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° [6,8].

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

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                      | Unit      | Uncoated woven fabric                      | 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/m²                               |           | 241.5 g/m²                                |           |
| 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]](image)

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

| No. | Parameter | Formula | U/M | Observations |
|-----|-----------|---------|-----|--------------|
| 1   | Specific modulus | \( M_s = \frac{E}{\gamma} \) | m | \( \gamma = \) specific weight |
| 2   | Specific weight | \( \gamma = \rho \cdot g \) | N/m³ | \( g = 9.8 \text{ m/s}^2 \) |
| 3   | Density of woven fabric | \( \rho = \frac{m}{V} = \frac{m}{L \cdot h \cdot g} \) | kg/m³ | [26, 27, 28] |
| 4   | Young’s modulus | \( E = \frac{\sigma}{\varepsilon} \) | N/m² | [26, 27, 28] |
| 5   | Relative elongation | \( \varepsilon = \frac{\Delta l}{l_0} \) | m | [26, 27, 28] |
| 6   | Cross-section area of fabric | \( A_s = \text{No. of yarns} \times A_{\text{yarn}} \) | mm² | \( A_s = \) cross-section area of fabric  
No. of yarns = number of yarns from cross section  
\( A_{\text{yarn}} = \) cross-section area of the yarn |
| 7   | Cross-section area of the yarn | \( A_{\text{yarn}} = \frac{\pi d^2}{4} \) | mm² |
| 8   | Yarn diameter | \( d_a = \frac{c}{\sqrt{N_{\text{m}}}} = A \cdot \frac{\sqrt{T_{\text{tex}}}}{\sqrt{T_{\text{den}}}} \) | 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 manufacturing technology [1]. |
In this case, the tested fabric is based on the plain-woven fabric – Figure 4.

![Fig. 4. Plain woven fabric](image)

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

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 (warp and weft) | 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 mm²                  | 6,760 mm²                   |
|                        | Weft density      | 100 yarns / 5 cm             | 0,292 mm                      | 0,06693 mm²                  | 6,693 mm²                   |
|                        | 45° density       | 80 yarns / 5 cm              | -                             | 0,06693 mm²                  | 5,354 mm²                   |
| Uncoated woven fabric  | Warp density      | 80 yarns / 5 cm              | 0,328 mm                      | 0,0844 mm²                   | 6,752 mm²                   |
|                        | Weft density      | 80 yarns / 5 cm              | 0,328 mm                      | 0,0844 mm²                   | 6,752 mm²                   |
|                        | 45° density       | 70 yarns / 5 cm              | -                             | 0,0844 mm²                   | 5,908 mm²                   |

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/m³           | 8579,067 N/m³   |
| Uncoated woven fabric       | 813,131 kg/m³           | 7968,683 N/m³   |

 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
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        | Uncoated woven fabric   |                    | 2778.587                  | 25.000            | 406.199              | 0.324 x10^6          |
| 3        | Uncoated woven fabric   |                    | 3073.813                  | 23.500            | 397.916              | 0.358 x10^6          |
| 4        | Uncoated woven fabric   |                    | 3160.798                  | 24.500            | 426.137              | 0.368 x10^6          |
| 5        | Uncoated woven fabric   |                    | 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        | Uncoated woven fabric   |                    | 3067.865                  | 24.500            | 434.926              | 0.357 x10^6          |
| 3        | Uncoated woven fabric   |                    | 3069.491                  | 24.000            | 417.417              | 0.358 x10^6          |
| 4        | Uncoated woven fabric   |                    | 2934.508                  | 25.000            | 441.199              | 0.342 x10^6          |
| 5        | Uncoated woven fabric   |                    | 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          |

| Crt. No. | Sample                  | Testing direction | Modulus (E-modulus) (MPa) | Tensile strain (%) | Tensile stress (MPa) | SPECIFIC MODULUS (m) |
|----------|-------------------------|-------------------|---------------------------|-------------------|----------------------|----------------------|
| 1        | Uncoated woven fabric   | 45°               | 942.755                   | 52.500            | 260.587              | 0.110 x10^6          |
| 2        | Uncoated woven fabric   |                   | 931.548                   | 52.000            | 271.582              | 0.108 x10^6          |
| 3        | Uncoated woven fabric   |                   | 942.555                   | 51.000            | 270.342              | 0.110 x10^6          |
| 4        | Uncoated woven fabric   |                   | 920.902                   | 52.500            | 259.736              | 0.107 x10^6          |
| 5        | Uncoated woven fabric   |                   | 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        | Coated woven fabric     |                    | 2131.001                  | 23.500            | 359.481              | 0.248 x10^6          |
| 3        | Coated woven fabric     |                    | 1982.709                  | 23.500            | 355.920              | 0.231 x10^6          |
| 4        | Coated woven fabric     |                    | 2010.496                  | 25.000            | 369.557              | 0.234 x10^6          |
| 5        | Coated woven fabric     |                    | 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          |
Coated woven fabric

|   |   |   |   |   |
|---|---|---|---|---|
| 1. | Coated woven fabric | Weft | 2064.804 | 24.000 |
| 2. | Coated woven fabric | Weft | 2176.739 | 24.500 |
| 3. | Coated woven fabric | Weft | 2138.688 | 24.500 |
| 4. | Coated woven fabric | Weft | 2073.281 | 23.000 |
| 5. | Coated woven fabric | Weft | 2171.016 | 22.500 |
| Average | Coated woven fabric | Weft | 2124.906 | 23.700 |
| STDEV | Coated woven fabric | Weft | 53.104 | 0.908 |

|   |   |   |   |   |
|---|---|---|---|---|
| 1. | Coated woven fabric | 45° | 672.381 | 48.000 |
| 2. | Coated woven fabric | 45° | 673.435 | 47.500 |
| 3. | Coated woven fabric | 45° | 687.422 | 48.000 |
| 4. | Coated woven fabric | 45° | 682.339 | 45.500 |
| 5. | Coated woven fabric | 45° | 704.613 | 46.500 |
| Average | Coated woven fabric | 45° | 684.038 | 47.100 |
| STDEV | Coated woven fabric | 45° | 13.096 | 1.084 |

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 x10⁶ - 0.368 x10⁶ |
| Uncoated woven fabric | Weft direction | 0.342 x10⁶ - 0.357 x10⁶ |
| Uncoated woven fabric | 45° direction | 0.107 x10⁶ - 0.114 x10⁶ |
| Coated woven fabric | Warp direction | 0.230 x10⁶ - 0.254 x10⁶ |
| Coated woven fabric | Weft direction | 0.240 x10⁶ - 0.253 x10⁶ |
| Coated woven fabric | 45° direction | 0.078 x10⁶ - 0.082 x10⁶ |

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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