DESIGN AND SIMULATION OF ADDITIVE MANUFACTURED STRUCTURES OF THREE-COMPONENT COMPOSITE MATERIAL

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I. INTRODUCTION

A main tendency in the modern technology era is the transition from using of traditional materials in the industry to using advanced materials with pre-defined properties such as composite materials. Nowadays, composite materials based on carbon fibers and polymer matrices are widely used in rocket-space and aviation engineering. The structures made of such materials have high strength and low mass. One of the modern approaches to creating composite materials is 3D printing or additive technologies. This manufacturing method allows to obtain composite structures almost any shape using different materials of binders and reinforcing fibers. The use of thermoplastic and thermosetting binders at the same time makes it possible to achieve good adhesion of the components while maintaining the inherent elasticity of the thermoplastics and maintainability of the material.

The production of such a three-component material is carried out in two stages. At the first stage, the carbon fibers is impregnated with a thermosetting binder and completely cured, at the second stage the resulting microplastic is coated with a melt of a thermoplastic binder in the process of 3D printing. When manufacturing composite products using the described technology, a certain spread of parameters inevitably arises in their microstructure and defects are also formed.

The studying and simulation of the mesostructures and microstructures of a three-component composite material obtained by the 3D printing method, as well as the studying the effect of a possible variation of the microstructure parameters on the mechanical characteristics of the material were described earlier in [1].

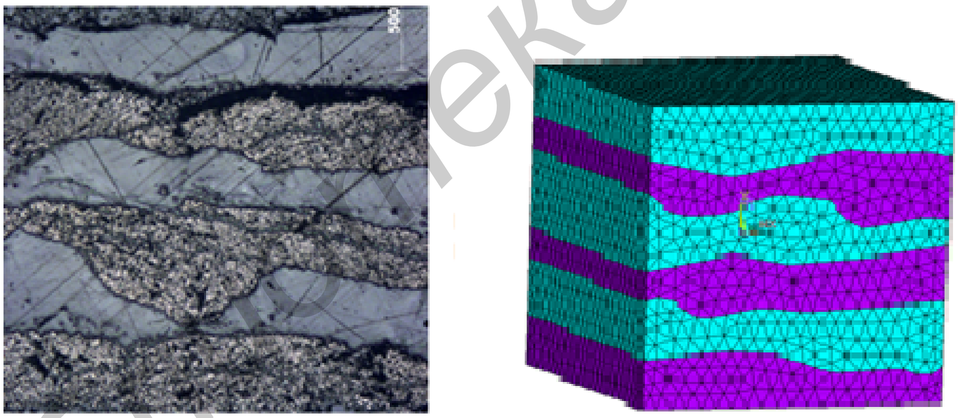

Figure 1 – Mesostructure of a three-component material and FE model

Figure 1 shows an example of mesostructure of real-scale sample manufactured by 3D printer [2] and FE models of that mesostructure we were using to simulate the behavior of composite material. The developed technique of calculation of three-component composite materials allows to model large-sized structures of any configuration.

II. OPTIMIZATION OF LATTICE STRUCTURES

Lattice structures have now become widespread in many areas. Their obvious advantages are the light weight and significant cost savings of the material. Application of unidirectional composite materials allows to preserve the exceptional strength properties of composites in the construction regardless of the loading direction. Therefore, lattice composite structures are now actively used in the aerospace industry.

The goal of this work is the study of the change of properties of lattice structures from three-component composite materials depending on their parameters, as well as the determination of the optimal configurations of these structures. In the process of work the software of finite element analysis ANSYS and the software for solving the tasks of criterion and multi-criteria optimization modeFRONTIER were used.

As an example of lattice structure we considered construction of plate type. The sample of the element of lattice structure has the overall dimensions (200 ± 5) · (200 ± 5) · (22 ± 1) mm. A sample of a large-sized lattice structure should have the overall dimensions (1400 ± 5) · (1400 ± 5) · (22 ± 1) mm. Variants of the initial configuration of the plate are shown in Figure 2.

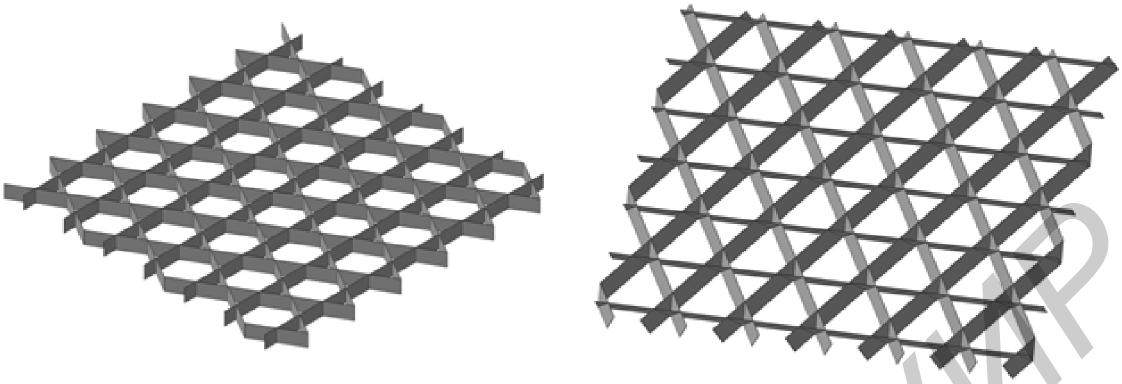

Figure 2 – Variants of the initial configuration of the plate

The following set of optimization parameters is assumed: number of inclined ribs, number of horizontal/vertical ribs, angle of inclination of the ribs to the horizontal axis in the plane of the plate, angle of inclination of the diagonal ribs to the vertical axis perpendicular to the plate. The solution of the problem is considered in a 2-criterion formulation. The target functions are: weight of the structure, maximum deflection. Before performing parametric optimization the effect of each optimization parameter on the target functions was investigated to study the possibility of limiting the parameters and the range of their variation. As a result of the study, it was determined that with a change in the angle of inclination of the ribs to the plane of the plate and with the addition of additional straight ribs, it is possible to obtain a deflection much less than in the initial configuration. Also, obviously, the deflection can be reduced by simply increasing the number of diagonal ribs in the structure. The most efficient configuration is with two straight ribs passing through the center of the plate. Figure 3 shows the dependence of the deflection of the plate on the angle of slope of the edges with a constant mass of the plate.

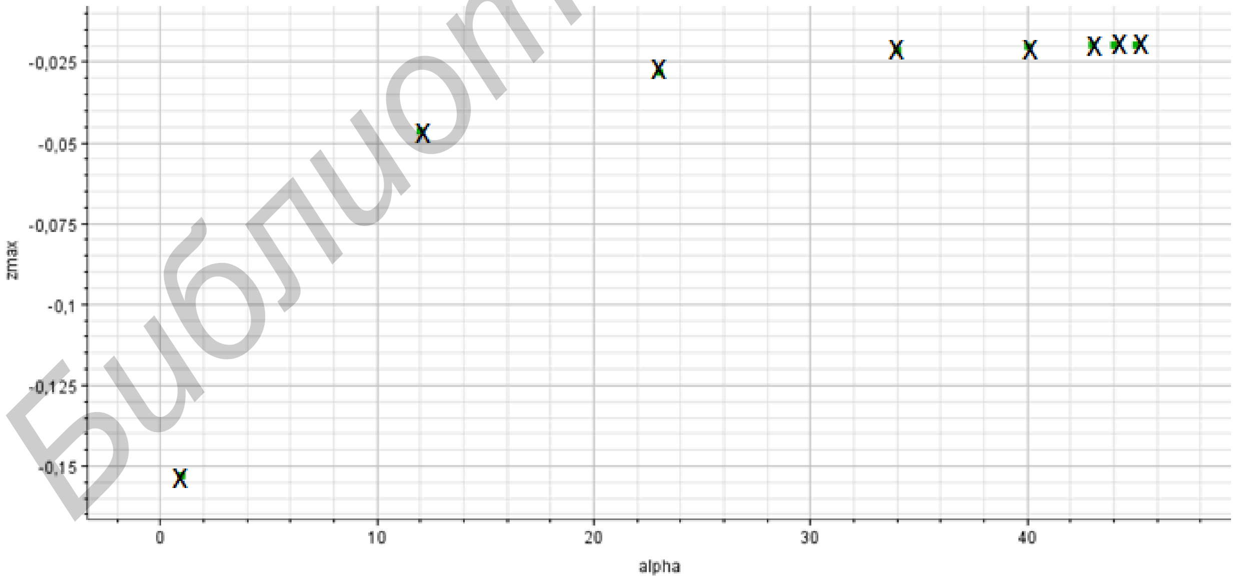

Figure 3 – The dependence of the deflection of the plate on the angle of inclination of the edges to the Ox axis

The solution of the parametric optimization problem is performed in the software modeFRONTIER. The geometrical model of the plate obtained during the optimization does not meet the technical requirements of the developed 3D printer. Therefore, an alternative version of the plate was designed to meet these requirements (Figure 4).

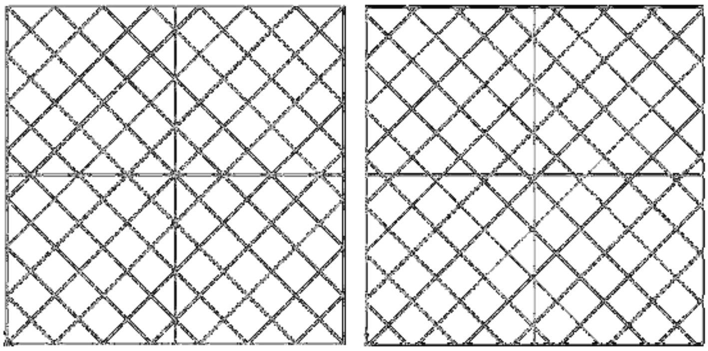

Figure 4 – Optimal and technologically-implemented plate configuration

II. FULL-SCALE EXPERIMENT

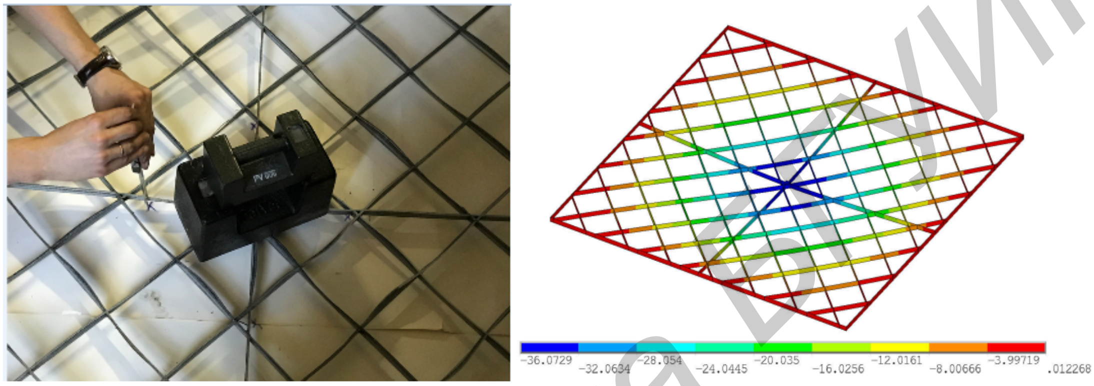

Figure 5 – Full-scale test and virtual test of plate

Virtual tests of the plate manufactured by 3D printing method is provided by the procedure of two-level submodelling described in [1] and correspond to full-scale tests carried out by the Testing Center «Polytechtest». Developed geometric and finite element models for the testing of plate correspond to full-scale plate, taking into account the identified defects. Figure 5 shows the manufactured plate and results of virtual tests. The values of the displacement are reasonably close and are 35.5mm in case of full-scale test and 36 mm in case of virtual test.

III. CONCLUSIONS

Within the framework of the study, parametric optimization of the lattice structure plate type was carried out. The dependences of the deflection and the first natural frequency on the mass of the plate are obtained, and a set of solutions optimal for the given criteria is determined.

It was found that the minimum deflection is achieved at an angle of inclination of the ribs 45^0 at a constant mass. The variation of the angle of inclination of the ribs to the plane of the plate is considered to be irrational.

Based on the results of solving the problem of parametric optimization, it is determined, from among the quasi-optimal realizations, a variant is selected with the maximum allowable deflection.

On the basis of multiscale simulations, an optimal configuration of the plate was designed and manufactured by 3D printer. The real-scale test results differ from the virtual nonlinear solution by 1%.

The plate carried out the load – after the load was removed, it returned to its original configuration.

ACKNOWLEGMENTS

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