NUMERICAL SIMULATION AND RESEARCH OF THE SPATIAL DAMAGE FOR THE MULTILAYER COMPOSITE SPECIMENS WITH CONSIDERING OF PROGRESSIVE DAMAGE REALIZED BASED ON MATERIAL STIFFNESS DEGRADATION

I. Voynov
Peter the Great St. Petersburg Polytechnic University, Saint Petersburg, Russia

I. INTRODUCTION

The composite are the widely used materials for different construction design. The main their advantages are the light weight and high strength at tensile and compressing loads, high impact strength and others. Determination of the ultimate load before complete failure is a difficult problem and it is not fully solved for the current time. There are many different mathematical models of the material behavior published and used in practical, but all of them have some restrictions and area of applicability. In the present study the mathematical model of the composite laminate progressive damage is proposed and some tests results are presented.

II. DESCRIPTION OF THE MODEL

The developed model is based on the two stages of damage: initializations and progressive failure. For detection of the initialization moment the Hashin criterion [1] is used. This criterion allows to estimate damage initialization separately for three orthogonal directions of laminate and two type of loading (tension and compression).
At the next stage depends on strain state of the composite layers the relaxation variables $\boldsymbol{\alpha_i}$ for stiffness degradation are calculated using following formula:

$$\boldsymbol{\alpha_i = (1 - \delta_i)\left(1 - e^{-\gamma_i \Delta\varepsilon_i}\right), \;\; i = 1, 2, 3}$$

where δi – coefficient of stiffness degradation, γi – stiffness degradation rate, $\Delta\varepsilon_i$ – failure strain of the material after damage initialization in i direction. In this relation δ и γi are the empirical parameters assigned by user and should be obtained based on experiments.

Coefficients of the stiffness matrix on the each numerical iteration and load step are recalculated in the following way

$$\boldsymbol{C_{ii} = (1 - \alpha_i d_i)\widetilde{C}_{ii}}, \text{ i=1, 2, 3}$$
$$\mathrm{C}_{\boldsymbol{ij}} = \mathrm{C}_{\boldsymbol{ji}} = \boldsymbol{(1 - \alpha_i d_i)(1 - \alpha_j d_j)\widetilde{C}_{ij}}, \text{ i,j=1, 2, 3; i} \neq \text{j.}$$

Here $\boldsymbol{\widetilde{C}_{ij}}$ are coefficients of stiffness matrix in the initial state before damage occurred. Here di is a damage factors. The main advantage of this model is possibility to use different degradation behavior independently for the three direction of composite material during its loading.

III. RESULTS

The described mathematical model has been implemented into the ABAQUS code as user material and some verification and validation tests have been performed. Validation test was carried out for several specimens with different number of layers and different fiber orientations. The first specimen is like to standard brick for the tension test and next one is the plate with central hole. The layup of the both laminates have 32 layers from combination of carbon and glass fibre-reinforced plastics. The geometries of the test specimens are presented at Figure 1.

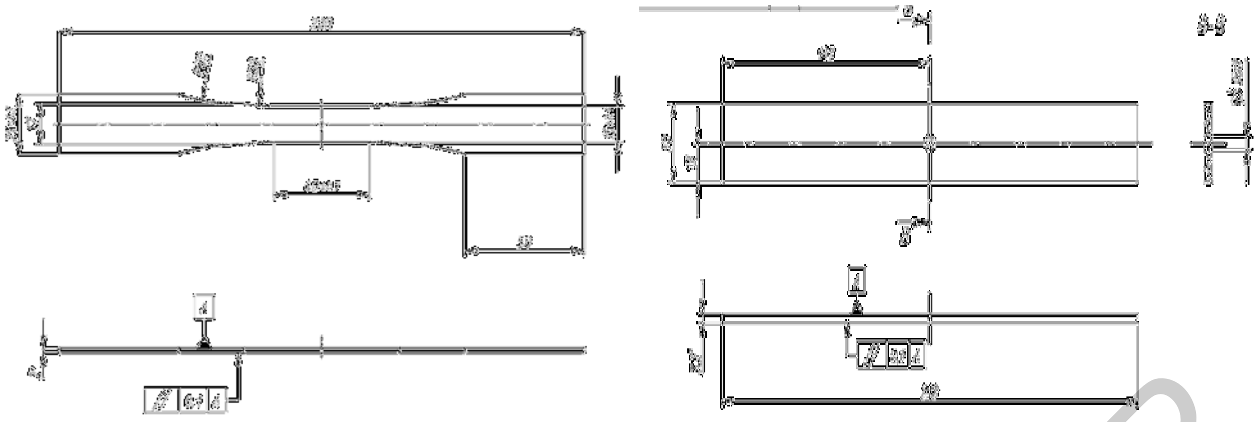

Figure 1 – Geometries of the specimens

To solve the problem of the composite laminate damage and progressive failure the finite element analysis was used. 3D finite element model from the hexahedral elements was generated. All layers were modeled directly using one element on thickness. Different tests for tension and compressions were considered during verification of the progressive damage model.

Results of the failure for two composite specimens under tensile loading are presented at Figure 2. The comparative data between experiment and numerical simulation are listed at Table 1.

Table 1 – Simulation results

	Ultimate load		
	Simulation	Experiment	Ratio
Specimen 1	31350 N	33580 N	6.6%
Specimen 2	20390 N	21760 N	6.3 %

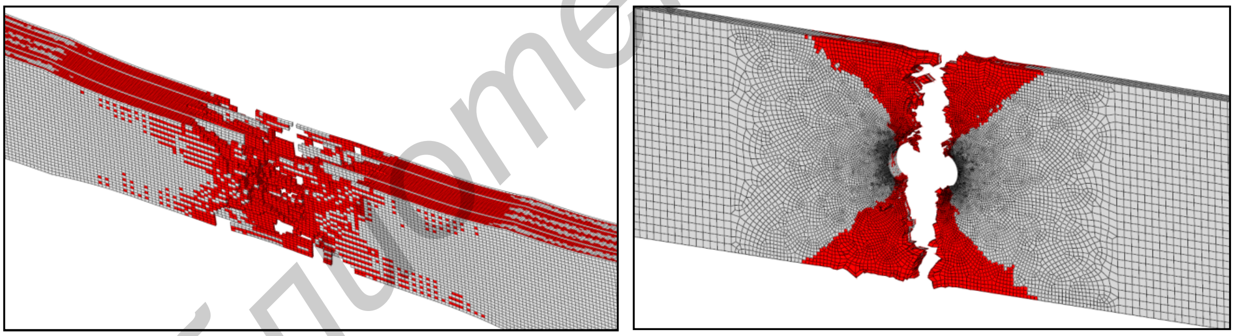

Figure 2 – The state of composite specimens after failure

As it can be seen from the Table 1 a deviation between experiment and numerical prediction are small enough and it’s equal about 6%. This result allows to say that developed and proposed model give a good prediction of an ultimate load as for tensile and compressive loading and can be used for the practical problems.

IV. CONCLUSIONS

The obtained results indicated that the presented mathematical model allows to estimate ultimate load with small error for different type of loads and form of the composite specimens. Nevertheless this model has some shortcomings. It cannot simulate delamination effect and the results are depended on element size and integration step. Moreover this model requires many mechanics properties which usually are unknown.

REFERENCES

[1] Hashin Z. Failure Criteria for Unidirectional Fiber Composites. Journal of Applied Mechanics 1980;47:329-34.