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A PUNCH TEST AS A SIMPLE VERIFICATION METHOD OF THE FABRIC MATERIAL MODEL

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ABSTRACT

The present paper describes the method of simple verification of the fabric material model. The study concerned the aramid plane weaved fabric, called Twaron T750. The verification process was based on comparison of the numerical and experimental results of the quasistatic punch test. The axial force, recorded during the test, was compared with the one obtained in numerical simulation. The fabric was described by selected constitutive model available in LS-DYNA material database and LS-DYNA implementation of Finite Element Method was used to solve the problem. The fabric material model studied in this paper included the simplified mechanics of yarns and homogenization technique. The conducted analysis demonstrated that the offered method can be applied as the verification or/and calibration of fabric material data.

Keywords: computational mechanics, material model, fabric, punch test.

INTRODUCTION

Every computer simulation of a mechanic issue needs the definition of the particular material properties. It is especially important in case of composite materials as the fabrics. The source of the difficulties in this case is multiscale structure where the individual fibers forming the yarns, which then form a weaved material. Thus, it is reasonable to seek relatively simple experimental test that can be used for verification and/or calibration data describing a specific fabric, and also to assess the suitability of the available formulations of constitutive models describing the fabric. For this purpose, the method and instrumentation adapted proposed in (Xiao, 2005), originally used to analyze the properties of the composite laminate. The cylindrical flat puncher axially loaded the square specimen which was fixed starting from assumed radius. These solutions require the use of certain modifications which were related to the method of fabric fixing and puncher shape, Fig. 1a. During the test the force as a function of axial displacement of the puncher was recorded. A similar parameter was specified for the numerical solution obtained by a computer simulation of this test. Computer simulation was performed using the Finite Element Method (FEM) implemented in the LS-DYNA. The fabric was described by selected constitutive model available in LS-DYNA material database. The fabric material model studied in this paper included the simplified mechanics of yarns and homogenization technique (Rao,2008), Fig. 1b.

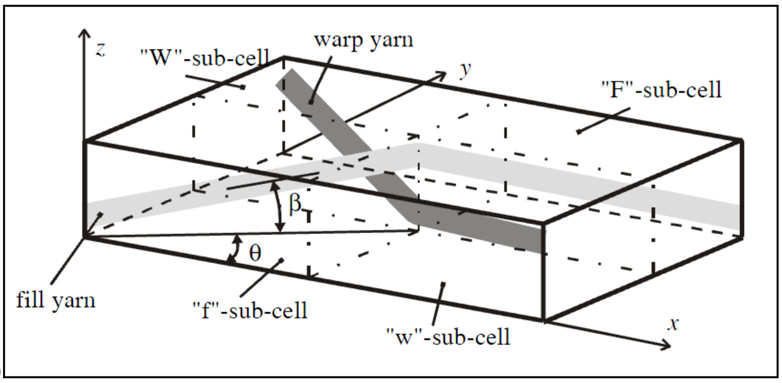
a)  b) 

Fig.1 Experimental and numerical parts: (a) instrumentation prepared to the punch test, (b) RVE (Representative Volume Element) for the material model MAT_235 (LSTC User's Manual, 2010)

The studied material constitutive relation can be expressed by known orthotropic linear relation (2.1-2.3) written for the single yarn. It is the starting point for the homogenization of the global fabric properties according to (Tabiei, 2002). The symbols **ε**, **σ** and **S** applied in equation (2.1) indicate the strains and stresses in vector notation and compliance matrix. Other listed parameters: E_1, E_2, v_{ij}, G_{ij} are Young's modulus in fiber and transverse directions, Poisson's ratios, and shear moduli of the yarn material. The parameter μ, which differs the presented relation from typical orthotropic model, is called as discount factor. It is a function of the braid angle, θ, and responses for the changes of the resistance to shear deformation of the fabric layer, Fig. 2. The last equation (2.3) is the symmetry condition of the compliance matrix.

$$\boldsymbol{\varepsilon} = \mathbf{S}\boldsymbol{\sigma}, \tag{2.1}$$

$$\boldsymbol{\varepsilon} \equiv [\varepsilon_{11} \quad \varepsilon_{22} \quad \varepsilon_{33} \quad 2\varepsilon_{23} \quad 2\varepsilon_{13} \quad 2\varepsilon_{12}]^T,$$

$$\boldsymbol{\sigma} \equiv [\sigma_{11} \quad \sigma_{22} \quad \sigma_{33} \quad \sigma_{23} \quad \sigma_{13} \quad \sigma_{12}]^T,$$

$$\mathbf{S} \equiv \begin{bmatrix} 1/E_1 & -\nu_{21}/E_2 & -\nu_{21}/E_2 & 0 & 0 & 0 \\ -\nu_{12}/E_1 & 1/E_2 & -\nu_{32}/E_2 & 0 & 0 & 0 \\ -\nu_{12}/E_1 & -\nu_{23}/E_2 & 1/E_2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/\mu G_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1/\mu G_{13} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/\mu G_{12} \end{bmatrix}, \tag{2.2}$$

$$\frac{\nu_{ij}}{E_i} = \frac{\nu_{ji}}{E_j}, \tag{2.3}$$

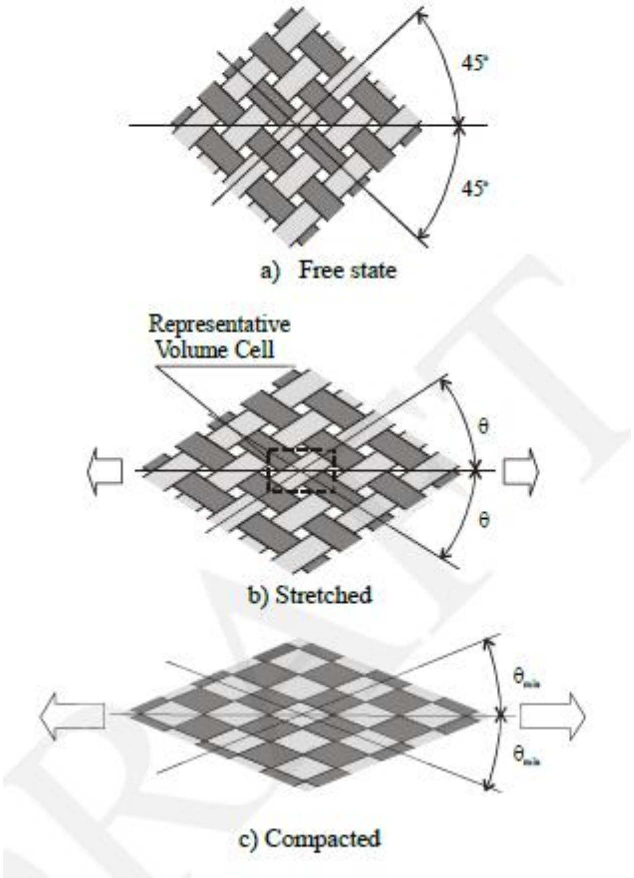


Fig.2 Material MAT_235 model concept (LSTC User's Manual, 2010)

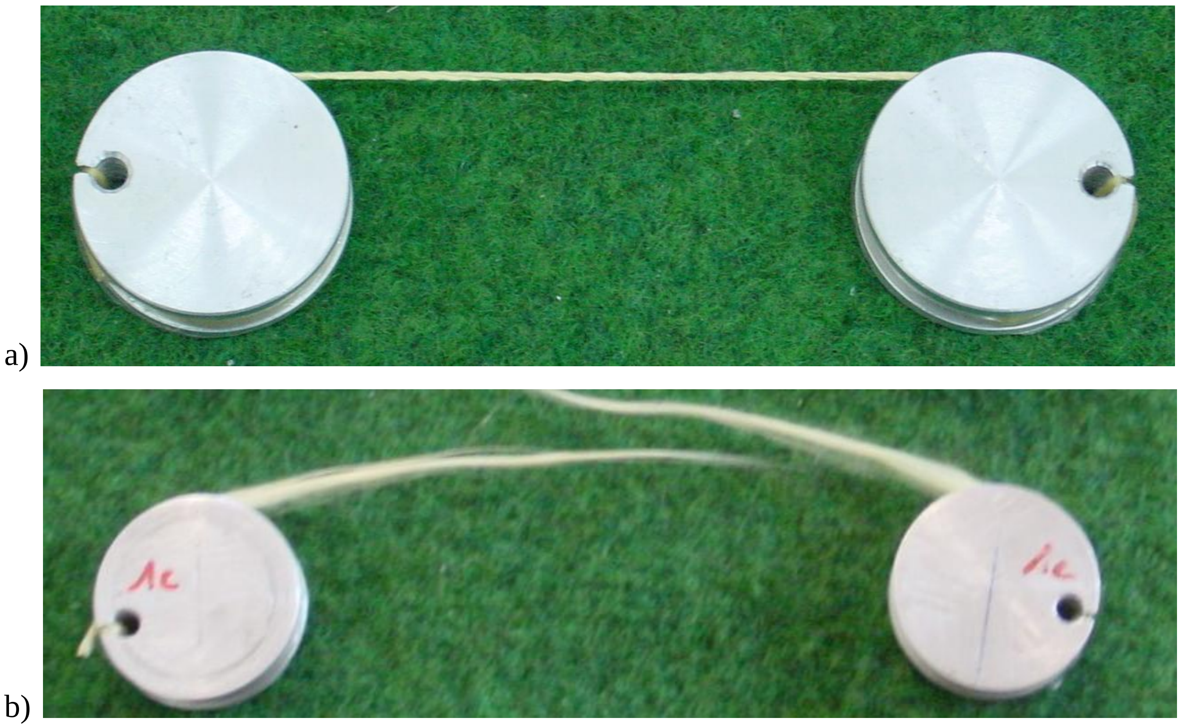


Fig.3 Tension Test of the single yarn of Twaron T750: (a) before test, (b) after test

Table 1 The samples dimensions and results of the yarn tension test

No	The length of the measuring [mm]	Area [mm^2]	Max Force [N]	Max displacement [mm]	Strength [GPa]	Strain at failure [%]	Elastic modulus [GPa]
1	150,3	0,33	517,8	5,3	1,56	3,6	51,0
2	147,4	0,33	550,8	5,3	1,66	3,6	50,5
3	139,5	0,33	495,1	5,0	1,49	3,6	50,5
4	147,0	0,33	518,8	5,4	1,56	3,7	52,3
5	143,0	0,33	559,6	5,3	1,69	3,7	50,6
Average:			**528,4**	**5,3**	**1,59**	**3,6**	**51,0**
Standard deviation:			**26,4**	**0,13**	**0,08**	**0,06**	**0,79**

To establish a set of data for the Twaron T750 needed to apply the described model of micro-mechanic of the fabric a single yarn tension test was performed, according to Fig. 2. The studied yarns were removed from the fabric layer, then its mechanical parameters could differ from nominal data included in manufactures specifications sheets. The loss of the elastic and strength properties is caused by weaving process. The obtained results are presented in Tab. 1.

RESULTS AND CONCLUSIONS

Twaron T750 fabric model was validated by comparison of the simulation results with the experiment. Experimental studies relied on static indentation of the fabric by the spherical puncher, whose diameter was 12.6 mm. Fabric shape sample possessed 200 mm square. Part of the fabric that was the subject of deformation formed 100 mm diameter circle. The rest of the fabric was used to fix the sample. Fig. 4 shows the deformation of the fabric at 21 mm displacement of the puncher. The simulation results of typical non-linearity was observed in deformation of fabric, particularly visible around the indenter, which has been confirmed in experimental studies. Quantitative measure of the agreement of the model with the experiment was a comparison of the vertical force acting on the indenter versus its displacement, Fig. 5. The shape of the reaction force curve in both cases is very similar. The zero reaction force at initial phase of the indenter movement was achieved by using the model taking into account the straightening of the material fibers of the fabric and the change of the angle between them under load.

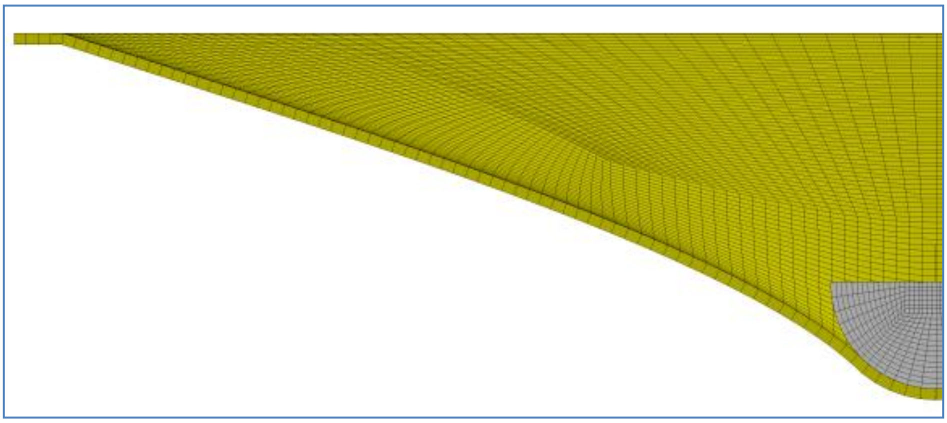
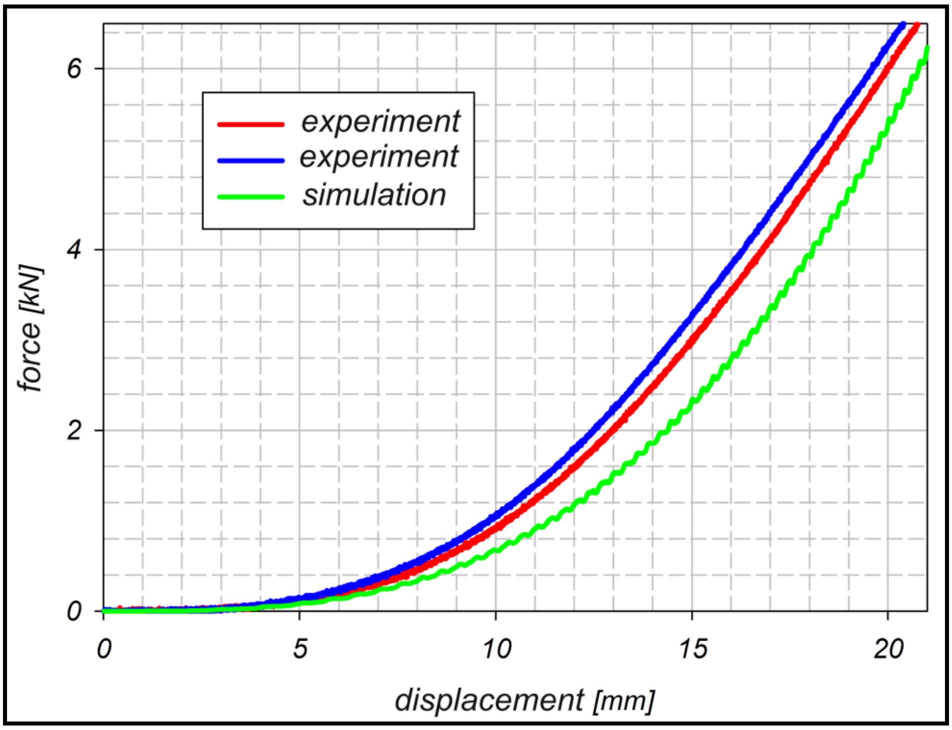


Fig.4 Deformation of T750 fabric layer at indenter displacement of 21 mm



b)

Fig.5 Comparison of the numerical and experimental results, reaction force versus puncher displacement

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