COMPUTED PROPERTIES OF WOVEN REINFORCED COMPOSITE MODELS FROM VARIOUS MATERIALS

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Abstract

It was studied woven reinforced composites with textile reinforcement and matrix. Micro-photos of real composites give us inputs for our models and the woven composites prepared by prepreg technology were modeled for elastic properties in FEM. The whole structure of a composite was defined for the 2D multi-scale modeling in the levels and transferred to the 3D where computation was done in the levels and computed through sequences from fibers to composite laminate. Some possibilities of computation are shown in the paper with results of elastic properties for materials carbon/carbon and glass/polysiloxane. The commercial software Comsol MultiphysicsTM was used for calculation with proper determination of the material properties. Results show occurring of elastic modulus in plane of woven reinforced composite in a meso-scale level and whole composite level.

1 Introduction

1.1 Composite testing with simulation

The brittle composites are satisfactory tested with the non-destructive methods. Numerical simulation is widely used one of them. Composites with textile reinforcement have got good resistance against to progression of cracks. Fabric is a bidirectional layer which gives good tensile properties in warp and weft directions. The structure modeling of woven composites is a complex problem. Defects are necessary to insert anyway in higher scales to precise results. Here is irregularly crimped textile reinforcement with various inherent defects (pores, bubbles and cracks) which has risen during pyrolysis process of polymer precursor in matrix. Different shrinkage during cooling plays its role too [1,2].

It is difficult to include all aspects of this complex structure to one model. The idealization is based on geometric models as the bricks or sinusoidal curve of woven reinforcement [3,4]. But results are different from experiments and it is necessary to adapt with experiment [5]. The description of woven interlace is very hard studied nowadays. If we use images of real composite, we should obtain models closer to reality with imperfection rise from lamination and curing. Composite with a plain weave reinforcement structure was studied by image analysis at the Technical University of Liberec.

2 Testing method

A complex structure of the composite has to be adapted for computing. The finite element method is a numerical tool for a simulation process of stress, strain, heat flow and more for physical models. 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 [7]. Tested area is covered with the net of triangles or quadrangles that cover surface without overlapping. Loadings in the sample body are transferred to the equivalent loadings in the net structure. Each element is taken as an independent area with some boundary conditions [6].

Plain stress and vibration analysis were used for testing of our models. Each model was computed as a clamped in the one part. It should be tested for the plain stress-strain loading along the fiber axis. Movement cross to the model axis is zero. We tested models for elastic properties.

A mechanical response of material is detected from various methods. The proof experimental method for obtaining mechanical properties is an evaluation of eigen-frequencies of vibration going through a composite plate [8]. The Lagrange′s theory is valid for the longitudinal oscillation. Theory Euler-Bernoulli is basic for the transversal oscillation and Rayleigh with Timoshenko made corrections of it [9]. We tested our samples for elastic modules and simulated FEM with free ends of models. It was tested at the Department of Structure and Mechanics of Rocks of Science Academy of the Czech Republic.

3. Model

The whole structure of a composite is defined in the levels: matrix and aligned fibers → matrix-fibers part with pores → three types of unit cell raised from observing the real composite microphotographs → laminas for all types of unit cells → whole composite.

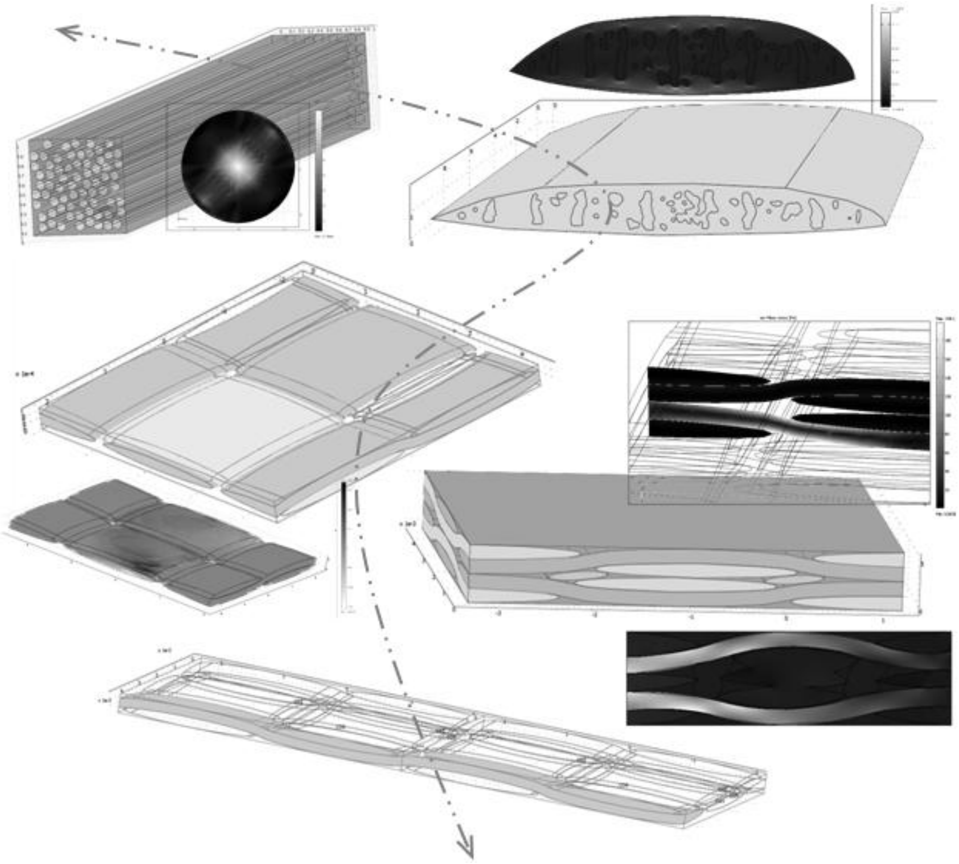

Figure 1. Multi-scale model visualization.

Figure 1 should be used as a description of our model in the stages which we insert in software and compute by FEM and PDE. Basically we start at the level of fibers and matrix. We can compute tensile properties in this stage and use them as input properties in the higher level. This level is whole bundle with imperfections. As we know from theory the most loaded area should be in composite part close to the defects and this critical tension lowered our results in computation too.

Meso-scale is represented by the types of unit cell which we observed in the real structure. We find out three basic lay-outs in position of lengthwise, crosswise bundles and defects all surrounded with matrix. Then we can use these results as a brick lamina combination and set them to the very simple composite brick model. We can make variations for number of laminas which is necessary from the requirements.

We are working on the system of our model where it is possible to compute in levels also from the whole composite body to the lower levels so the advantage would be obvious. We want to compute from average specifications to obtain proper material properties and then simulation can predict us the optimal material components for our composite. Even when we prepare models with different woven reinforcement we can predict the best type of it for defined end usage.

4. Results

Simulated carbon/carbon and glass/polysiloxan material results are in good agreement for 2D and even better for 3D models with the experimental values. Difference between 2D and 3D models are higher than carbon composite for glass/polysiloxan because of difficult interaction of components in the structure and the surface bonds.

Table 1 describes carbon/carbon composite elastic properties in the directions which 3D model offer in one stage and for 2D model we used two different models for one scale in two visualizations when it was necessary for structure difference in plane. Longitudinal modulus for warp [MPa] means axis x at the models in our case, Longitudinal modulus for weft [MPa] is represented by axis z and Transversal modulus [MPa] is axis y.

Scale and type of the tested sample	Longitudinal modulus for warp [MPa]	Transversal modulus [MPa]	Longitudinal modulus for weft [MPa]
2D Unit cell 1	54813 <56332;53294>	408 <419;397>	54813 <56332;53293>
2D Unit cell 2	62375 <64104;60646>	717 <736;697>	62375 <64103;60646>
3D Unit cell 1	38768 <39842;37693>	3056 <3140;2971>	43837 <45052;42621>
3D Unit cell 2	49751 <51130;48372>	3782 <3886;3677>	47816 <49141;46490>
Composite from experiment	103000 <105854;100145>	not measured	108000 <110993;105006>
Whole composite structure from simulation 2D	85968 <88350;83585>	572 <587;556>	85968 <88350;83585>
Whole composite structure from simulation 3D	102283 <105118;99447>	3444 <3539;3348>	105992 <108929;103054>

Table 1. Results of computation carbon/carbon composite multi-scale model

Unit cell results for carbon/carbon differ a bit in longitudinal modulus in warp and weft directions. In the transversal modulus is results even one digit higher in 3D case. We interpret it with the interlacing of the structure. In the basic unit cell is the interlacing in the structure in presence only in case of 3D model of course. So the results should be closer to the reality. Our comparison of experiment and 2D or 3D simulation was quite successful. We predict in our 2D simulation results very close to the experimental results and we found out the symmetry very precise in the fourth-order to the rotation symmetry axis and not only orthoropy because our statistical confidence are coincided together still with sufficient preciseness.
Table 2 shows results of computation in levels for glass/polysiloxan composite. Unit cell was simulated in three times in different thickness according to real composite which was produced this way. Longitudinal modulus is shown here only for simple comparison of results. Multi-scale model was used in two different ways. Simulation was used in all scales for the first time and the consequential simulation was based also on the real results from meso-scale measurement because we have tensile measurement from unit cell level.
When we covered problem with bonds in our 3D model properties insertion for glass/polysiloxan composite, our results in Unit cell became a bit lower that previous calculation though results are more accurate and collate better with proved 2D models.

Scale and type of the tested sample	Longitudinal modulus for warp A sample [MPa]	Longitudinal modulus for warp B sample [MPa]	Longitudinal modulus for warp C sample [MPa]
Simulated Unit cell 2D	24,8 <26,9; 22.6>	22,4 <24,6; 20,2>	35,9 <38,1; 33,7>
Simulated Unit cell 3D	32,1 <34,2; 29,9>	37,2 <39,4; 35,0>	40,3 <42,5; 38,1>
Simulation on all scales 2D whole composite	26,7 <28,9; 24,5>	29,2 <31,4; 27,0>	44,3 <46,5; 42,1>
Simulation on all scales 3D whole composite	32,7 <34,9; 30,5>	34,2 <36,4; 32,0>	55,6 <57,8; 53,4>
Experimental inserted to composite simulation on meso-scale 2D	29,4 <31,6; 27,2>	31,5 <33,7; 29,3>	56,8 <58,9; 54,6>
Experimental inserted to composite simulation on meso-scale 3D	35,6 <37,8; 33,4>	39,5 <41,7; 37,3>	61,9 <64,1; 59,7>

Table 2. Results of computation glass/polysiloxan composite multi-scale model

5. Conclusion

Presented study affords 2D multi-scale model with the good match for the testing of the real composites in-plane of the laminate and even 3D multi-scale model tests also transversal elastic properties in a better numbers. Combination of the multi-scale and the finite element simulation provide relevant data of elastic. If we compare simulated values with experiment when it is possible, we can verify our models and all inputs to construct usable tool for prediction of various properties close to real structure. After more research we are expected to have model in stages possible to compute from maximal level and obtain properties from which will be set the best fibers and matrix. So both levels direction calculation will be good advantage of our model.

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