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STUDY ON THE INFLUENCE OF THE TEMPERATURE AND STRAIN RATE ON THE BEHAVIOR OF POLYAMIDE 6.6 AT THE UNIAXIAL TENSILE TEST

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Abstract – The current paper intends to present a study on the influence of the testing temperature and the strain rate on the behaviour of Polyamide 6.6 fibres used for the manufacturing of woven fabrics for airbags, during uniaxial tension tests. For this study, Polyamide fibres were tested at three different strain rates: 10 (mm/min), 100 (mm/min) and 200 (mm/min) and at three different temperatures: -40 (^{0}C), 20 (^{0}C) and 100 (^{0}C).

Keywords **-** Experimental studies, Polyamide 6.6, Strain rates, Temperature

I. INTRODUCTION

TEXTILE materials that are woven, knitted or obtained by various other technological procedures, are widely used and have a very large range of applications in many industrial branches. The most well-known usage of these materials is in the textiles industry, for realising various clothing items. Nonetheless, textile materials are also used in a wide range of engineering applications from other industry branches, such as the automotive industry, where they are used for the manufacturing of airbags, of safety belts, of various covers, the last two applications being found also in the aeronautics industry. Another domain where these materials are employed is that of the various sports and/or camping accessories, such as parachutes, tents etc.

Generally, the behaviour of a textile material on one direction depends on the behaviour on another direction, usually non-linearly. Even in the case of a uniaxial loading, the response of the woven fabric is a profoundly non-linear one, both due to its geometry and due to the characteristics of the fibres within the fabric. In many applications there occur very large strains in the fabrics. The deformation mechanism of the fabrics includes two effects: elastic (fibre elongation) and non-elastic (fibre slippage, resistance to friction) [1]. Consequently, in order to define a woven fabric, there can be developed a continuous, non-elastic, anisotropic model suitable for large strains and for finite specific strains.

Numerous such models exist at world level, some being really close to the real behaviour of the textile material for which they were created. The kinematic behaviour of most fabrics is dominated by the kinematics at microscopic level, of their components. The fabrics' macroscopic behaviour presents non-linearity due to the motions present in the yarns' interior [2]. These motions are due to the displacement of the fibres inside de yarns [3]. The main deformation mechanisms of the fabrics, for example the crimping that occurs at the biaxial tensile loading or the stair-like movement at the shearing loading show the dependence of the macroscopic deformation behaviour on the microstructural behaviour of the fibres and yarns.

Airbags are designed to minimize concentrated forces and to reduce the excessive motion of a passenger whose safety belt is fastened. Generally, the airbags are made of textile membrane fabrics realised for the most part of multi-filament polyamide 6.6 (nylon) yarns. In order to study the fabrics behaviour we must well-known the yarns behaviour [4]. The aim of this paper is to determine the mechanical properties of polyamide yarns on different test conditions (temperatures and speed tests).

Polyamide is obtained by repeating the bonds within an amide and is also known as nylon. In practice there exist various types of polyamide „manufactured" using mono- or diacid and mono- or diamid monomers [5]. The number that is found in the name of a specific polyamide type indicates the number of CH „units" between the monomers. Polyamide is the first synthetic fibre manufactured entirely of inorganic ingredients: coal, water and air.

Most polyamide types are condensation polymers formed through the reaction of equal parts of diamine and of dicarboxylic acid. The most common variant is polyamide 6.6 or nylon 6.6, made from hexamethylene diamine and adipic acid, which give it a total of 12 carbon atoms, this being also the reason for the ending 6.6 in the name of the material. Polyamide 6.6 has the highest melting temperature, 256 (°C) of all synthetic fibres. This causes it to be very resistant to heat and friction and allows it to cope well with repeated torsions [6], [7].

Among the many advantages of this material there can be mentioned: a very good resistance to abrasion, a very high resilience, an excellent resistance to chemical agents; a very good resistance to wear, a very good capability of mixing with other types of fibres, such as: cotton, wool, Lycra; high resistance to ultraviolet rays and heat and an evenness in properties.

Although there have been sustained efforts to model the kinematics of the unfolding and of the impact of airbags, the literature referring to the experimental assessment and modelling of the mechanical properties of airbag fabrics is very limited. Keshavaraj and collaborators [8] have studied the biaxial properties of Nylon 6, Nylon 6.6 and polyester fibres using a bubble inflation device.

II. Experimental Layout

The tension tests were performed on an Instron 5587 testing machine, provided with a computer interfacing with the load frame, capable of keeping a constant strain rate. The Instron 5587 was also equipped with an Instron 3119 temperature control chamber, allowing a testing temperature that can be varied between -40 (°C) and 300 (°C).

The used Instron 5587 tensile-compression testing machine has following characteristics: maximum load capacity: 300 (kN); force cell with +/- 0.25% linearity; repeatability of readings in the domain of 0.4 – 100% of capacity; working space between the body and crosshead: 1200 (mm); working space between the columns: 800 (mm); electromechanical command of the crosshead; testing speed in the domain of 0.001 – 500 (mm/min); serial/parallel computer interface.

For these tests of the polyamide yarns, there has been used a special fastening system meant to prevent the slipping of the yarns out of the clamping dies. The system was attached to the machine’s clamping dies. Any possibility of slippage was eliminated by using a twisting procedure (five times clockwise, three times anti-clockwise and once more clockwise). Moreover, fastening was ensured by applying an adhesive on the yarn’s surface in order to attach the fibres to it.

The polyamide yarns were cut into pieces with a length of 120 (mm) and fastened in the fastening system. Any loose fibre was removed in order to not affect the test.

III. Experimental Studies Regarding the Behaviour of Polyamide 6.6 Yarns at the Uniaxial Tensile Test

Tension tests were performed on polyamide 6.6 yarns with the linear mass density 470 (dtex) and 145 fiber filaments. The polyamide yarns were kept in the laboratory, prior to the tests, at a temperature of 25°C and a humidity of approximately 40%.

In the present paper the results are focused on maximum true stress and maximum true strain for all tested specimens.

Polyamide 6.6 yarns were tested at three temperatures as follows: -40°C, 20°C and 100°C. Three test strain rates were used for the study: 10 (mm/min), 100 (mm/min) and 200 (mm/min). The strain rates were chosen function of the minimal and maximal possibilities offered by the testing machine. For other tests, realised with higher rates, it is necessary to build another testing device, namely Hopkinson rods, that allow the testing at very high strain rates of up to 1000/sec.

The results of the tests (the real stress-real strain curves) are presented in Fig. 1., Fig. 2., ... Fig. 9. and the detailed numerical results of these tests are presented in Table I.

TABLE I
MEAN VALUES OF TRUE STRESS AND TRUE STRAIN

Temperature (^{0}C)	Strain rate (mm/min)	Maximum true stress (MPa)	Maximum true strain (mm/mm)
-40	10	1197	19.47
-40	100	1343	20.77
-40	200	1453	22.01
20	10	805	27.92
20	100	889	29.56
20	200	984	33.21
100	10	632	32.75
100	100	734	34.25
100	200	845	36.78

The diameter of the polyamide yarn was been calculated using the following formula:

$$d_N = \sqrt{\frac{4 \cdot 10^{-6} \cdot dtex}{\pi \cdot \rho}}. \quad (1)$$

In this formula, *tex* is the measurement unit for the linear density of the fibres, defined as the mass of fibres, in grams, on a length of 1000 meters. Decitex, or dtex is the mass, in grams, on a length of 10,000 meters. Polyamide 6.6 has 470 (dtex).

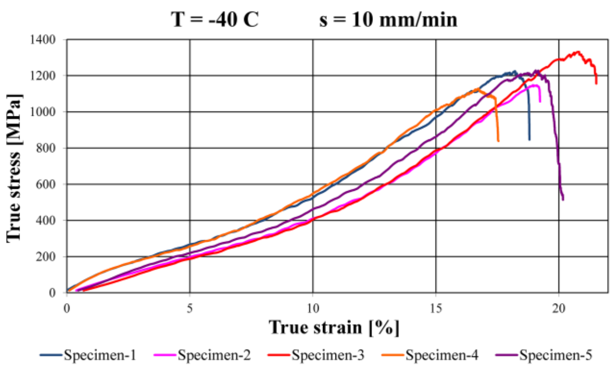

Fig. 1. True stress – true strain curves for tensile tests for T = -40 ^{0}C and s = 10 mm/min

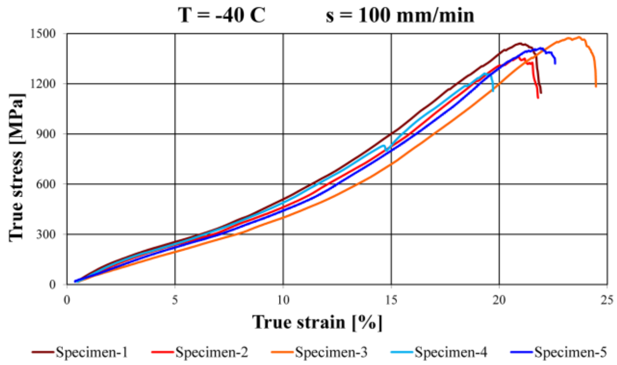

Fig. 2. True stress – true strain curves for tensile tests for T = -40 ^{0}C and s = 100 mm/min

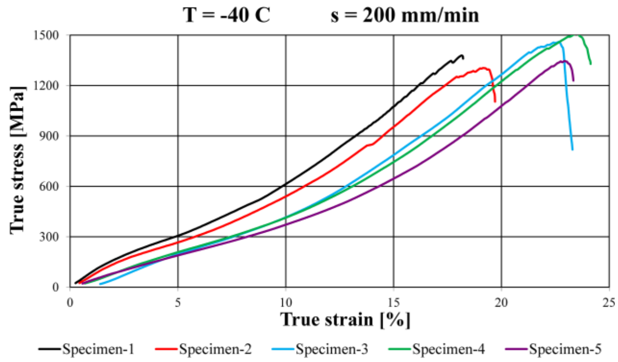

Fig. 3. True stress – true strain curves for tensile tests for T = -40 ^{0}C and s = 200 mm/min

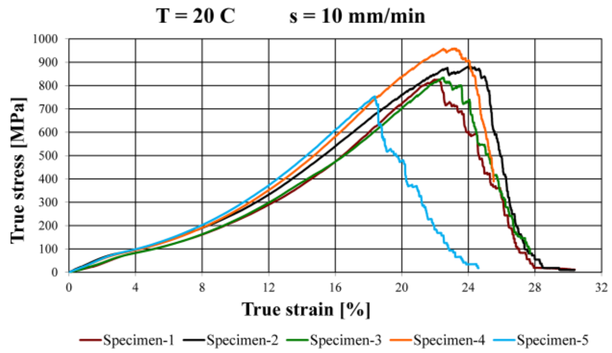

Fig. 4. True stress – true strain curves for tensile tests for T = 20 ^{0}C and s = 10 mm/min

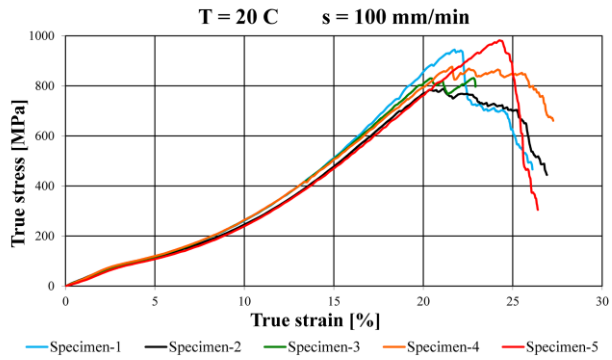

Fig. 5. True stress – true strain curves for tensile tests for T = 20 ^{0}C and s = 100 mm/min

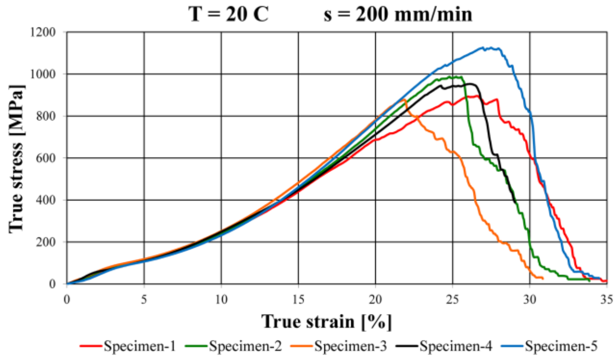

Fig. 6. True stress – true strain curves for tensile tests for T = 20 ^{0}C and s = 200 mm/min

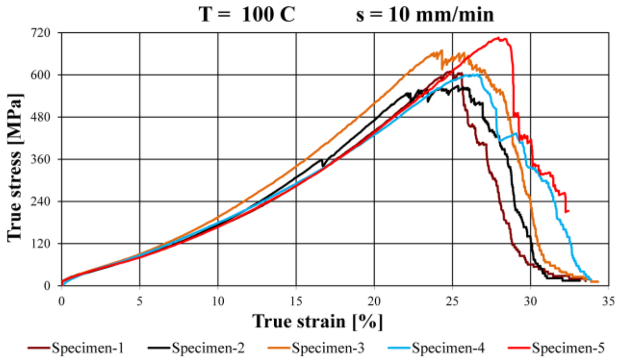

Fig. 7. True stress – true strain curves for tensile tests for T = 100 ^{0}C and s = 10 mm/min

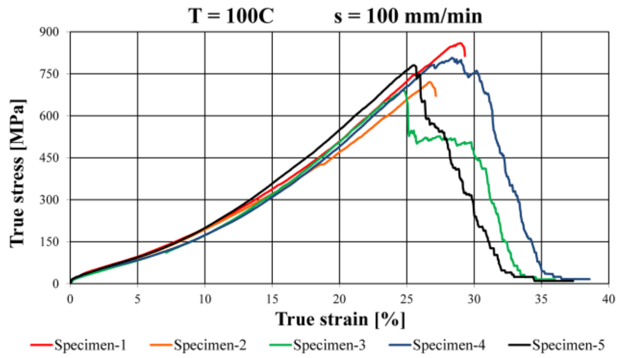

Fig. 8. True stress – true strain curves for tensile tests for T = 100 ^{0}C and s = 100 mm/min

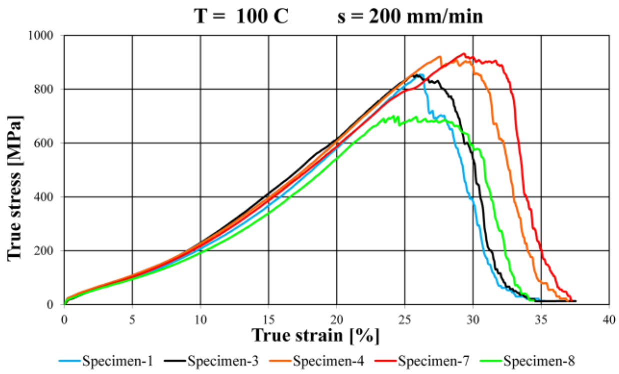

Fig. 9. True stress – true strain curves for tensile tests for T = 100 ^{0}C and s = 200 mm/min

ρ represents the material's density in grams per cubic centimeter; for polyamide 6.6, $\rho = 1.14$ (g/cm^3). Based on these data, the diameter of the polyamide yarn can be calculated as:

$$d_N = \sqrt{\frac{4 \cdot 10^{-6} \cdot dtex}{\pi \cdot \rho}} = \sqrt{\frac{4 \cdot 10^{-6} \cdot 470}{\pi \cdot 1.14}} \cdot 10 = 0.229. \qquad (2)$$

The area of the transversal cross-section of the yarn is:

$$A_{0N} = \frac{\pi \cdot d_N^2}{4} = \frac{\pi \cdot 0.229^2}{4} = 0.041. \qquad (3)$$

The real stress and the real relative elongation, respectively, which, as is known, do not coincide with the conventional stress and with the conventional elongation, respectively, can be calculated with following relationships:

$$\sigma_{true} = \frac{P}{A_{0N}} \cdot \left(1 + \frac{\Delta \ell}{\ell_{0N}}\right)$$
$$\varepsilon_{true} = \ln\left(\frac{\ell_{0N} + \Delta \ell}{\ell_{0N}}\right). \qquad (4)$$

where: $A_{0N} = 0.041$ (mm^2) and $l_{0N} = 120$ (mm).

IV. CONCLUSIONS

From the graphs obtained from the tensile tests for Polyamide 6.6 it can be noticed that there exist two distinct regions on the real stress – real strain curve. The first region is the beginning area that defines the hyperelastic behaviour of the polyamide 6.6. The second region is characterized by a sudden drop of the stress value, which indicates the decrease of the tensile capability supported by the yarn. The last area contains also the area in which the material breaks.

The results are those expected for this type of material, meaning that the ultimate strength decreases with the increase of the temperature, while the specific strain increases with the increase of the temperature. Fig. 10. and Fig. 11. presents the variation of the maximal values of the true stress and true strain function of the temperature for the four strain rates.

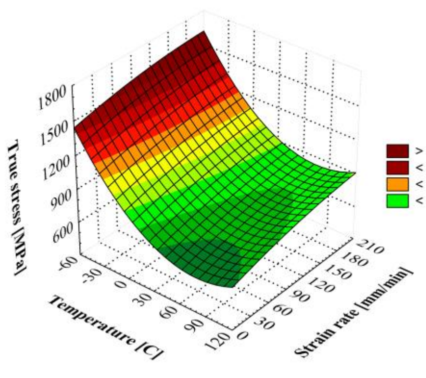

Fig. 10. The dependence chart for the maximum true stress function of test temperature and strain rate

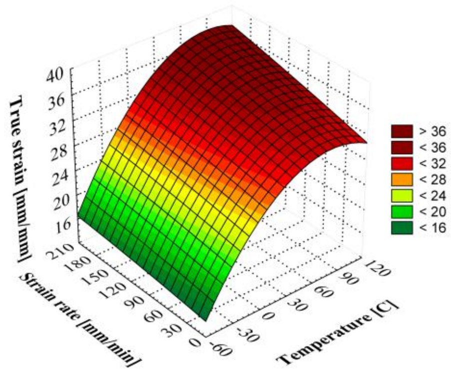

Fig. 11. The dependence chart for the maximum true strain function of test temperature and strain rate

An individual breaking of polyamide fibres can be noticed even from the end of the hyperelastic area. Nonetheless, most fibres break in the second area, when the yarns are basically separated into two parts.

Concerning the influence of the strain rate, it can be noticed that an increase in the strain rate leads to the increase of the ultimate strength of polyamide 6.6 yarns. There can be also noticed an acceptable dispersion of results, which is due also to the yarns' structure, they being a conglomerate of several separate fibres with slightly different properties. At the same time, this can also be due to the continuing breaking of fibres even from the end of the hyperelastic area.

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