Structural Mechanics for Real Geometry of Basalt Woven Composites

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Abstract: Woven composites with basalt reinforcement plain 1x1 are examined to define structural mechanics. Woven composites were created by the prepreg technology, 8 layers of plain-weave basalt fabrics were saturated by the precursor, polysiloxane matrix Lukosil®, and joint pressed during temperatures of 200°C and 600°C. The yarns consist of 8000 fibres assembled without twisting. Voids complete entire structure. Elementary woven cell was defined from binary images using flim2curve and contour functions of Comsol. This is time consuming process, because it is necessary to define points and subdomain, see Fig. 1. Reorganization of the yarns during composite manufacturing seems to be a very important phenomenon for mechanical behaviour.

Keywords: structural mechanics, real geometry, woven composites, basalt

1. Introduction

Today, woven composites are very favourite and modern material. Their mechanical and thermo-mechanical behaviour there is useful to know. Physical properties could be predicted by Finite Element Method (FEM). Many autors connect modelling of physical properties with modelling of internal structure geometry. Different approach we have in this paper. Experimental observation, based on the geometrical approach, seems to have more advantages, and to be more realistic than other methods. It is necessary to define the textile geometry of meso-mechanical models. From meso-scale point of view, see Fig.1, the system consists of two systems of parallel yarns crossing at right angles. Real internal structuire is obtained from microphotograph as raster format data

It can be considered as the very compliated anisotropy system from the structural point of view. In order to analyse the properties of woven fabric reinforced composites, it is necessary to precisely indentify the yarn paths in the structure and to determine the real structure. Boolean operations and Bezier curves could be use here.

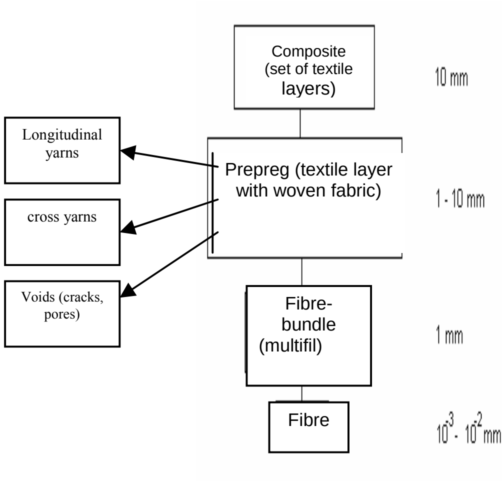

Fig. 1 Structure hierarchy of woven composites

Structural defects are very undesirable in woven fabrics. Their precisely detection is an important step in determining quality. Detection could be carried out in many ways. One of them is Fast Fourier Transform (FFT).

2. Approach description

In this paper, woven composites with basalt reinforcement plain 1x1 are examined to define their structural mechanics. Woven composites were created by the prepreg technology, 8 layers of plain-weave basalt fabrics were saturated by the precursor, polysiloxane matrix Lukosil®, and joint pressed during temperatures of 200°C and 600°C. The yarns are identical in the warp and weft directions and they consist of 8000 fibres assembled without twisting. Voids complete the entire structure. Therefore, the main components of the internal structure consist of longitudinal yarns, cross-section yarns and voids.

Defining the structural mechanics originates from geometrical parameters. These were obtained from microphotographs of cross sections of the real internal structure. The microphotographs were scanned by the method of composed images, taken by the metallurgical microscope Nikon Eclipse ME 600 D, which was connected to CCD camera DS-5M. These were further processed to binary images using the tools of image proccesing toolbox in MATLAB®.

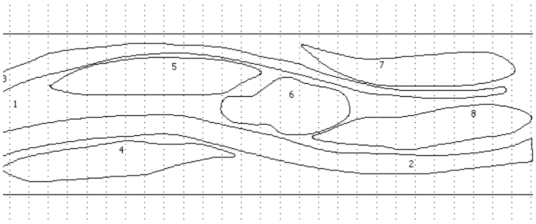

Fig. 2 Elementary woven cell – 1-matrix, 6- voids, 4,5,7,8-cross yarns, 2,3-longitudinal yarns

The multi-scale modelling allows decomposition of complex heterogeneous structure to the partial levels from the simplest composition to the composition of whole sample body. A continuous area is discretized to the countable number of units. It is possible to apply the simulation for a long-term testing and for a detection of critically loaded area. Each element –periodic unit cell (PUC) - is taken as an independent area with some boundary conditions. The PUC is based on the type of reinforcement and on the scale. A stiffness and a compliance tensor describe the PUC with a mean stress and a mean strain in the element of the element of the material. Defects are mentioned here, but only defects between laminas and voids raised during pyrolysis and layering. The experiment is included with a partialy measured data in meso-scale level. Computation is based on the macroscale model and all interior boundaries were activated.

2.1 Theoretical background

Reinforcement. matrix and voids were premised anisotropic. System was defined as plate sheet with free ends in 2D, it was mentioned void imperfection. It was modelled pressure, total displacement, principal stress and strain energy.

Using the best notation, we can write relationship between stress and strain

$$-\nabla \cdot \sigma = \mathbf{F} \tag{2.1.1}$$

where **σ** is the stress tensor

Including temperature, Navier's equation for static conditions is

$$-\nabla \cdot (c\nabla \mathbf{u}) = \mathbf{F} \tag{2.1.2}$$

General form PDE for stationary system is for N = 2 solution components in n = 2 space dimensions with M = 2 constraints:

$$\begin{cases} \nabla \cdot \Gamma_1 = F_1 & \text{in } \Omega \\ \nabla \cdot \Gamma_2 = F_2 & \text{in } \Omega \end{cases} \tag{2.1.3}$$

with the generalized Neumann boundary conditions

$$\begin{cases} -\mathbf{n} \cdot \Gamma_1 = G_1 + \frac{\partial R_1}{\partial u_1}\mu_1 + \frac{\partial R_2}{\partial u_1}\mu_2 & \text{on } \partial\Omega \\ -\mathbf{n} \cdot \Gamma_2 = G_2 + \frac{\partial R_1}{\partial u_2}\mu_1 + \frac{\partial R_2}{\partial u_2}\mu_2 & \text{on } \partial\Omega \end{cases} \tag{2.1.4}$$

and the Dirichlet boundary conditions

$$\begin{cases} 0 = R_1 & \text{on } \partial\Omega \\ 0 = R_2 & \text{on } \partial\Omega \end{cases} \tag{2.1.5}$$

The relationship between the dimensionless and physical pressure and volume forces, respectively, are

$$\begin{cases} p^* = \frac{p}{\rho U^2} \\ \mathbf{F}^* = \mathbf{F}\frac{L}{\rho U^2} \end{cases} \tag{2.1.6}$$

3. Use of COMSOL Multiphysics

Elementary woven cell was defined from binary images using *flim2curve* and *contour* functions of Comsol. Contour inserting of structural elements have to be in parts. Contours of voids were inserted at first, contours of longitudinal yarns were inserted at second, contours of cross yarns were inserted last. It is necessary to keep linear calibration of images. This is a very complicated and time consuming process, during which it is necessary to pay attention to the accuracy of the transfer of the bitmap image to the vector structure. It is also necessary to define the individual points, graphs and subdomain. After inserting real geometry FEM-model can be built, can be define material, boundary conditions and initiate FEM-mesh for computation. Combination of experiment and simulation gives us verified data.

Tab. 1 Application Mode Properties

Property	Value
Default element type	Lagrange - Quadratic
Analysis type	Static linear
Large deformation	Off
Implementation	Principle of virtual work
Specify eigenvalues using	Eigenfrequency
Frame	Reference frame
Weak constraints	Off

Dependent variables: u, v, p, Shape functions: shlag(2,'u'), shlag(2,'v'), shlag(1,'p'), Solver type: Linear system solver

The Structural Mechanical Module was used for computation in Comsol Multiphysics™ 3.2. The Eigenfrequency Analysis was set as application. The structure was defined at first. The properties of components, the boundaries and the external impact have been defined in Physics. The auxiliary constants and equations could be defined in Options. After Meshing and Solving the result graphs have been shown in Postprocessing.

Tab. 2 Advanced

Parameter	Value
Constraint handling method	Elimination
Null-space function	Automatic
Assembly block size	5000
Use Hermitian transpose of constraint matrix	Off
Use complex functions with real input	Off
Type of scaling	Automatic
Manual scaling	
Row equilibration	On
Manual control of reassembly	Off
Load constant	On
Constraint constant	On
Mass constant	On
Damping (mass) constant	On
Jacobian constant	On
Constraint Jacobian constant	On

4. Results

From the results shown on Fig. 3- 9 it is clear there are the most important lengthwise fibre bundles for longitudinal modulus and crosswise fibre bundles for the shear modulus. The results correlate well with a theory. Dangerous loading is going to be predicted.

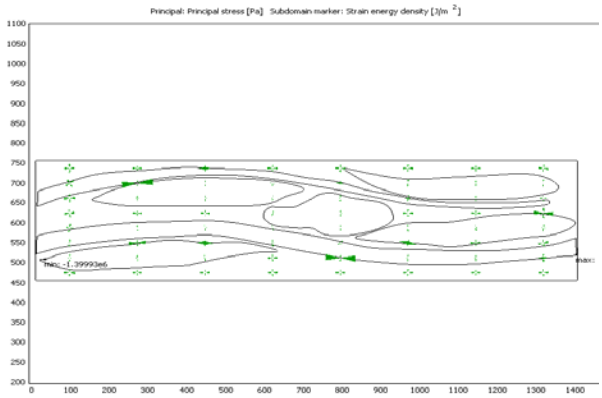

Fig. 3 Elementary woven cell – principal stress [Pa] and strain energy density [J/m^2]

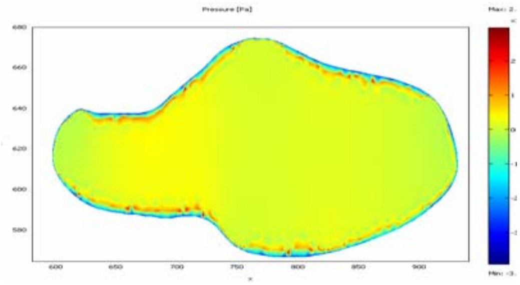

Fig. 4 Voids - Pressure [Pa]

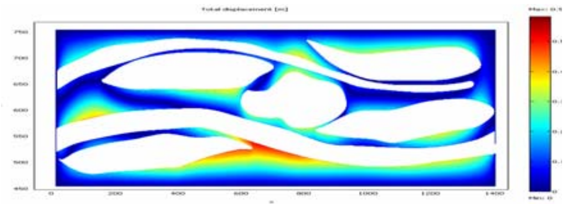

Fig. 5 Matrix – Total displacement [m.10^{-3}]

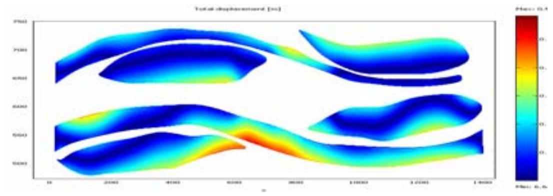

Fig. 6 Reinforcement – Total displacement [m.10^{-3}]

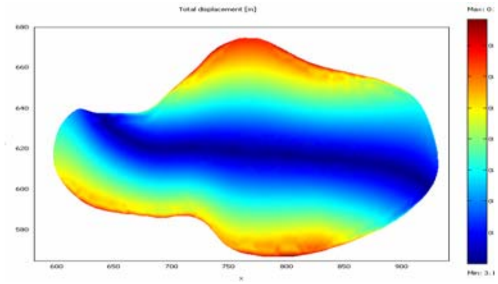

Fig. 8 Voids – Total displacement [m.10^{-3}]

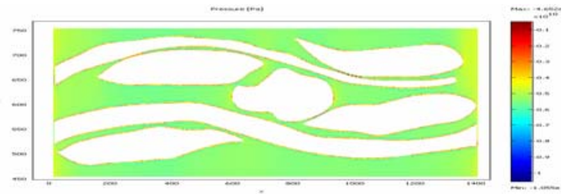

Fig. 7 Matrix – Pressure [Pa]

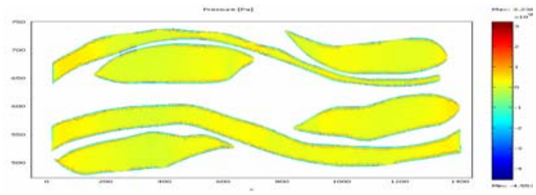

Fig. 9 Reinforcement – Pressure [Pa]

5. Conclusions

The observation of real composite structure is not easy, but it is a very important point of view. Microscopical investigation of real woven internal structure is very forcefull tool for macroscopical modelling and vizualization of woven composites. Reorganization of the yarns and fabrics during composite manufacturing seems to be a very important phenomenon for mechanical behaviour. All this information can be used for more specification of meso-mechanical and micromechanical models and for proposing of optimization algorithm. Further work will focus on the sensibility research of the considered system by using the thermo effect of the composite plate and it is necessary to include defects in the bundles. Non-destructive tests and FEM-calculations of real structure are others possibilities to improvement of investigation in future.

6. Acknowledgements

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7. References

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