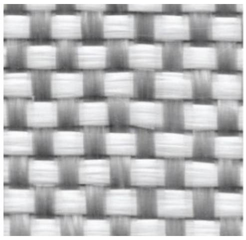

Fig. 4. Plain woven fabric [7,11,12, 35]

Fig. 5. Cross-section of plain woven fabric [4, 10,17, 19, 20]

In the table 3 the values of calculated parameters for the three directions of the fabric: warp, weft and bias (45°) were centralized:

Table 3. Values of the calculated parameters

Fabric	**Density direction**	**No. of yarns**	**Yarn diameter (warp and weft)**	**Cross section area of the yarn**	**Cross section area of fabric**
Coated woven fabric	Warp density	101 yarns / 5 cm	0,292 mm	0,06693 mm^2	6,760 mm^2
	Weft density	100 yarns / 5 cm	0,292 mm	0,06693 mm^2	6,693 mm^2
	45° density	80 yarns / 5 cm	-	0,06693 mm^2	5,354 mm^2
Uncoated woven fabric	Warp density	80 yarns / 5 cm	0,328 mm	0,0844 mm^2	6,752 mm^2
	Weft density	80 yarns / 5 cm	0,328 mm	0,0844 mm^2	6,752 mm^2
	45° density	70 yarns / 5 cm	-	0,0844 mm^2	5,908 mm^2

Observation: We chose 5 cm because the width of the test specimens was 5 cm
In the table 4 the values of specific weight, which was set in the software, before starting practical tests on the Instron machine were calculated.

Table 4. Specific weight calculation

Fabric	Density of woven fabric	**Specific weight**
Coated woven fabric	875,415 kg/m^3	8579.067 N/m^3
Uncoated woven fabric	813,131 kg/m^3	7968,683 N/m^3

Observation: These two values of specific weight were entered in the dynamometer software.

5 Practical work

Figure 6 shows how the modulus of longitudinal elasticity (Young's modulus) was calculated. It is observed on the tensile test curve graph a first step that starts from point "A" and ends at "B". This area is the one where the yarns of the fabric "are preparing" for tensile, with movement and friction between them, causing pretension loads on the fabric structure. The area for the calculation of the modulus of elasticity is the linear area between point "B" and point "C", because in this portion the yarns were pretensioned and there is proportionality between stresses and deformations [7,11,12,14, 34].

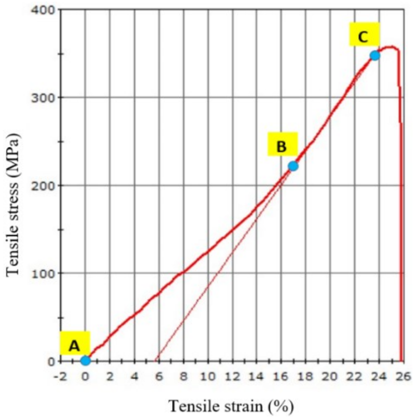

Fig. 6. Example of calculation for Young's modulus for the 6 types of specimens [5, 6, 15,16].

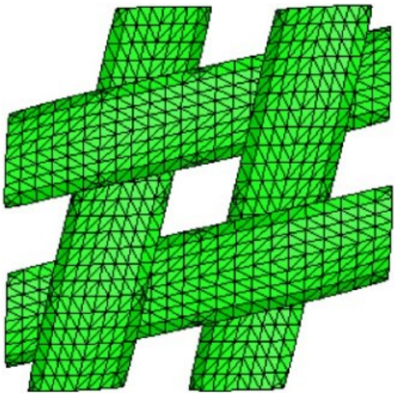

Fig. 7. Configuration of warp and weft yarns, after crossing zone A-B [4, 13, 21, 33].

6 Graphs

Figures 8-13 present the conventional stress graphs which have the force-deviation coordinates for the 6 cases and the tables 5 and 6 present the numerical results of the tests.

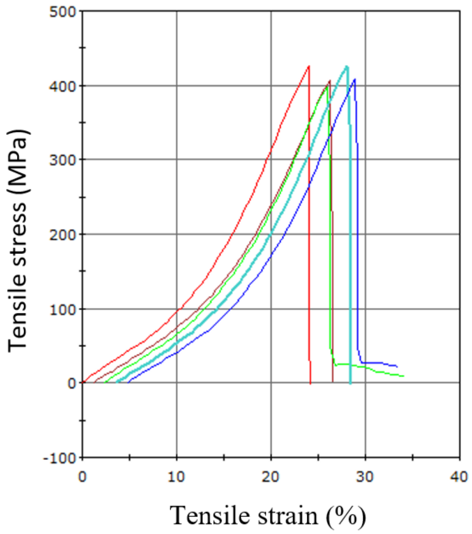

Fig. 8. Tensile strain-stress for uncoated specimen – warp direction

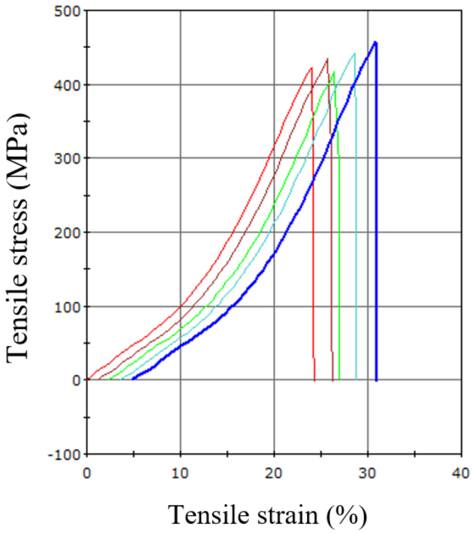

Fig. 9. Tensile strain-stress for uncoated specimen – weft direction

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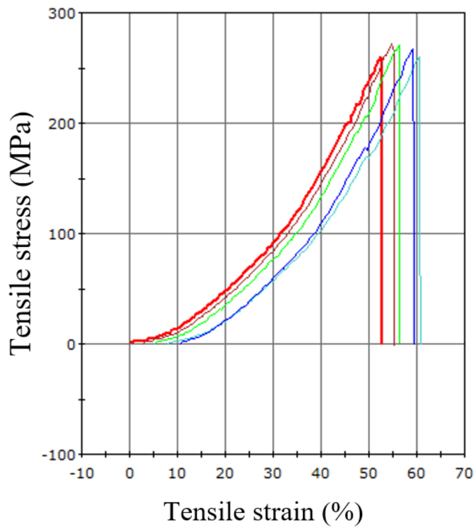

Fig. 10. Tensile strain-stress for uncoated specimen – 45° direction

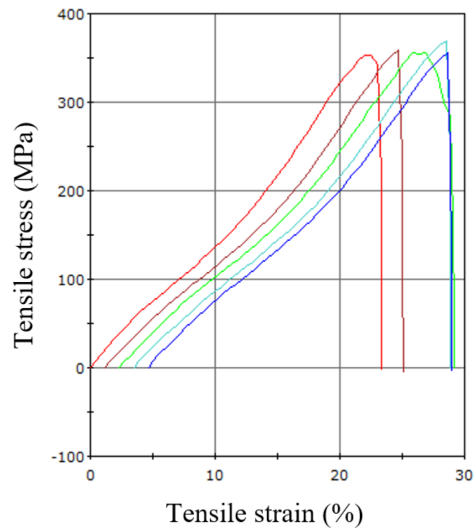

Fig. 11. Tensile strain-stress for coated specimen – warp direction

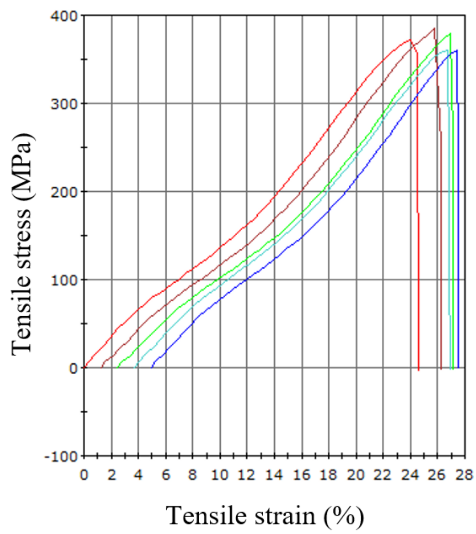

Fig. 12. Tensile strain-stress for coated specimen – weft direction

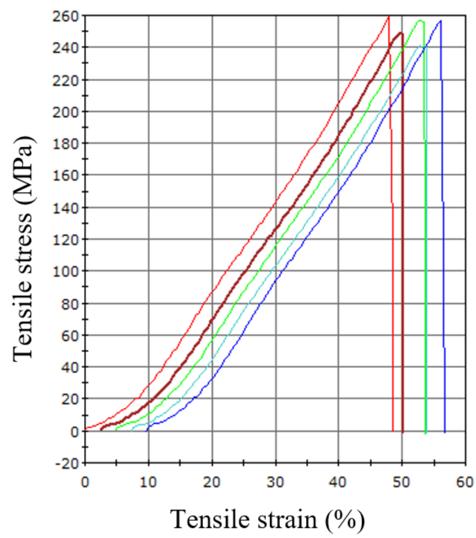

Fig. 13. Tensile strain-stress for coated specimen – 45° direction

7 Results

In the tables below, we show the results of specific modulus for uncoated and coated samples. Five specimens for each type of woven fabric were tested, then the average calculation related to the four parameters: E-Modulus, Tensile strain, Tensile stress, Specific Modulus.

Table 5. Test results for uncoated woven fabric

Crt. No.	Sample	Testing direction	Modulus (E-modulus) (MPa)	Tensile strain (%)	Tensile stress (MPa)	SPECIFIC MODULUS (m)
1.	Uncoated woven fabric	Warp	3157.133	24.000	425.058	**0.368 x10^6**
2.			2778.587	25.000	406.199	**0.324 x10^6**
3.			3073.813	23.500	397.916	**0.358 x10^6**
4.			3160.798	24.500	426.137	**0.368 x10^6**
5.			3080.141	24.000	408.902	**0.359 x10^6**
Average			3050.094	24.200	412.842	**0.355 x10^6**
STDEV			157.237	0.570	12.333	**0.018 x10^6**
1.	Uncoated woven fabric	Weft	2971.379	24.003	422.674	**0.346 x10^6**
2.			3067.865	24.500	434.926	**0.357 x10^6**
3.			3069.491	24.000	417.417	**0.357 x10^6**
4.			2934.508	25.000	441.199	**0.342 x10^6**
5.			3047.037	26.000	457.364	**0.355 x10^6**
Average			3018.056	24.701	434.716	**0.351 x10^6**
STDEV			61.493	0.836	15.806	**0.007 x10^6**
1.	Uncoated woven fabric	45°	942.755	52.500	260.587	**0.110 x10^6**
2.			931.548	52.000	271.582	**0.108 x10^6**
3.			942.555	51.000	270.342	**0.110 x10^6**
4.			920.902	52.500	259.736	**0.107 x10^6**
5.			982.909	48.500	267.512	**0.114 x10^6**
Average			944.134	51.300	265.952	**0.110 x10^6**
STDEV			23.485	1.681	5.496	**0.003 x10^6**

Table 6. Test results for coated woven fabric

Crt. No.	Sample	Testing direction	Modulus (E-modulus) (MPa)	Tensile strain (%)	Tensile stress (MPa)	Specific modulus (m)
1.	Coated woven fabric	Warp	2179.622	22.000	352.892	**0.254 x10^6**
2.			2131.001	23.500	359.481	**0.248 x10^6**
3.			1982.709	23.500	355.920	**0.231 x10^6**
4.			2010.496	25.000	369.557	**0.234 x10^6**
5.			1977.962	24.000	355.826	**0.230 x10^6**
Average			2056.358	23.600	358.735	**0.239 x10^6**
STDEV			92.789	1.084	6.485	**0.011 x10^6**

1.	Coated woven fabric	Weft	2064.804	24.000	372.468	**0.240 x10^6**
2.			2176.739	24.500	384.561	**0.253 x10^6**
3.			2138.688	24.500	379.317	**0.249 x10^6**
4.			2073.281	23.000	360.184	**0.241 x10^6**
5.			2171.016	22.500	360.209	**0.253 x10^6**
Average			2124.906	23.700	371.348	**0.247 x10^6**
STDEV			53.104	0.908	11.046	**0.006 x10^6**
1.	Coated woven fabric	45°	672.381	48.000	259.133	**0.078 x10^6**
2.			673.435	47.500	249.142	**0.078 x10^6**
3.			687.422	48.000	256.731	**0.080 x10^6**
4.			682.339	45.500	240.991	**0.079 x10^6**
5.			704.613	46.500	256.459	**0.082 x10^6**
Average			684.038	47.100	252.491	**0.080 x10^6**
STDEV			13.096	1.084	7.438	**0.002 x10^6**

8 Comments and conclusions

In the tables 5 and 6 the maximum force (column 5) and the maximum elongation corresponding to the force (column 4) are presented. For each of the two types of specimens and for the three directions of testing (warp, weft and 45°) we have also calculated the average value and the average square deviation. Also, based on these data, the machine software automatically calculates the modulus of elasticity (Young's modulus) - column 3 and the specific modulus of the fabrics - column 6.

By examining the result values for each experiment (Tables 5 and 6), it is noted that, for the variation domains of the specific modulus, the considered characteristics vary within the following limits:

Table 7. Specific modulus depending on test direction and fabric

Sample	**Test direction**	**Specific modulus (m)**
Uncoated woven fabric	Warp direction	**0.324 x10^6 - 0.368 x10^6**
	Weft direction	**0.342 x10^6 - 0.357 x10^6**
	45° direction	**0.107 x10^6 - 0.114 x10^6**
Coated woven fabric	Warp direction	**0.230 x10^6 - 0.254 x10^6**
	Weft direction	**0.240 x10^6 - 0.253 x10^6**
	45° direction	**0.078 x10^6 - 0.082 x10^6**

By analyzing the graphs - figures 8 to 13, it is easy to see that both samples have continuous and linear curves, without a local maximum or minimum.

Regarding the maximum force occurring in the specimen during uniaxial tensile stress, we can conclude that higher values appear for the uncoated fabric.

Also, the higher values of the force were registered in the weft direction, compared to the warp or 45° direction.

If we refer to the comparison of the specimens taken in the warp or weft direction, it is observed that the rule existing for the maximum force is not respected. Here, the maximum elongation occurs in the case of the weft direction over the elongation that occurs in the case of the application in the warp direction.

This is because the warp threads are stretched and weft threads are wavy - they must go through the warp. These crimped yarns will straighten because of the application of traction force and tend to elongate more, to become longer.

By analyzing both the graphs and the obtained values it is easy to notice that we have a good uniformity of the geometry for the analyzed fabrics.

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