THE INFLUENCE OF THE SILICONE LAYER ON
POLYAMIDE 6.6 FABRICS SUBJECTED TO UNIAXIAL AND
EQUIBIAXIAL TENSILE TESTS

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ABSTRACT: The current paper aims to present a study regarding the influence of silicone coating on woven polyamide PA 6.6 specimens subjected to equibiaxial tension. There were carried out both uniaxial tension and equibiaxial tension tests using a specially designed testing installation. This installation uses a hemispherical, hydraulically driven punch. In order to measure the strains, there have been used optical methods. The researches were oriented towards measuring the maximal force, measuring the maximal height of the dome before the failure, measuring the major and minor strains, as well as the material’s thickness reduction.

KEYWORDS: equibiaxial tensile test, silicone coated polyamide 6.6, major strain, thickness reduction

1 INTRODUCTION

When a vehicle collides with an obstacle or another car, it can undergo a rapid change in terms of the speed, while the passengers continue moving until the occurrence of an opposing force. The very concentrated opposing forces that originate in the car’s interior or in the safety belt can lead to serious harms for the passengers. Airbags are designed to minimise these concentrated forces and to reduce the excessive motion (especially the rotation of the upper body) of a passenger that is secured by means of a safety belt.

In the case of a collision, a charge is initiated, inflating the airbag that creates a cushion between the passenger and the car’s interior. The sequence unfolds very fast, within 25 to 30 milliseconds after the moment of detecting the collision until the full inflation of the airbag, the airbag’s inflation speed reaching up to 160 km/h [Crouch, 1994; Mukhopadhyay, 2008]. During this time, for a few milliseconds, there can be reached gas pressures of up to 70 kPa and temperatures of almost 600°C [Gon, 2010; Mukhopadhyay, 2008]. The airbag’s internal pressure is applied evenly on the passenger, the airbag gently dissipating the passenger’s kinetic energy, distributing the contact force over a large area and minimizing the rotations of the passenger’s joints. The mechanisms contributing to the absorption and dissipation of energy by the airbag are the biaxial mechanical stretching (tension) of the fabric and the gasses exiting through it.

A special point of interest regarding the airbag producing industry is brought by Zacharski [Zacharski, 2008] who attempts to achieve a better understanding of the airbag’s functioning by identifying its behaviour. Most authors consider the materials from which airbags are manufactured as orthotropic materials with elastic linear behaviour [Dornhoff et al., 2008; Hirth, Haufe and Olovsson, 2007]. The modulus of elasticity taken into account is determined based on the tensile curve. However, during their functioning airbags are actually subjected to biaxial tension. The current paper aims to determine the behavior of these materials and the influence of coating during biaxial tension.

2 EXPERIMENTAL FACILITIES AND METHODOLOGY

It is a well-known fact that many composite materials consisting of fabrics impregnated with various compounds (of which silicone is the most employed one) are used in the automotive industry for the manufacturing of airbags. As component elements of a vehicle’s safety system, they have an outstanding importance, which also makes understanding their behavior to various types of loads very important. Most researches emphasise these materials’ behaviour in the case of uniaxial tension. However, airbags are subjected during their functioning to biaxial tension rather than uniaxial tension. Therefore, this paper aims to show the behaviour of composite materials with textile matrix in the case of equibiaxial loading. For the tests, there was used a facility from the endowment of the "Lucian Blaga" Blaga University of Sibiu, together with the Aramis optical analyser.

In order to subject them to equibiaxial tension, the specimens are fastened in a fastening device and loaded by a hemispherical punch. The force needed
for fastening the material and the active force needed for actuating the punch are generated by two separate hydraulic circuits. Certainly, from the point of view of the research described in this paper, the authors were interested in determining the force-displacement curve of the punch. Using pressure sensors, a data acquisition system and the Matlab software package, the pressure is transformed into electrical voltage and then into a force. Using a constant speed and acquiring on another channel the time variable, it was possible to determine the force-displacement point pairs for four types of specimens: uncoated and coated with silicone, with stress concentration point and without stress concentration point. The obtained data can be displayed graphically directly in force-displacement coordinates.

Figure 1. The experimental facility with the optical measurement system Aramis used for the equibiaxial tension tests

The virtual instrument for acquisition created in Matlab is presented in figure 2. From the conditioning modules, the two electrical signals are received by the acquisition device on the two channels, the first channel being for the main hydraulic circuit (the circuit driving the punch), while the second channel is for the pressure transducer from the blank-holding hydraulic circuit that drives the blank-holding ring. The two electrical signals are transformed from electrical voltage into pressure by means of a multiplier block. For the current researches, there authors were interested only in acquiring the variation of the pressure from the main circuit, the pressure from the blank-holding circuit being of no significance for these researches. The signal multiplication factor was determined only for the pressure transducer from the main circuit by means of a calibration process.

Figure 2. The virtual instrument for data acquisition and processing

The calibration of the pressure transducer from the main circuit consisted in modifying the pressure in the hydraulic circuit in at least five stages and simultaneously reading the pressure value on the hydraulic circuit’s manometer and the value of the voltage of the electrical signal generated by the transducer. The graph of the pressure function of the acquired signal (in V) was determined by means of the linear interpolation of the line passing through the measurement points, leading to the calibration graph for the pressure transducer (fig. 3).

Figure 3. Calibration of the pressure transducer

For determining the specific local strains there was used an optical strain measurement system - Aramis, produced by Gom. This system offers the possibility to measure in real time strains occurring in the specimen subjected to equibiaxial tension.

By coupling the experimental installation and the optical measurement system, it was possible to determine the major, minor and equivalent strains, as well as the size of the dome formed before the failure.

In order to determine the strains with the help of the Aramis optical measurement system, the specimens were prepared through the deposition of
fine droplets of black paint on a layer of matted white paint that had been applied earlier (fig. 4).

Figure 4. Specimens prepared for carrying out the equibiaxial tension test

Even when the degree of deformation was high, the paint did not peel off the specimen, allowing the determining of the strains. Since the area intended to be lighted was rather dark, it was necessary to supplement the light sources both during the calibration of the optical measurement system and during the actual experiment.

The experimental programme for determining the mechanical behavior of PA 6.6 polyamide fabrics coated with silicone and uncoated, with and without stress concentration points, was based on the following elements:
- there were extracted sets of five specimens for each type of material, i.e. for uncoated PA 6.6 polyamide fabric and for the same type of fabric coated with silicone;
- there was created a virtual instrument in Matlab software. The acquisition rate was set to 100 points/second. This virtual instrument allows the acquisition on two channels from the acquisition device of the values of pressures in the two circuits and parallel to this the acquisition of the time as a distinct variable. Based on the calibration equation, there was created another instrument, also in Matlab, allowing the direct display of the force-displacement curve;
- the loading rate was set to 10 mm/min;
- the specimens were of square shape with an area of 250 x 250 mm. The equibiaxial tension tests were carried out on the same types of fabrics as the ones used for the tension test;
- the acquired output data were the maximal force [N] and the elongation corresponding to the maximal force [mm]. Beneath the mentioned data, there will be also saved the primary data of the test (the characteristic curve in coordinates force [N] – displacement [mm]). These data are found as point pairs in the coordinates indicated above in the file corresponding to each test, in Excel format.

3 RESULTS OF THE EXPERIMENTS

Before the equibiaxial tensile tests, the two types of materials were subjected to uniaxial tension, determining the maximal force supported by the material and the maximal elongation before the occurrence of the failure. Both materials were tested on the warp direction. The results obtained after the tensile test are shown in table 1.

Table 1 Results of the uniaxial tests on warp direction for the uncoated fabrics and for silicone coated fabrics

<table>
<thead>
<tr>
<th>Case</th>
<th>Maximal force $F_{\text{max}}$ [N]</th>
<th>Elongation at maximal force $\Delta L_{\text{max}}$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoated fabric</td>
<td>1375.59</td>
<td>39.55</td>
</tr>
<tr>
<td>Silicon coated fabric</td>
<td>1521.45</td>
<td>44.22</td>
</tr>
</tbody>
</table>

Figures 5 and 6 present the conventional loading graphs in force-displacement coordinates for the warp direction for the two cases.

Figure 5 Load – elongation curves for uncoated fabrics – warp direction

Figure 6 Load – elongation curves for coated fabrics – warp direction

Examining the graphs in figures 5 and 6 there can be noticed that in the case of the silicone coated fabric, the characteristic loading curves are continuous and smooth, without local maxima or minima, as opposed to the characteristic curves of...
the uncoated fabrics, that show some "peaks". The presence of these peaks is explained by the manner in which the failure occurs in the case of fabrics, i.e. a gradual, successive failure of the fibres on the loading direction.

With regard to the maximal force that occurs in the specimen at the uniaxial tensile test, it can be concluded that the larger values occur for the case of the silicone coated fabrics, which was to be expected, since by coating the fabric with silicone there occurs a stiffening of the fabric and the material is changing its behaviour.

Figures 7 and 8 present the conventional loading graphs in force-displacement coordinates for the two cases, while table 2 shows the numerical results of the equibiaxial tension tests.

Table 2 Results of the equibiaxial tests for the uncoated fabrics and for the silicone coated fabrics

<table>
<thead>
<tr>
<th>Case</th>
<th>Maximum force $F_{\text{max}}$ [kN]</th>
<th>Maximum height $\Delta H_{\text{max}}$ [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncoated fabric</td>
<td>22.66</td>
<td>41.05</td>
</tr>
<tr>
<td>Silicon coated fabric</td>
<td>31.65</td>
<td>45.42</td>
</tr>
</tbody>
</table>

Figures 9 ... 17 show the results obtained using the optical measurement system Aramis for the cases of the silicone coated fabrics and of the uncoated fabrics, respectively.
CONCLUDING REMARKS

From examining the values resulted for each experiment (table 2), it can be noticed that both the force needed for the specimen's failure and the maximal height obtained for the dome are larger in the case of the silicone coated fabric. Thus, the maximal values for this type of specimen are: $F_{\text{max}} = 31.65$ kN and $\Delta H_{\text{max}} = 45.42$ mm.

When examining the graphs in figures 7 and 8 it can be noticed that in the case of the equibiaxial tension test, both the curves obtained for uncoated fabrics and for silicone coated fabrics show smooth variation. This is due to the specifics of this test, more precisely due to the simultaneous stretching on both directions (on the warp direction and on the weft direction). The only area where small variations are visible is the starting portion of each curve and these small oscillations are due to the fact that in this area the fibres on the weft direction are not yet perfectly stretched. Once these fibres are fully loaded, the curve is smooth until its maximum point at the moment before the occurrence of the failure. For this type of test, as opposed to the uniaxial test, the failure occurs in several fibres simultaneously and not successively. This failure manner too is specific for this type of test.
The maximal height of the dome varies in the same manner as the maximal force. i.e. the maximal value is obtained for the case of silicone coated specimens. When analyzing the succession of figures 9 .. 18 that show the variation of the major strains ε₁, of the minor strains ε₂, of the equivalent strains εVM, of the relative thickness reduction of the specimen before failure and of the displacements on vertical direction, there can be drawn some conclusions regarding the behaviour of these specimens in the case of equibiaxial tension.

From studying the figures presenting the variation of major strains (fig. 9 and fig. 10) it cn be noticed that both in the case of uncoated specimens and in the case of silicone coated specimens, the major strain ε₁ has the same variation pattern across the specimen’s surface. The maximal values of the major strain coincide with the direction of the warp fibres, but values close to these ones are obtained also on the direction of the weft fibres. The minimal values of the major strains are obtained at an angle of 45° to the directions of the warp and weft fibres. The maximal value of the major strain ε₁ is obtained in the case of the silicone coated fabric and is of 29.93%, while the same major strain has a value of 24.91% in the case of the uncoated fabric.

The variation of the minor strain ε₂ (fig. 11 and fig. 12) is not similar to that of the major strains, its maximal values being obtained in the upper part of the specimen, on a rhombical surface with the corners oriented towards the areas where the major strains have minimal values. At the base of the specimen, on the directions of the warp and weft fibres there are reached minimal values of the minor strain. The maximal value of the minor strain ε₂ is obtained for the silicone coated fabric, being of 19.9%, while the same minor strain has a maximal value of 17.7% in the case of the uncoated fabric.

When analyzing the images showing the variations of the equivalent strains εVM (fig. 13 and fig. 14) there can be noticed the fact that the maximal value for these strains is obtained, just like in the case of the minor strain, in the upper part of the specimen, this time on a circular area. The maximal value of the equivalent strain εVM is obtained for the silicone coated fabric, being of 46.35%, while the same type of strain has a maximal value of 39.90% in the case of the uncoated fabric.

There was presented also the variation of the relative thickness reduction before the occurrence of the specimen’s failure. It should be mentioned that this value of the thickness reduction is obtained through calculation. The Aramis software calculates the values of the major and minor strains, that in the presented case are both strains occurring in the specimen’s initial plane, after which the third strain (the strain on the fabric’s width) is calculated based on the law of constant volume, representing the specimen’s thickness reduction. Thus, the specimen’s thickness reduction is calculated analytically based on the previously calculated major and minor strains. The variation of the relative thickness reduction (fig. 15 and fig. 16) is similar to that of the equivalent Von Misses strain in that the maximal values occur in the dome’s upper part. The maximal value is obtained for the silicone coated fabric and is 31.7% while in the case of the uncoated fabric the value is 28.7%.

The dome’s maximal height (fig. 17 and fig. 18) is in agreement with the values indicated in table 2 and the maximum value occurs of course in the specimen’s upper part. The maximal value is obtained for the silicone coated fabric and is of 45.6 mm, while the maximal value for the uncoated fabric is of 41.5 mm.

5 REFERENCES