FINITE ELEMENT ANALYSIS OF WEFT KNITTED COMPOSITES

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ABSTRACT

In the present paper mechanical properties of knitted fiber reinforced polymer laminates are investigated experimentally and numerically, using unspecialized FEA. For this purpose the material unit cell was observed and its stress-strain statement was simulated using ANSYS commercial software depending on applied external loads. As example tensile properties (namely elastic modulus) in two principal directions of epoxy matrix E-glass knitted fabric laminated composites were obtained. The numerically predicted composite material mechanical parameters were compared with the experimental results and with the data obtained from previously performed analysis based on FEA software Solid Works. The numerically obtained longitudinal and transverse modulus comparison with the performed experiments has shown the ability to predict the material properties with reasonable accuracy.

Key words: textile composites, knitted fabric reinforcement, modeling, mechanical properties

INTRODUCTION

Knitted fabric reinforced composites show attractive properties - good impact resistance and high energy absorption, simultaneously high reinforcement deformability makes them possible to fit various complex preform shapes without forming folds (Miravete 1999). At the same time, mechanical properties prediction for such composite materials still needs additional investigations. It is worth mentioning that direct experimental determination of stiffness and strength for textile composites may be expensive and time consuming (Ernst 2010), however the results may be disappointing. Therefore, it is important to attempt to predict the composite materials properties and behavior and to optimize their internal structure and components features.

In the present paper the material (namely glass weft-knitted fabric/epoxy laminate) structure unit cell was recognized and its numerical model, based on ANSYS software, was elaborated and numerically exploited. Tensile testing in two principal directions of material was simulated. The obtained results (elastic modulus in two principal directions) were compared with the experimental data and the similar case study previously made by numerical simulation analysis executing SolidWorks (Kononova 2012, Krasnikovs 2012) software.

MATERIALS AND METHODS

Materials

The subject of investigation was weft-knitted glass fabric/epoxy laminated composite. E-glass fiber yarns, produced by JSC "Valmieras stikla šķiedra" (Latvia), were used. Density of the glass fibers was $\rho=2540$ kg/m^3, diameter of the yarn $d=0.37\times10^{-3}$ m. Linear density of the glass yarn was calculated and it was equal to 275.6 tex. The value of elastic modulus for glass yarn was adjusted by the manufacturer and it was equal to 73.4 GPa.

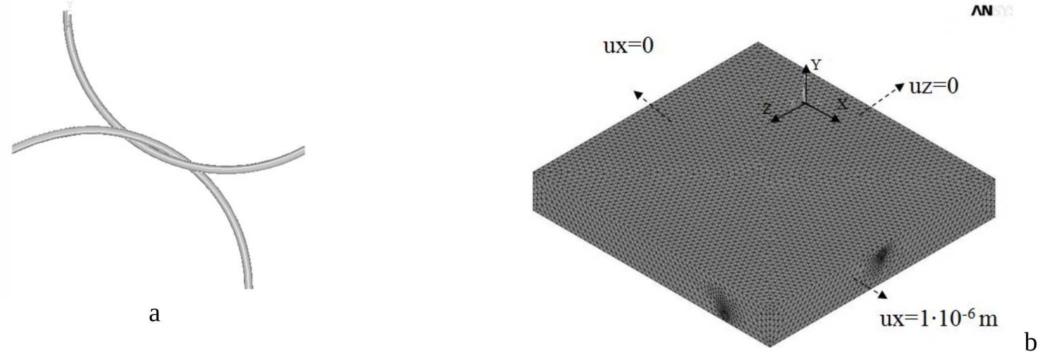
Figure 1. Structure of weft knitted fabric laminate (created in WeftKnit software (KU Leuven))

Glass knitted fabric with stitch density W=1.053 loops/cm, C=2 loops/cm was prepared by the authors on a flat-bed type knitting machine Neva-5. The fabrics were stacked and impregnated by polymer thermoset resin at room temperature. Epoxy resin was used. The laminate lay-up was $[0]_4$ (Fig. 1). Two plates were produced with thicknesses 0.176 and 0.202 cm.

Modeling

The material structural repeating element (unit cell) is shown in Figure 2. The material internal structure model was based on Leaf and Glaskin (Ramakrishna 1997, Ramakrishna 2000) geometrical formulas and was created using properties of real knitted textiles. The basic assumptions were: a) each yarn has a circular cross-section and it remains constant along the length of the yarn; b) the projection of the central axis of the yarn on the plane of the fabric is composed of circular arcs. Yarn is modeled as a solid element, although in reality the structure of each yarn consists of fibers. The fabric in composite is in a relaxed state without pre-stretching.

Yarn 3D model was obtained, inputting x, y and z coordinates for both yarns after they were approximated by spline functions. Each yarn was simulated as a curved homogeneous elastic rod that creates a base by moving a profile (circle with certain diameter) along a particular spline curve. The model was meshed by eight-node Solid 45 elements.



a

b

Figure 2. Material unit cell komponents: a – yarns in knitted fabric (top view), b – meshed unit cell (isometric view)

And at last, the assembly between the yarns and matrix was created. In the framework of this study it was accepted that between the yarns and matrix there is perfect bonding.

Performing tensile loading simulation, displacements were applied to the boundaries of the unit cell. The boundary condition for the studied laminate unit cell (with the goal to obtain longitudinal elastic modulus) is displacement along axis x direction equal to zero (ux = 0). On the opposite boundary ux=$1 \cdot 10^{-6}$ m. On other sides symmetry boundary condition was applied, boundaries of the unit cell remain flat during the deformation process. The coordinate axis and boundary conditions for longitudinal elastic modulus evaluation are shown in Fig. 2b. The scheme of the deformation process is shown in Fig. 3.

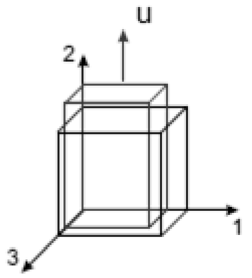


Figure 3. Deformed shape of the material unit cell

When deformed volume condition was achieved, the average value of longitudinal stress component on the stretched sample edge was obtained and the elastic modulus in the stretching direction was calculated. Figure 4 shows the yarn-matrix meshed contact zone.

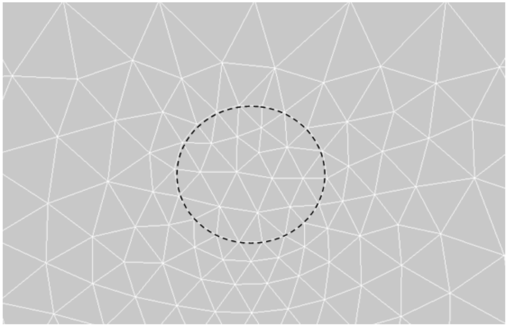


Figure 4. Yarn-matrix meshed contact zone on one of the boundaries

RESULTS AND DISCUSSION

In this paper FE model is used for predicting the elastic modulus of knitted glass fiber fabric reinforced epoxy composites. This methodology allows predicting the preliminary elastic properties of weft knitted fabric-reinforced composites.

The principal elastic modulus (longitudinal and transverse) obtained from the finite element analysis and from the tensile testing according ASTM D 5083-02 (Kononova 2012) in the wale and course directions with respect to the knitted fabric are summarized in Table 1. FE model shows higher modulus especially in the course direction (Fig. 5 and 6).

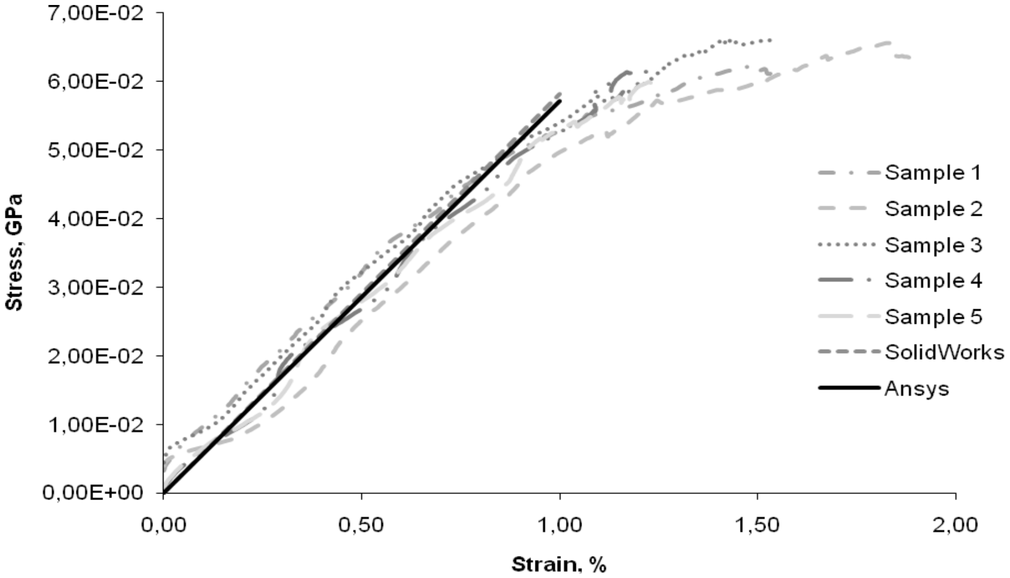


Figure 5. Stress-strain graphs for experimental, SolidWorks and Ansys FEM results for tensile testing in the wale direction

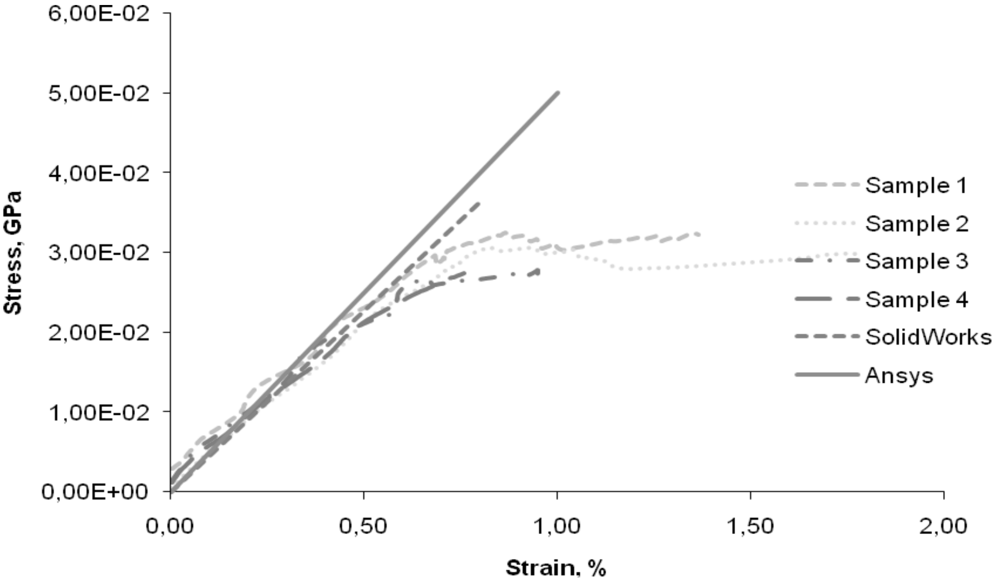


Figure 6. Stress-strain graphs for experimental, SolidWorks and Ansys FEM results for tensile testing in the course direction

Table 1

Comparison of the obtained elastic modulus of plain knitted glass fiber fabric/epoxy composite

Method	Longitudinal modulus E_x, [GPa]	transverse modulus E_z, [GPa]
Experiments	5.46	3.95
Ansys	5.71	5.00
SolidWorks (previous studies)	5.82	4.55

The differences between the experimental and simulation results may be attributed to inhomogeneous microstructure of the real material and the uncertainty on the fabric parameters as the fiber content, orientation and distribution in yarns, contact between composite components and yarns diameter variability, especially in yarn intersection zones.

Both the FE model yarn and matrix materials are considered isotropic, that can be a true assumption for epoxy resin, but unlikely for glass fibers and yarns. Also, there is a difference of load between the FEM simulation and experimental. Deviation between the results from different software can be explained with different mesh size and different solvers.

Efforts are being made to improve the described model and obtain realistic and reliable FEM modeling of this material model. Using the described unit cell FEA predicting the strength properties can be possible. Anisotropic material models can also be analyzed in future work.

CONCLUSIONS

The effective elastic constants (longitudinal and transverse modulus) of plain weft knitted glass fiber fabric reinforced epoxy 4-ply laminate were calculated. The unit cell approach was used; the spatial geometry of yarns were obtained using Leaf-Glaskin model. According used geometrical model yarns central axis projections are assumed composed of circular yarns and cross-sections are circular and constant. In the framework of this study yarns and matrix are perfectly bonded. Unit cell were simulated in FEM software (namely Ansys). Tensile properties in two principal directions were obtained and compared with the previously obtained experimental results. The predicted values show acceptable results comparing with the experimental results and previously obtained results in another FE program. This study shows that mechanical behavior of knitted textiles and its composites can be modeled using universal FEA software packages

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