THE INFLUENCE OF THE STRESS CONCENTRATOR ON SILICONE COATED POLYAMIDE 6.6 FABRICS SUBJECTED TO UNIAXIAL TENSION TESTS

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ABSTRACT: This paper aims to conduct a study on the influence of the stress concentrator on silicon coated polyamide PA 6.6 specimens subjected to uniaxial tension. The specimens were drawn in the warp direction and the weft direction resulting in four experimental cases. The research has been aimed at measuring the maximum force occurring prior to rupture, measuring the elongation corresponding to the maximum force, and determining the major and minor strains by optical methods.

KEY WORDS: silicone coated, polyamide 6.6, uniaxial tensile test, stress concentrator, strain measurement.

1 INTRODUCTION

The definition of a composite material is that it is a combination of two different materials whose combined properties can exceed the sum of properties of the two materials taken individually. When it is desired to manufacture a composite material reinforced with fabrics, it is useful to be aware of the straining mechanisms that take place inside them so that the manufacturing process can be optimized to produce materials that best meet the requirements for which they were created.

This paper aims to study of composite materials reinforced with fabrics used for manufacturing airbags. Most authors believe that the materials from which airbags are made are orthotropic materials with linear elastic behavior [Dornhoff et al., 2008; Hirth, Haufe and Olovsson, 2007]. The airbag is made of woven textile membranes that are made mostly of polyamide 6.6 (nylon) multi-filament yarns. The structure of the woven material used in airbags is the flat fabric where warp yarn and the weft yarns are woven into a regular sequence with one going beneath and one above. The airbag fabric can also be covered with an elastomer, which reduces the permeability of the fabric and provides an ablative shield for the fabric against hot gases [Crouch, 1994; Gon, 2010; Schwark & Muller, 1996]. Oleksik [Oleksik, 2013] also shows a special interest in the airbag industry, and by identifying the behavior of the airbag, she tries to achieve a better understanding of its operation.

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The first generation of airbags used a neoprene coating, while the current airbags are almost exclusively coated in silicone. There have been many discussions in the airbag industry related to the behavior of the coated and uncoated fabrics [Gon, 2010; Mukhopadhyay, 2008; Keshavaraj and all, 1996]. The coated fabrics have better resistance to high temperatures, better resistance to rupture and low permeability. On the other hand, the process of coating the fabric is non-ecological. The fabric becomes difficult to handle due to the permeability of the coating liquid's solvent.

Most experimental research on the behavior of the reinforced composite materials involves either tensile or shear tests. Since most airbags are fitted with gas exhaust orifices or with mounting orifices, the present paper aims to study the influence of the stress concentrators on the uniaxial tension test behavior of the silicon coated polyamide 6.6 woven materials.

2 EXPERIMENTAL FACILITIES AND METHODOLOGY

The tests were carried out using the following experimental facilities in the "Lucian Blaga" University of Sibiu: the traction, compression and buckling testing machine Instron 5587 and the strain measuring optical system Aramis;

The traction testing machine which was used is a universal testing instrument having a maximum loading capacity of 300 kN, an adjustable testing speed in the range of 0.001-500 mm/min and a power cell with a +/- 0.25% linearity and +/- 0.25% repeatability for readings in the 0.4-100% range.

Since the traction, compression and buckling testing machine Instron 5587 is equipped with a single extensometer with a 50mm calibrated length which can be mounted along the longitudinal direction of the specimen, for determining the local specific strains a strain measuring optical system was used, the Aramis, manufactured by Gom. This system gives the possibility of conducting a real-time measurement of the stains occurring in the specimen subjected to uniaxial tension test.

The calibration of the measuring system was required to perform the experiments to determine the strains. A series of calibrators of different sizes that the measuring system is equipped with can be used for this purpose, depending on the dimensions of the area to be measured. A 120 x 120 mm caliber was used in this paper. The aperture of the optical camera's iris and the exposure time were adjusted, since there must be a good correlation between them so that there are neither under-exposed nor overexposed areas. The calibration consisted in acquiring a number of 12-18 successive images in which the measurement system could identify certain markers that are found on the calibers. By identifying these markers, the 3D space in which the operating system can operate with a minimal error rate is thus "delimited".

In order to carry out the experimental research by means of the Aramis measuring system, it is necessary to priory coat the surface of the part with a grid. If in the case of laminated composites, sheets or other (generally rigid) materials it is preferable to coat the surface of the part with a layer of matte white paint in order to eliminate undesirable reflections and then to cot it with a graphite point grid, in the case of the composite textile materials we have chosen another method of determining the strains, namely coating the surface to be measured with a dark grid. We chose this method of marking the grid on the piece because if in the case of composite laminates (which have a high thickness) the matte paint layer does not influence the properties of the tested materials, in the case of the impregnated textile composites (which have a much smaller thickness, sometimes comparable to that of the paint layer) this layer can induce significant errors in the analysis. With the thus prepared specimens, the testing process started, and the number of images desired by the user was acquired.

In the present research, the CCD camera acquisition rate was set to 1 image/second, as recommended by the literature. When cracks begin to show on the specimen, the recording stops. At the end of the testing process, the area to be measured is determined, by eliminating the areas which are unnecessary in the measuring process, and then a reference (starting) point is selected (automatically or by the user) for calculating the strains. It should be noted that this point must be present in all the images acquired throughout the test and that the choice of this point has no influence on the accuracy of the measurement. After all the images have been processed, the optical measurement system determines the displacements on the three axes of the system of coordinates of each point on the specimen.

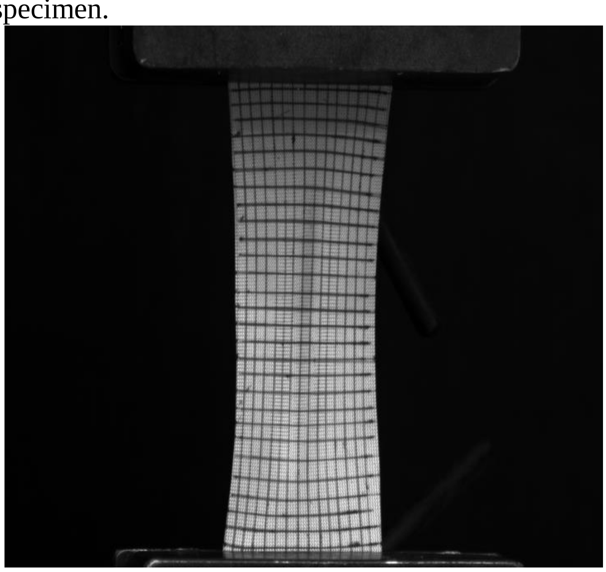

Figure 1. Specimen prepared for experiments with a linear grid deposed on the analyzed surface

By making additional calculations, the second-order unknown variables are determined, namely the elongations (or shortenings) along the x, y and z directions as well as the specific rotation. By rotating the trihedral of the coordinate axes so as to eliminate the specific rotations, we determine the major and minor strains, the relative thinning (where appropriate), the shear strain (shear angles) and the equivalent Von Mises or Tresca stresses.

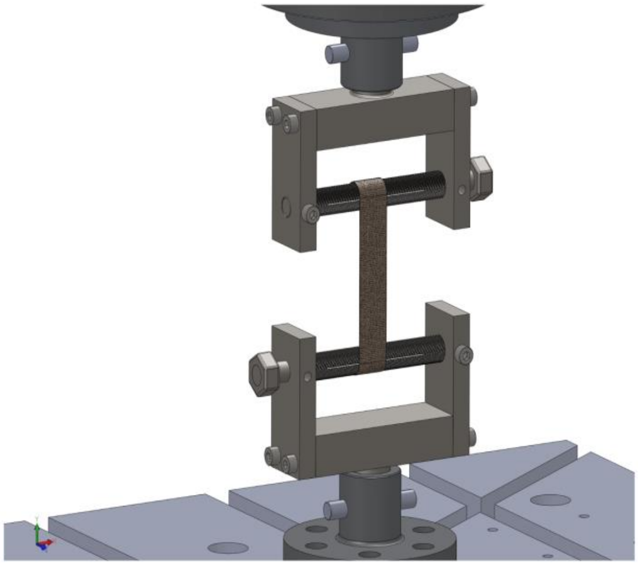

Figure 2. Experimental layout for uniaxial tension tests

Since the Instron 5587 traction testing machine did not have the necessary rams to test the fabrics, it was necessary to design such rams.

The biggest drawback is that, unfortunately, standardized rams do not allow the adjustment of the clamping force, and consequently lead to crushing the composite textile material. Thus, the stand shown in Figure 2 was designed to be used for both uniaxial tension test on the warp or weft direction, but also for the Bias test, the difference between the two tests being the width of the specimen and the mode of sampling.

The stand is conceived in such a way that the movement of the crosshead does not cause the detachment of the textile specimen from the roll on which it was coiled.

3 UNIAXIAL TRACTION TEST OF THE SILICONE COATED POLYAMIDE FABRICS WITH AND WITHOUT STRESS CONCENTRATORS

Since these textile support composite materials are materials used in the manufacture of airbags, they will not be included in the airbags under the form in which they come from the loom but they will suffer a series of different diameter perforations required for mounting, for introducing the pyrotechnic staples etc. For this reason, we considered useful to conduct a comparative study between the behavior of these silicone-coated materials in the case of the existence or the absence of a stress concentrator.

Figures 3 and 4 show the rupture modes for two silicon coated polyamide PA 6.6 woven specimens that have been punctured with a Φ 10 mm perforated orifice prior to the test, and loaded on the direction of the warp (Figure 3) or of the weft (Fig. . 4). The analysis of the two figures proves that in the case of the weft strain the yarn change their orientation due to the fact that their shape changes by stretching.

The experimental program for determining the mechanical properties for the silicone coated fabrics with and without a stress concentrator provides the following steps:

- sets of five specimens were taken for each type of material, that is, both in the direction of the warp yarn and in the direction of the weft yarn. The shape of the specimens was the standard one for this type of test, but in addition, in the case of the specimens having a stress concentrator, each specimen was punched with a 10 mm diameter orifice in the middle;

- the testing method was developed in the Instron testing machine's language, namely Bluehill 2. The following were established at this stage: the type of test (traction), the material data (specimen shape, specimen width, machine stroke distance), test speed, constraints of the machine, the machine's acquisition rate (10 points/second), the type of the output file (ASCII or DIF - Data Interchange Format, a file format that can be downloaded in any of the statistical data processing software), the type of the output data to be acquired;

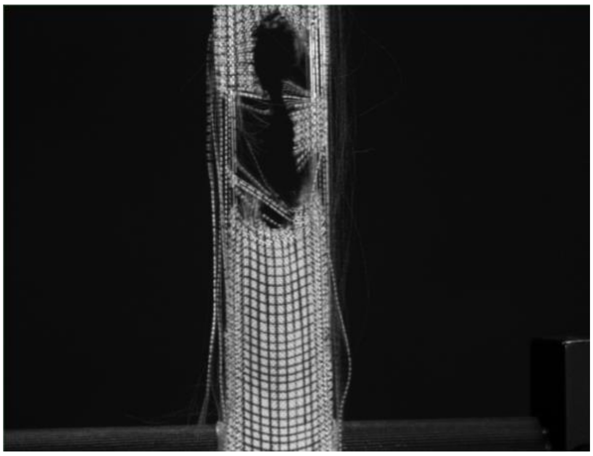

Figure 3. Fracture type for a PA 6.6 silicone coated fabric specimen loaded on the warp direction

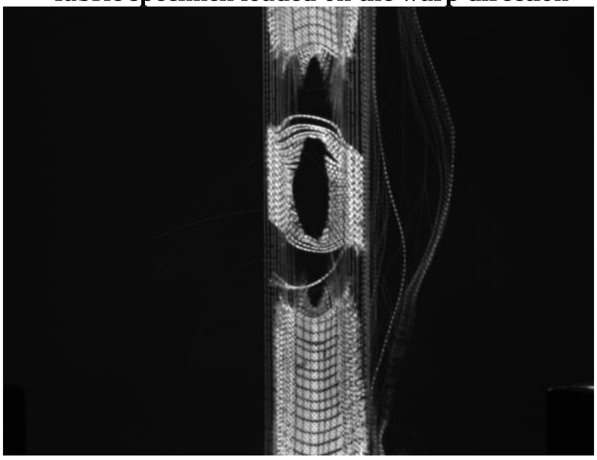

Figure 4. Fracture type for a PA 6.6 silicone coated fabric specimen loaded on the weft direction

- the uniaxial tension tests were performed on coated or uncoated fabrics consisting of 840 denier polyamide yarns and 136 filaments. Prior to performing the experiments, the specimens were kept in the laboratory at a constant temperature of 25° C;

- the output data consisted in the maximum force [N] and the elongation corresponding to the maximum force [mm]. We chose the two output data at the expense of the tensile strength and the rupture elongation because the moment when the testing machine detects the rupture is the one in which the tensile force abruptly decreases by 10-20%. This is beneficial for the metal specimens or for the layered composite materials. The composite material on an impregnated textile support behaves differently from these types of materials because the polyamide yarns break successively, the force decreasing smoothly throughout the testing process. This makes it impossible for the testing machine to determine the rupture of the specimen and implicitly it is impossible to determine the tensile strength and the rupture elongation;

- the test speed was set at 10 mm/min;

- the width of the specimen was b_0 = 20mm and the free measuring distance l_0 = 100mm;

- for the purpose of determining the major strain, using the Aramis optical measuring system, the specimens were prepared by drawing a rectangular grid on the measured surface. We would like to mention that we initially applied the grid for the Aramis and only then we performed the punctures with the diameter Φ 10 mm. This method is optimal because the thickness of the paint layer can influence their characteristics.

The tests led to the identification of four different cases: specimens taken in the direction of the warp yarns without stress concentrators (case 1), specimens taken in the direction of the weft yarns without stress concentrators (case 2), specimens taken in the direction of the warp yarns with a stress concentrator (case 3), specimens taken in the direction of weft yarns with a stress concentrator (case 4). Table 1 shows the mean values, in the four cases, for the maximum force F_{max} and for the elongation on the maximum force ΔL_{max}.

Table 1 Results of the tension tests for the silicone coated fabrics with and without stress concentrators

Case	Maximum force F_{max} [N]	Elongation on maximum force ΔL_{max} [mm]
1.	1522.34	44.25
2.	1420.16	61.64
3.	594.09	29.03
4.	439.40	39.13

The sequence of figures 5...8 shows the conventional straining graphs in the force-elongation coordinates for the four cases.

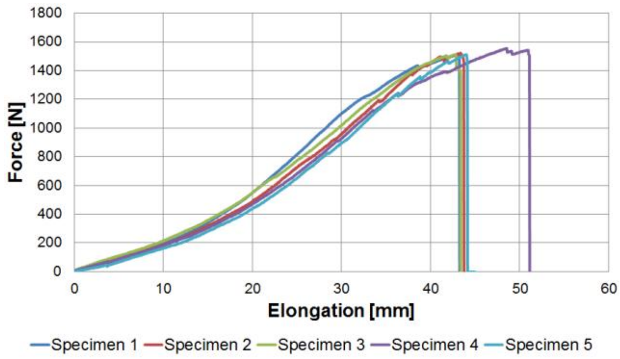

Figure 5 Force-elongation curve for specimens loaded on the warp direction without stress concentrator

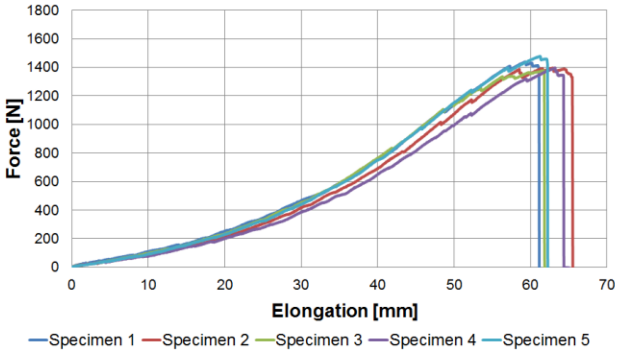

Figure 6 Force-elongation curve for specimens loaded on the weft direction without stress concentrator

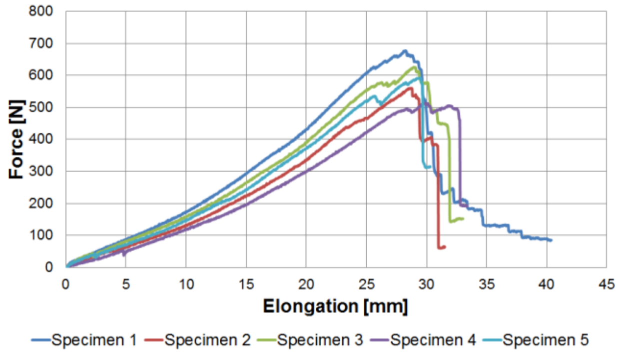

Figure 7 Force-elongation curve for specimens loaded on the warp direction with stress concentrator

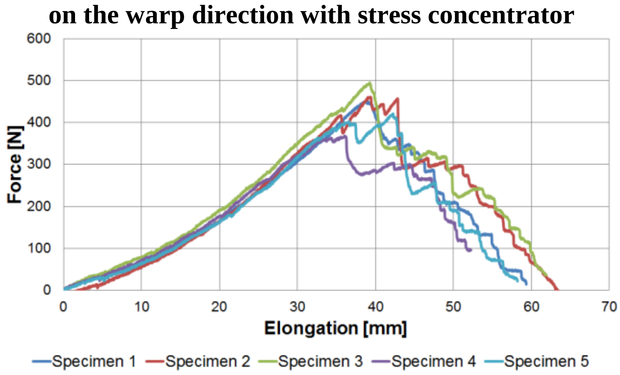

Figure 8 Force-elongation curve for specimens loaded on the weft direction with stress concentrator

Figures 9...16 show the results obtained by means of the Aramis optical measuring system for the major strain and minor strain values at the moment before the rupture for the specimens taken in the warp and weft direction.

4 CONCLUDING REMARKS

The examination of the values obtained for each experiment (Table 1) proves that for the variation domains of the two parameters, force and elongation, the considered characteristics vary within the limits: F_{max} = 439…1522 N and ΔL_{max} = 29.03…61.64 mm.

Judging strictly from a quantitative point of view, it can be concluded that the maximum value of the force drops 2.5 ... 3 times when there is a stress concentrator compared to the maximum value of the force in the absence of this concentrator. As for the value of the elongation for maximum elongation, it decreases approximately 1.5 times when there is a stress concentrator compared to the maximum elongation value corresponding to the maximum force in the absence of the stress concentrator.

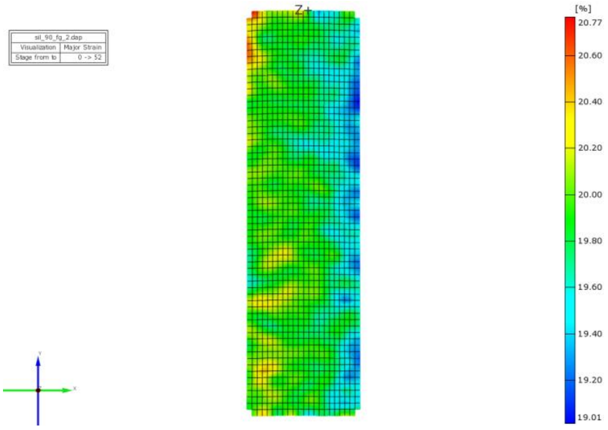

Figure 9 The values of major strain for a specimen without stress concentrator loaded on the warp direction

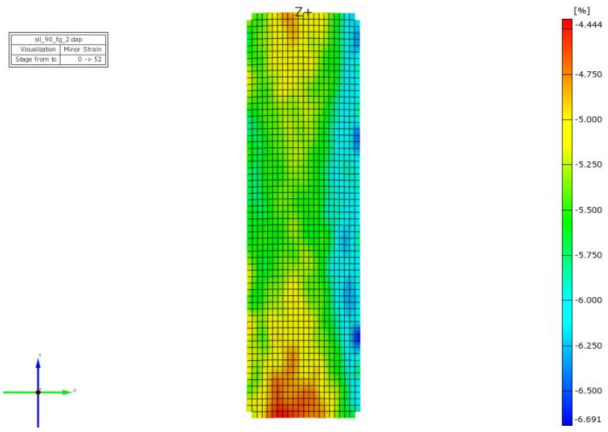

Figure 10 The values of minor strain for a specimen without stress concentrator loaded on the warp direction

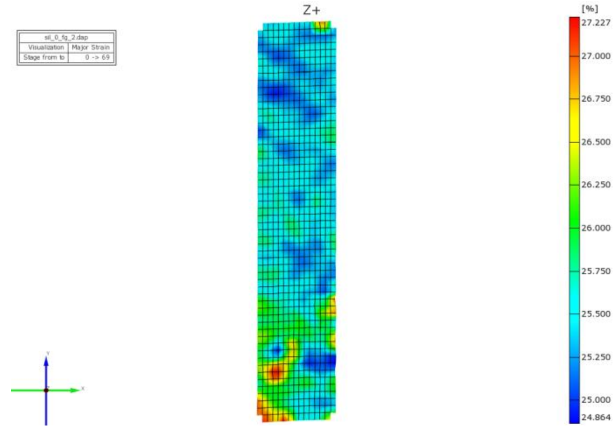

Figure 11 The values of major strain for a specimen without stress concentrator loaded on the weft direction

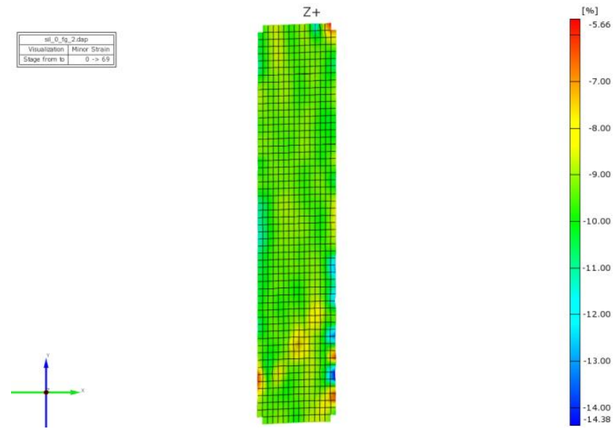

Figure 12 The values of major strain for a specimen without stress concentrator loaded on the weft direction

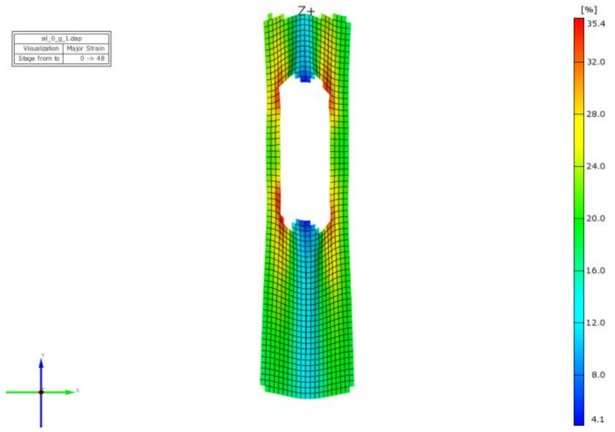

Figure 13 The values of major strain for a specimen with stress concentrator loaded on the warp direction

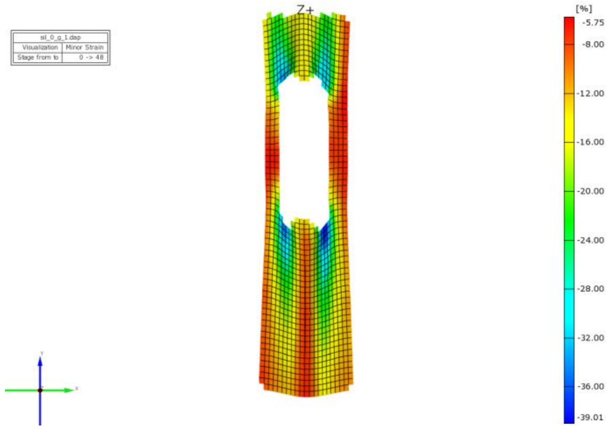

Figure 14 The values of minor strain for a specimen with stress concentrator loaded on the warp direction

Regarding the comparison of the specimens taken in the direction of the warp or of the weft, it is noticed that the rule for the maximum force is not observed. Here the maximum elongation occurs in the case of the fabric loaded in the direction of the weft as compared to the elongation that occurs in the case of the application of strain in the direction of the warp. This is due to the fact that in the direction of the warp the yarns are stretched and in the direction of the weft the yarns are undulated, since they must go through the warp yarns. These undulated yarns will straighten out due to strain and tend to elongate more.

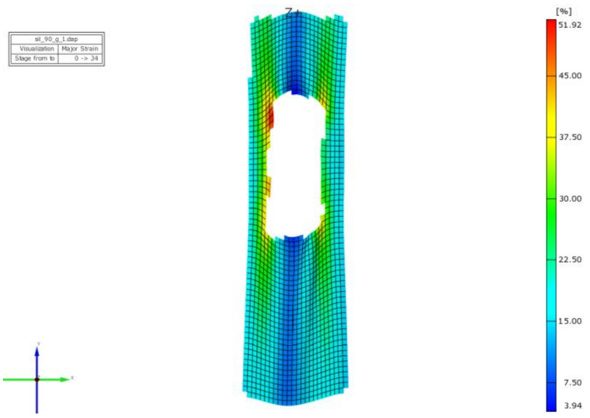

Figure 15 The values of major strain for a specimen with stress concentrator loaded on the weft direction

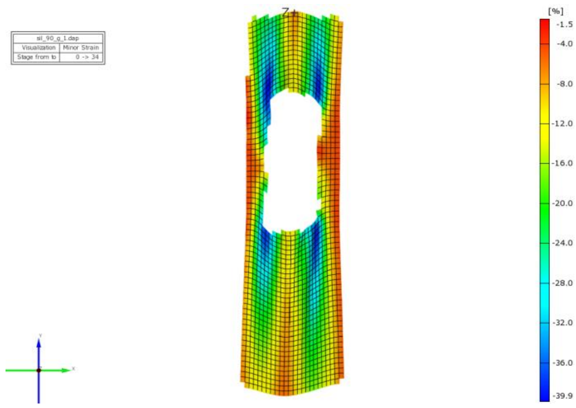

Figure 16 The values of minor strain for a specimen with stress concentrator loaded on the weft direction

By studying the images showing the variation of the major and minor strains (fig. 9 ... 16) (the direction of the major strain coincides with the direction of straining and the direction of the minor strain is perpendicular to the first one), it is observed that both types of strains are evenly distributed in the silicon coated fabrics, the difference being 3-4 percent between the maximum value and the minimum value. The smallest difference is that of the warp direction strain, about 1.6 percent.

The study of the images showing the variation of the main strains shows that in the case of the specimens having a stress concentrator there is no more homogeneous distribution even if the strain occurs in the warp or the weft direction. The maximum values of the major strain occur at an angle of approximately 45^0 relative to the strain direction regardless of how the specimen was taken. The variation of the minor strains is similar to that of the major strains, the maximum values occurring in the same areas. It is worth noting that if in the case of the no-stress concentrator specimens the value of the minor strains was very low (up to 5%) in the case of the specimens having a stress concentrator the maximum value is significant.

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