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Using Finite Element Method to Study the Behavior under Uniaxial Traction of Different Types of Weaves

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Abstract

This study presents an analysis with the aid of the finite element method of different type of weaves (plain weave, basket weave and satin weave) concerning their behavior in uniaxial tension test. There are revealed the results obtained for the case of uniaxial soliciting type of these three types of weaves with and without defects. The purpose of this study is to determine the way in which the defects that may appear have an influence (and in what way) upon mechanical characteristics of these types of structures used in the manufacturing of airbags in the facility of cars.

Keywords: *uniaxial tension, finite element method, wave behavior*

Introduction

Textile materials, weaved, knitted or obtained through other diverse technological procedures, have a large utilization and a great variety of functions in numerous fields of industry. The most known utility of them is in the light industry, for producing diverse clothing landmarks. However, textile materials are used at high scale in diverse engineering functions from other fields of industry, such as machine industry, where there are used for the manufacturing of airbags, of safety belts, of diverse coverings, these last functions being also made in aeronautical industry. Another field in which this materials are utilized is the one of diverse sportive and/or camping accessories, such as parachutes, paraglide, tents etc. some special tissues ate used in civilian building like roofs for distinct buildings, while others are used in military industry, for the manufacturing of protection equipment (anti-bullet vest) for military staff [1, 2, 4].

All these functions can be developed or improved using modern projecting techniques and the optimization of elastic and mechanical characteristics of diverse textile materials, thus succeeding the creation of some "smart" textile materials.

The Current Stage of Mesoscopic and Macroscopic Behavior

When there is wanted the manufacturing of a composite material reinforced with waves, it is useful to known all the mechanisms of deformation, that occur within them, so that the process can be optimized to produce quality parts.

For example, it is well established by previously studies that the main mechanism of wave's deformation and in multi-layer reinforced composite materials with continuous fibers is shear intern fiber-fiber or the "trellis effect". In order to obtain a good understanding of the behavior of knitted, woven and composites materials reinforced with waves, generally the mechanisms of deformation of these materials must be taken into account and identified [5-8].

There are identified two major levels namely the macro level and the mezo level of deformation. Each of these categories contains a number of different mechanisms. Among these mechanisms we will present in this paper only the mesoscopic mechanisms.

A comparative study between mesoscopic and macroscopic approach in the case of composite reinforced with fibers is presented by [3]. The paper refers to the type of composites product LCM-type (liquid composite molding) where manufacturing process consists of applying a resin over a fiber structure made previously and the plastic deformation of these types of materials. Usually, there are three approaches regarding the study of the behavior of these types of materials, of which two are of major importance. The first of these approaches refers to the behavior of the composite material at a macroscopic level, and it consists of treating the part as a continuum solid and implies input the material data regarding at the behavior in terms of the wave's mechanical strength. There are already a number of mathematical models for these types of approach, however, in many cases, not faithfully reflect the behavior of the composite materials.

Another approach is to study each component of the composite material as separate elements on the scale of the waves yarn (mezoscopic behavior) or on the waves scale (microscopic level). Of course, a microscopic scale study would be ideal but, considering the fact that one yarn is made up of 3000 to 96000 fibers, this is practically impossible especially in the case we want to introduce this pattern into a numerical analysis program. [3] presents another comparative study between two major approaches, the mezoscopic and macroscopic. The main advantage of the macroscopic approach is that it can simulate the behavior of complex shaped parts that can not be achieved with mezoscopic behavior because we obtain a very large number of finite elements.

Gatouillat [3] presents the way in which the shear state plane occurs in reinforced composite materials. These, in a first stage, the yarns are rotate towards each other. In this stage only the friction forces between yarns are presents any resistance. In the second stage, the yarns are in a lateral contact because of their rotation, which leads to a significant increase in the stiffness waves. In the third and final stage the yarns are transversally compacted. These stages are presented separately on graphs that contain the variations of shear forces versus shear angle.

After the analysis of the two type's behavior mezo and macroscopics the authors proposed a combined approach of these for a composite material reinforced with fiberglass. Such deformation process simulation is made at macroscopic scale but the simulation of the waves is made at mezoscopic scale. Within this process the degrees of freedom is reduced from 47214 in the case of mezoscopic approach to only 216 in the case of the combined mezzo/macroscopic approach.

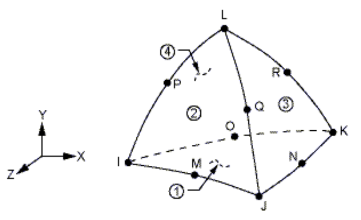
The Finite Element Analysis for Mezoscopic Approach for Different Weaves Types

Due to the complex configuration of different types of waves and for a higher precision of calculations, has been chosen the finite element method. For this study purpose there were initially modeled three types of waves (made from Nylon 6.6) namely the plain wave, basket wave and satin wave. The three types of waves were modeled parameterized. After the modeling all the three types of waves were imported into ANSYS Workbench 12 where they were discretized and then they were apply loads and constrains. The complex spatial structure of waves was discretized using the finite elements of Solid 92 type.

The characteristics of this type of element are presented in Table 1.

Discretization of the model in finite elements has been performed using the “free mesh” method but there were controlled the maximum size of the element as well as the way in which the transition from big dimension elements to the small ones. After the meshing step, they defined the contracts between the wave’s yarns for each type of waves, choosing type of the contract model, the friction model.

Table 1. The characteristics of the SOLID 92 finite element type

Finite element type	The element’s sketch	Form functions for the rigid matrix
SOLID 92		$u=\frac{1}{8}(u_I(1-s)(1-t)(1-r)+u_J(1+s)(1-t)(1-r)-$ $u_I(1-s)(1-t)(1-r)+u_K(1+s)(1+t)(1-r)+u_L(1-s)(1+t)(1-r)+$ $u_M(1-s)(1-t)(1+r)+u_N(1+s)(1-t)(1+r)+u_O(1+s)(1+t)(1+r)+$ $u_P(1-s)(1+t)(1+r)$ $v=\frac{1}{8}(v_i(1-s)...\quad ana\log u$ $w=\frac{1}{8}(w_i(1-s)...\quad ana\log u$

All analyzes were conducted static type analyzes, where loads and constrains applied are independent of time. This type of analysis was chosen because dynamic analyzes required a larger amount of time and considerable amount of memory the computer system. The thickness of the nylon fiber was of 0.323mm for all analysis.

The achieved analyzes was: three analyzes of uniaxial tension for the three types of waves (without defects), their results are presented in Figures 1 ... 12, and three analyzes of uniaxial tension for the three type of waves (with defects), their results are presented in Figures 13 ...24.

The achieved defects consist in the interruption of one or more fibers situated perpendicular on the loads direction. There have been attempts to achieve such a defects on a fiber situated parallel with the solicited direction but this was not possible due to the occurring extremely large nodal displacement that led to the loss of analysis stability. This phenomenon is normal because if we pull an interrupted yarn in reality, it would come out of the wave.

The results evaluated for structural static analysis was: equivalent stress von Mises σ_{VM} [MPa], principal stress σ_1 and σ_2 [MPa], shear stress σ_f [MPa], nodal displacement [mm] and equivalent strain [mm/mm].

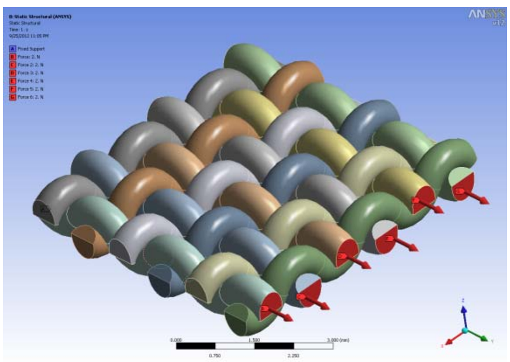


Fig. 1 Plain weave subject to uniaxial stretch

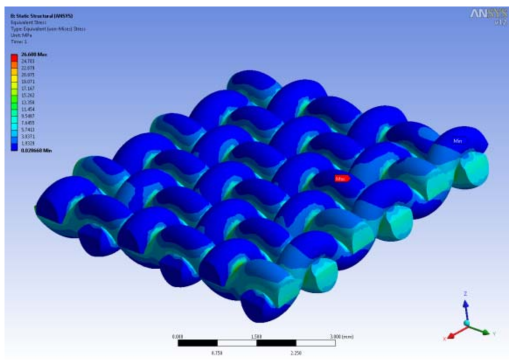


Fig. 2 The Von Mises stress variation on a plain weave subject to uniaxial stretch [MPa]

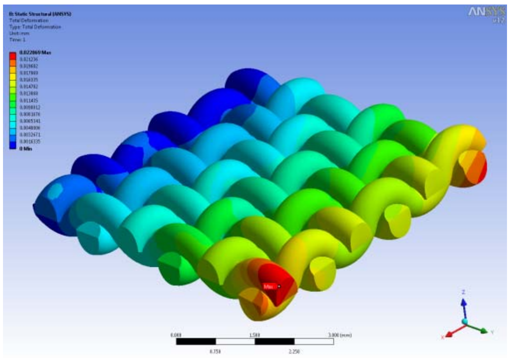


Fig. 3 The nodal displacement variation on a plain weave subject to uniaxial stretch [mm]

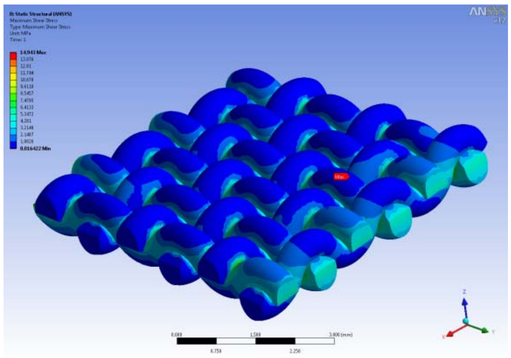


Fig. 4 The shear stress variation on a plain weave subject to uniaxial stretch [MPa]

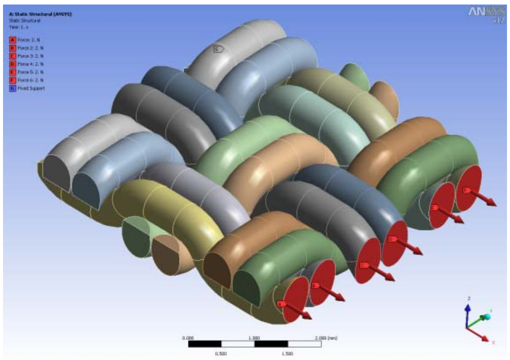


Fig. 5 Basket weave subject to uniaxial stretch

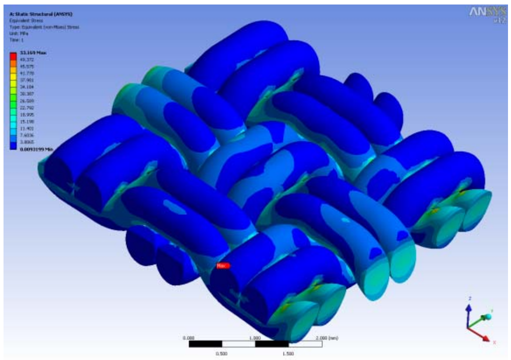


Fig. 6 The Von Mises stress variation on a basket weave subject to uniaxial stretch [MPa]

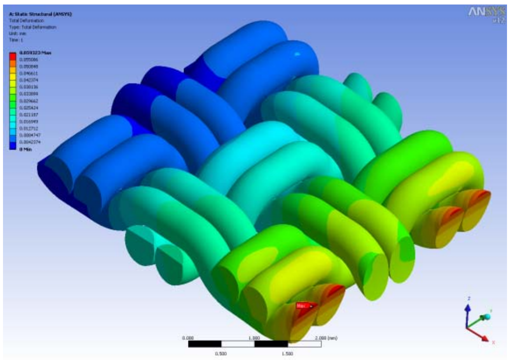


Fig. 7 The nodal displacement variation on a basket weave subject to uniaxial stretch [mm]

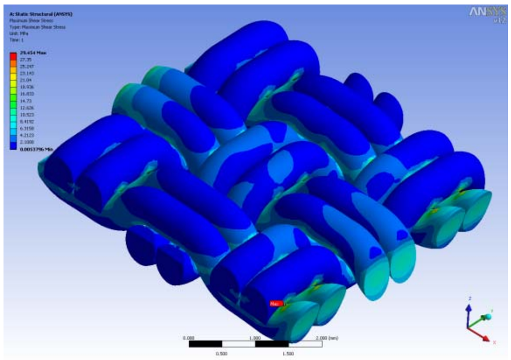


Fig. 8 The shear stress variation on a basket weave subject to uniaxial stretch [MPa]

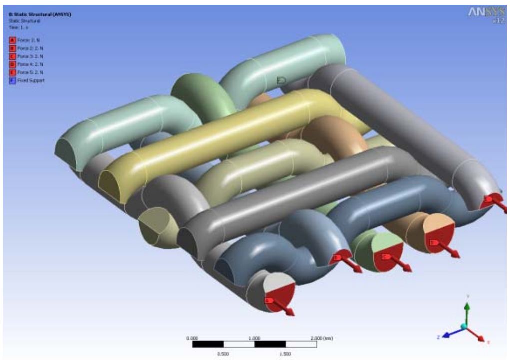


Fig. 9 Satin weave subject to uniaxial stretch

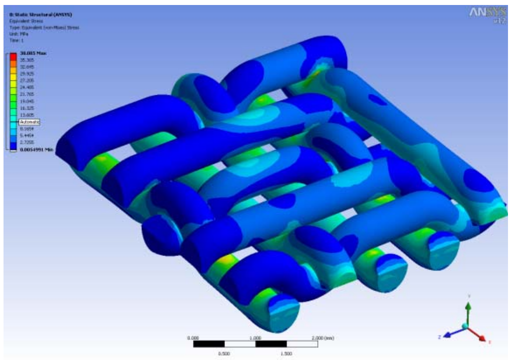


Fig. 10 The Von Mises stress variation on a satin weave subject to uniaxial stretch [MPa]

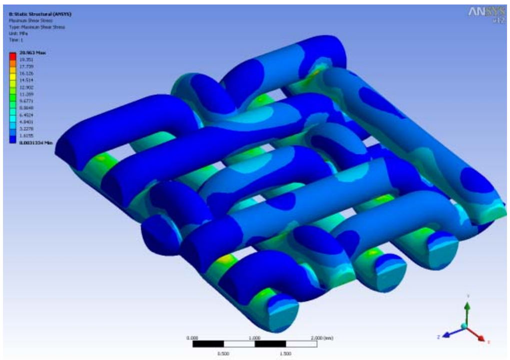


Fig. 11 The shear stress variation on a satin weave subject to uniaxial stretch [MPa]

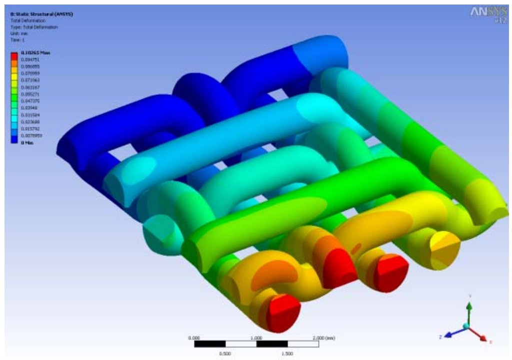


Fig. 12 The nodal displacement variation on a satin weave subject to uniaxial stretch [mm]

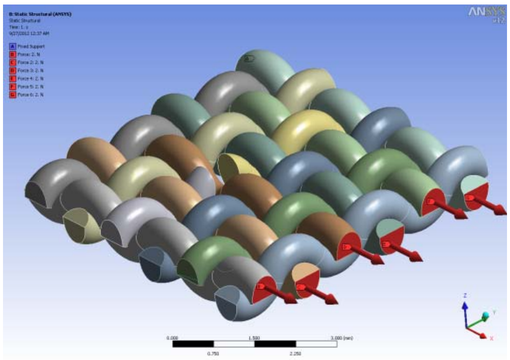


Fig. 13 Defective plain weave subject to uniaxial stretch

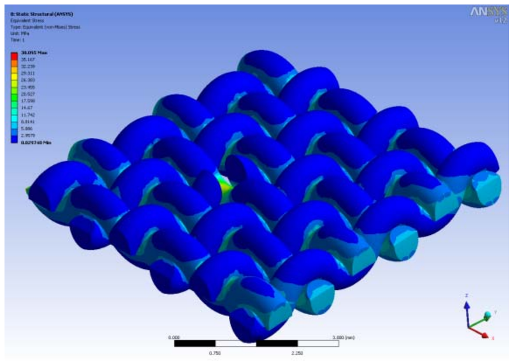


Fig. 14 The Von Mises stress variation on a defective satin weave subject to uniaxial stretch [MPa]

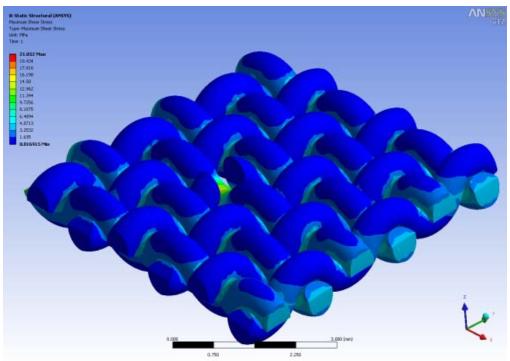


Fig. 15 The shear stress variation on a defective plain weave subject to uniaxial stretch [MPa]

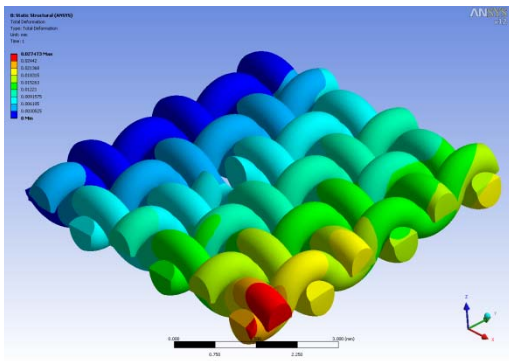


Fig. 16 The nodal displacement variation on a defective plain weave subject to uniaxial stretch [mm]

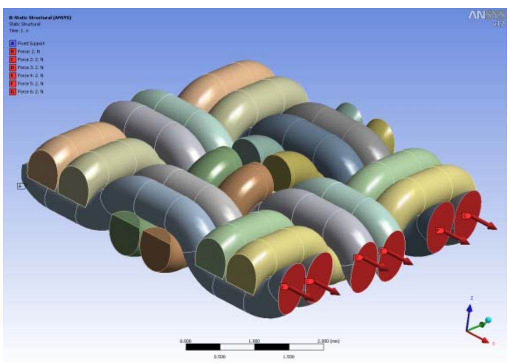


Fig. 17 Defective basket weave subject to uniaxial stretch

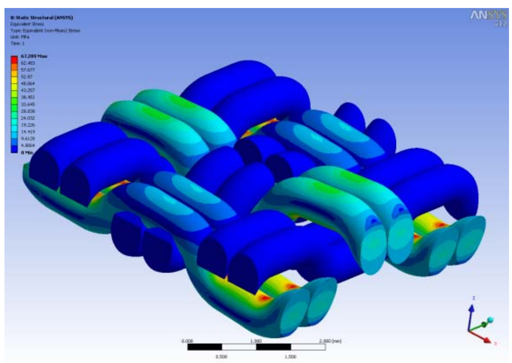


Fig. 18 The Von Mises stress variation on a defective basket weave subject to uniaxial stretch [MPa]

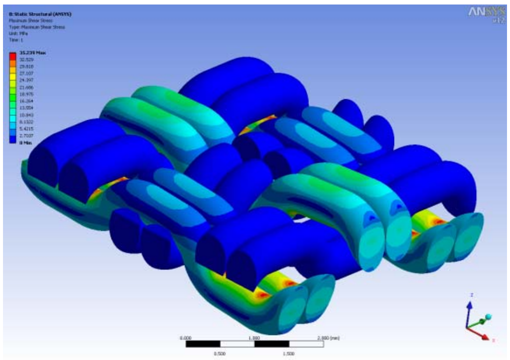


Fig. 19. The shear stress variation on a defective basket weave subject to uniaxial stretch [MPa]

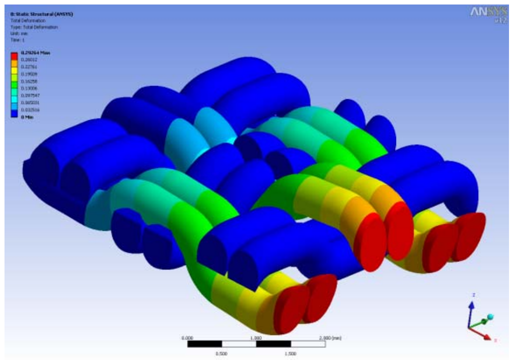


Fig. 20. The nodal displacement variation on a defective basket weave subject to uniaxial stretch [mm]

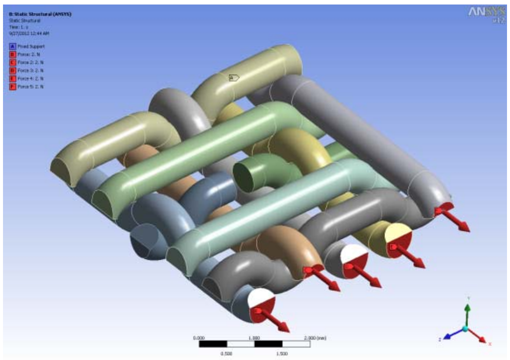


Fig. 21. Defective satin weave subject to uniaxial stretch

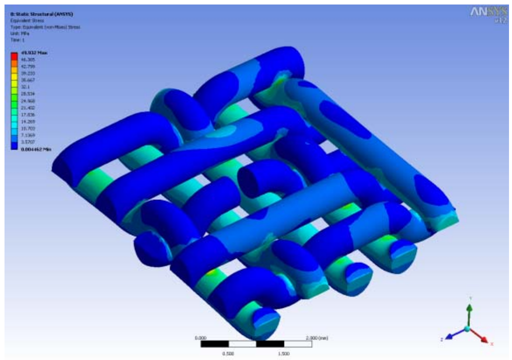


Fig. 22. The Von Mises stress variation on a defective satin weave subject to uniaxial stretch [MPa]

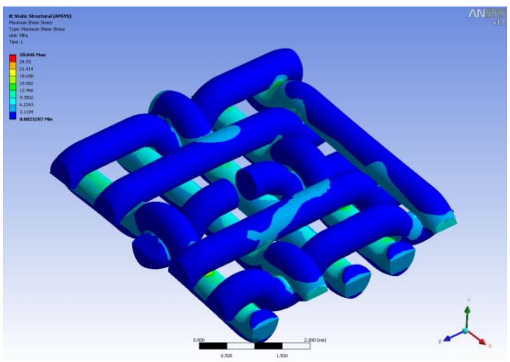


Fig. 23. The shear stress variation on a defective satin weave subject to uniaxial stretch [MPa]

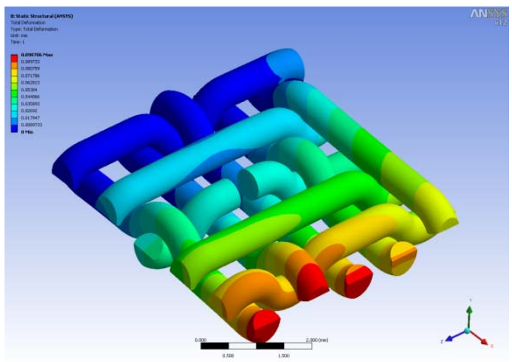


Fig. 24. The nodal displacement variation on a defective satin weave subject to uniaxial stretch [mm]

In Tables 2 and 3 are show (summarized) the result of numerical simulation by finite element mesoscopic level for all four distinct types of weaves.

Table 2. The numerical results obtained on different weaves subjected to uniaxial stretch tests

Weaves model / Result	**Plain weave**	**Basket weave**	**Satin weave**
Equivalent von Mises stress [MPa]	26.69	53.17	38.08
Principal stress [MPa]	35.06	95.52	65.80
Secondary stress [MPa]	13.22	52.92	31.54
Shear stress [MPa]	14.94	29.45	20.96
Nodal displacement [mm]	0.023	0.059	0.103
Equivalent von Mises strain [mm/mm]	0.009	0.017	0.012

Table 3. The numerical results obtained on different defective weaves subjected to uniaxial stretch tests

Weaves model / Result	**Plain weave**	**Basket weave**	**Satin weave**
Equivalent von Mises stress [MPa]	38.09	67.29	49.93
Principal stress [MPa]	50.01	71.09	56.20
Secondary stress [MPa]	20.02	17.93	30.23
Shear stress [MPa]	21.05	35.24	28.04
Nodal displacement [mm]	0.027	0.293	0.098
Equivalent von Mises strain [mm/mm]	0.0126	0.022	0.016

Conclusions

After ongoing static analysis subjected uniaxial stretch, the following conclusions can be drawn:

- the maximum equivalent for Von Mises stress occurs in the case of basket weave with 53.17 MPa followed by satin weave with 38.08 MPa and plain weave 26.69 MPa
- the same trend can noticed therefore in the case of main and secondary stress value as well as the equivalent Von Mises strain;
- plain weave and satin weave evince the lowest values in the case of maximum shear stress 14.94 MPa (plain weave) and 20.96 MPa (satin weave);
- plain weave (0.023 mm) and basket weave (0.024 mm) thus evince the lowest values for nodal displacement.

After ongoing static analysis requesting uniaxial stretch waves with defects, the following conclusions can be drawn:

- the maximum equivalent for Von Mises stress occurs in the case of basket weave with 67.29 MPa as against 53.17 in the case of the same wave but without defects. It is followed by defective satin weave with 49.93 MPa, in comparison to 38.08 MPa defective satin weave free and defective plain weave – 38.09 MPa as against 26.69 at plain weave without defect;
- therefore it can be seen that in all cases the defect produces an increase in stress value with a procent between 26% and 42%;
- in the case of main and shear stresss but also for equivalent strain the same variation remains;
- only for secondary stress, basket weave type has the lowest value (17.93MPa);
- the lowest values of nodal displacements are encountered in plain weave type (0.013mm) and satin weave (0.016mm).

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Utilizarea metodei elementului finit la studiul comportării la tracțiune uniaxială a diferitelor tipuri de țesături

Rezumat

Lucrarea de față prezintă un studiu cu ajutorul metodei elementului finit a diferitelor tipuri de țesături (tip pânză, tip coş şi satin) privind comportarea acestora la tracțiune uniaxială. Sunt prezentate rezultatele obținute pentru cazul de solicitare uniaxială a acestor trei tipuri de țesături fără defecte şi cu defecte (fire rupte). Scopul acestui studiu este de a determina modul în care defectele ce pot apare au influență (şi în ce mod) asupra caracteristicilor mecanice ale acestor tipuri de structuri utilizate la confecționarea airbag-urilor din dotarea automobilelor.