FINITE NUMERICAL ANALYSIS OF COMPOSITE STRUCTURE UNDER COMPLEX LOADING CONDITIONS - OPTIMAL PLY DESIGN OF LAMINATE

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Abstract

The paper presents FEA numerical analysis of composite structure subjected to complex loading conditions (tension and shear). The layered structures were characterized from the standpoint of optimal selection and strength parameters. The subject of the examinations was a composite: glass fibres reinforced polymers-M12/26%/TVR380R-glass prepreg system (Hexcel, R-glass fibres-undirectional, M12 epoxy resin). The composite system is use in helicopter blades. It exhibits good fatigue life and hot/wet performances up to 100°C. The strength properties were investigated according to ISO and ASTM standards. The composites for the study were produced by autoclave technique. The Layup-Ply method with ABAQUS/Standard program was applied as an analysis tool which was carried out the leading of calculation. It was used an incremental iterative Newton-Raphson's method in a range of nonlinear geometric. Numerical calculation was made as a part of introduction to failure analysis composite materials. The risk of laminate's damage could be estimated as a possible appearing in dangerous points of construction. There were taken four criteria: the Maximum Stress Criterion, Tsai-Hill's Criterion, tensor criterion of Tsai-Wu and Azzi-Tsai-Hill's criterion.

Keywords: finite element analysis, laminates, strength of composite structures, composites damage, composites optimization

1. Introduction

Polymer Matrix Composites (PMCs) are actually advanced engineering materials having wide range of applications in aerospace. The PMCs can be characterised by superior physicochemical and mechanical properties particularly higher strength to weight ratio [5, 8]. Among these materials, glass, carbon and kevlar fibres reinforced epoxy matrix composites are one of the materials deserving special attention. Moreover, the high level advanced manufacturing technology of polymer composites (autoclave technology) is permitted to application these materials in aviation as a primary (the elements of critic's character) and secondary structure [6].

An optimization of a composite structure is a fundamental meaning in a process of creating composite materials and it depends on exploitation loading conditions. In this range numerical analysis are a modern tool basic on useful method which is named FEA (Finite Element Analysis) [1-4, 9, 11].

In this paper was presented the numerical analysis FEA an optimal selection in terms of strength parameters. A configuration of plate was subjected to a complex loading conditions-tension and shearing. The aim in leading calculations was labelled as an influence of fibres configuration on different layers in laminate and properties in strength composite structure.

2. Material

The subject of the examinations was glass/epoxy composite-M12/26%/TVR380R prepreg system (Hexcel, R-glass fibres-unidirectional tape, M12 epoxy resin). The fibre volume content was about 60%.

M12/26%/TVR380R-glass system is a good performance, self extinguishing, tough epoxy matrix for use in helicopter blades. It exhibits good fatigue life and hot/wet performances up to 100°C.

The strength properties were investigated according to ISO and ASTM standards. The composites for the study were produced by autoclave technique. A process of optimization was carried out for 8 layers configuration in structure, which was made in shape of composite plate on 600x600mm overall dimensions. The nominal ply thickness was 0.25 mm after curing. Selected mechanical properties of composite used in numerical analysis are listed in Table 1.

Tab. 1. Selected mechanical properties of M12/26%/TVR380R-glass composite

Tensile strength F_{TU} [MPa]		Tensile modulus E_T [GPa]		Poisson's ratio ν		In-plane shear strength F_{SU} [MPa]	In-plane shear modulus [GPa]	Compression strength F_{CU} [MPa]	Compression modulus E_{CU} [MPa]
0°	90°	0°	90°	0°	90°	±45°	±45°	0°	0°
1534	74.5	46.43	14.92	0.269	0.0896	57.55	5.233	1046.3	2133.7

3. Numerical analysis

3.1. Range of carried out numerical analysis

Numerical calculations in a model of composite plate were run by using a technology of modelling laminates available in Abaqus/Standard programme. It was under complex loading conditions. The aim in leading calculations was defined as an optimal configuration in glass/epoxy layer laminate. The laminate was performed to square plate and under tension and shearing load in aspect to guarantee the best strength parameters in composite structure.

The numerical calculations were introduction to failure analysis in the composite materials. A zone was depended on estimation in numerical model of appearance direction, where there was a risk of failure laminate under an external load. Preceding analysis was based on universal in the scientific literature strength criterions of the composite materials. In carried out researches a stress criterion was used to estimate degrees of effort in composite. A criterion of maximum stresses, Tsai-Hill's criterion, tensor Tsai-Wu's criterion and Azzi-Tsai-Hill's criterion were a basic to specify the strength in studying composite structure [7, 10-12]. The studies were made until achieving a moment, where a boundary of strength composite was got and then it was supported by one of mentioned criterions. The analysis was also a geometric non-linear question using an incremental-iterative of Newton-Raphson's method.

3.2. Descrete model of FEA

A descrete model of composite plate which was performed in Layup-Ply layer configuration was created on the basis of 4 shells kinematic pairs a type Shell-S4. They had got 6 degrees of freedom at all of the kinematic pairs. The optimum selection at an angle of strength parameters for

layer configuration in this composite structure was 6 configurations composed fibres in relation to the edge of plate. The following configurations was taken: a quasi-isotropic $[0/90/\pm45]_S$, $[0]_8$, $[90]_8$, $[\pm45]_{2S}$, $[0/+45/2]_S$, $[0/90]_{2S}$. A general view on the numerical model with layer configuration by the quasi-isotropic properties was illustrated on a Fig. 1.
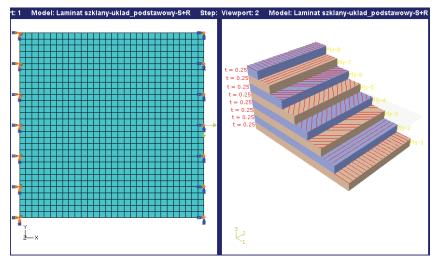

Fig. 1. Discrete numerical model of composite plate for quasi-isotropic system

A boundary condition in numerical model was realised through fasten left vertical edge of plate and blocked kinematic pairs of all degrees of freedom. Additionally of them which were on the right edge of plate were locking a translation degree of freedom in perpendicular to surface plate-direction Z axis and rotationally degrees of freedom which were blocked a rotate of respecting X and Y axis co-ordinate system from the model-Fig. 1.

A structure of plate was carried out to complex loading conditions where a component was tension and shearing load. Both of them in the numerical model was realised through applying the concentrated forces to a reference point. This point was in a half of vertical edge of plate and it was ensured tension (direction X axis) and shearing (direction Y axis). Applying the load to the reference point was steadily distributed at a uniform rate for the kinematic pair's right edge of plate and used to kinematic relations to the reference point with kinematic pairs in this edge.

3.3. Material properties for FEA

An elastic model of the *Lamina* material was used to modelling properties of composite structure. It was made possible for describing material properties and it was connected with fibres configuration in defining direction [1, 2]. For applying model of this material was required to define a value of Young's modulus on fibres direction i.e. 0º and 90º direction, Poisson's ratio as well as a value of Kirchoff's modulus for 3 perpendicular directions linking with fibres configuration. A range of numerical calculations was also included a test of possibility to estimate an appearance failure in composite structure under influencing external load. Carrying out this analysis was demanded to define parameters in the material. It was connected with designating properties of composite for different directions: F_{TU}-strength for tension in 0º and 90º fibres direction, F_{CU}-strength for compression in 0º and 90º and F_{SU}-strength for shearing in a configuration plane $[\pm45]$. These properties were marked in the experimental researches.

4. Results of numerical analysis

In the inspecting composite structure was given a possibility to estimate state of strain and effort through taking the numerical calculations. The analysis of results was observed at the

problem from an angle to specify an optimum configuration layers in the composite. The best strength properties in construction were guaranteed where the tension and shearing load was activated. The analysis of degree effort of material as was the plate , was moved in this aim for different configuration of layers in composite. It was based on the acceptable strength criterions in the composite i.e. maximum stress criterion, Tsai-Hill's criterion, Tsai-Wu's and Azzi-Tsai-Hill's criterions. The analysis of strength in composite was labelled for a properly level in kind of stresses in the material and made a comparison to strength material given load thanks to applying criterions. Calculations were run until the moment when the strength limit of the material was obtained what was symbolized reaching a value 1 (proportion given a value of stress to a properly value of strength limit of the material) according to one of taking criterions. In all of cases the basic criterion was Tsai-Wu's tensor failure criterion, where in the material was obtained the quickest value of limit stresses meaning a failure of composite. On the Fig. 2 was represented as an example maps of effort of composite plate in configuration where layers were packed like this $[0]_8$ for all acceptance in calculations strength criterions in composite materials.
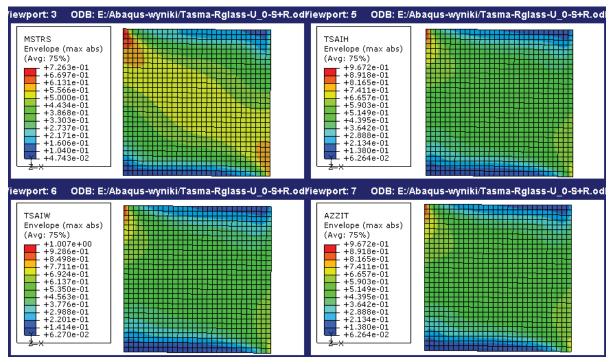

Fig. 2. *The composite effort of $[0]_8$ system in all layers: (a) the Maximum Stress Criterion, (b) Tsai-Hill's criterion, (c) Tsai-Wu criterion, (d) Azzi-Tsai-Hill's criterion*

A mark of strength parameters in composite structure was possible thanks to receiving effects from numerical calculations and it was depended on fibres configuration at an individual plate layers. For the optimum configuration layers in selection was achieved with the aid of the value of permissible load where the stresses value in material were maximum according to strength criterion.

5. Conclusions

The best under the strength aspect was the configuration layers in composite where it was $[0]_8$ configuration. It was thanks to numerical analysis in acceptance of simultaneous tension and shearing load. It was the highest value of external load, whereas the lowest values were referred to $[\pm 45]_{2S}$ the configuration layers. In spite of the fact that the shearing load was not appearing an optimum solution in case of complex loading conditions where this configuration in practice was applied. A leading load plate in this case was tension fibres in material, what in analysis

was confirmed, the best properties were of composite for this $[0]_8$ layers configuration. In researches the dominant character for reasons tension stresses on the fibres, the edges of plate were demanded to stiffening. It could be possible for different kinds of profiles or introducing boundary condition for example a reinforced rib. It was a very essential meaning especially for possibility buckling skin elements. Producing a change in this case a tangent load to the edge of plate could be a main criterion. It could decide about permissible value external load.

The analysis which was carried out, confirmed a possibility of applying FEA to analysis and optimization of strength parameters in composite structures. An identification of failure mechanism in composite was demanding additional on the experimental researches in order to allowing for calculations. It was aimed at determining strength properties in material for individual direction. Formulating adequate numerical models were possible to give the optimization in the composite structure for beginning stage of designing.

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