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# Investigation of elastic deformations of cured CFRP structures with embedded cellular metallic elements subjected to a microwave electromagnetic field

I V Zlobina

Yuri Gagarin State Technical University of Saratov, 77 Politechnicheskaya street,  
Saratov, 410054, Russia

E-mail: Irinka\_7\_@mail.ru

**Abstract.** Based on the analysis of trends in the development of aviation equipment for various purposes, the expansion of the use in its bearing structures of polymer composite materials, reinforced with carbon fibres with a combined structure containing distributed in the volume of metal honeycomb fillers is shown. This increases the anisotropy of the physical and mechanical properties of such structures of different chemical composition and properties of materials, which makes it difficult to manoeuvre the aircraft due to the different stability of metals and composites to multidirectional dynamic bending and shear loads. It is stated that the problem of increasing the strength characteristics of PCM can be solved by their quasi-structuring in the microwave electromagnetic field, but the influence of this factor on complex structures containing metal regular elements needs further study. Experimental studies of the effect of short-term exposure to microwave electromagnetic field with a frequency of 2450 MHz on the modulus of material elasticity, which is a structure of two plates of carbon fibre with aluminium cellular elements located between them. It was found that compared with the control samples, the samples exposed to microwave electromagnetic field have an increased modulus of elasticity by 31.8%. Limit shear stresses also increase by 29%. Thus, the treatment of formed and cured polymer composite materials with built-in cellular metal structures in the microwave electromagnetic field is possible and allows to perform hardening quasi-structuring of such products and increase their performance parameters.

## 1. Introduction

Structural elements of aviation equipment for various purposes, in particular, unmanned and remotely piloted aircraft, have recently been made of polymer composite materials (PCM) such as carbon fiberglass and fiberglass plastics, as well as organoplastics, consisting of a polymer matrix and a reinforcing structure of fibres of various nature. In bearing structures of aircraft, carbon plastics are most widely used due to their high strength characteristics, heat and moisture resistance. According to the data of analytical reviews and scientific publications, the volume of the world market of carbon plastics will reach 23.55 billion dollars by 2022 [1-2]. At the same time, polymer composite materials reinforced with fibres are characterized by low flexural strength and interlayer shear, determined by the type and orientation of the reinforcing components [3-4], which makes it necessary to strengthen the structure in dangerous areas [5-6], but at the same time to weight gain. Known methods for improving the performance of products from PCM, in particular - strength, consisting in the use of



high-quality fibres, the use of new binder compositions (matrix), the improvement of the technologies of formation and curing of compositions [7], do not take into account the influence of technological heredity of post-processing operations on the final characteristics of the finished products. The introduction of new methods of forming the structure, changing the existing technologies for the preparation of fibres, prepregs, calculations of compositions, etc. are associated with large costs caused by restructuring of established technologies and re-equipment of production.

For these reasons, it is important to find alternative methods for improving the quality of products from PCM without serious interference with streamlined technological processes.

## **2. Problem statement**

To increase the strength of PCM products and increase the uniformity of its values in various parts of the structure, it is advisable to use the methods of short-term exposure to the microwave electromagnetic field as a modifying finishing operation.

Analysis of materials of domestic and foreign scientific publications [8-10] shows that the greatest attention in the development of research in the field of microwave processing of dielectric materials is paid to the use of microwave heating technologies to replace the existing technology of heat treatment of compositions at the stage of their formation and curing, which does not eliminate the negative impact on the internal stresses arising in the process of dimensional processing and assembly of products. Mathematical modelling of the interaction processes of the microwave electromagnetic field with dielectrics and their compositions, as well as the study of the structure, also concerned mainly materials prior to their curing with the microwave effect on the formed composition in a viscous-fluid state or on the original fibres [11-12], which did not take into account changes structure in the subsequent stages of the manufacturing process products.

Previously, we obtained positive results on increasing the strength characteristics of finally hardened fibre-reinforced composite materials that were exposed to a microwave electromagnetic field of an average power level within 1-3 minutes [13-15]. At the same time, internal stresses arising at the moment of material destruction as applied to static loading conditions were studied. The issues of deformation of materials without bringing them to the limit loads were not considered. At the same time, the question of elastic deformation of power structures and plating is important for ensuring the durability of the object and its operation under dynamic loading conditions.

In modern and future aviation, the main volume of bearing elements has a complex structure consisting of external and internal panels made of PCM (for example, carbon fibre) with cellular elements located in between aluminium or other lightweight and durable alloy. Metals and their alloys are good reflectors of super high-frequency waves, including the frequency range used for technological purposes, which suggests some difficulties in the implementation of the technological method developed by us for strengthening the modifying hardened PCM in the microwave electromagnetic field due to the assumed shielding effect of cellular aggregates. The question of increasing the strength of PCM with integrated cellular structures remains open.

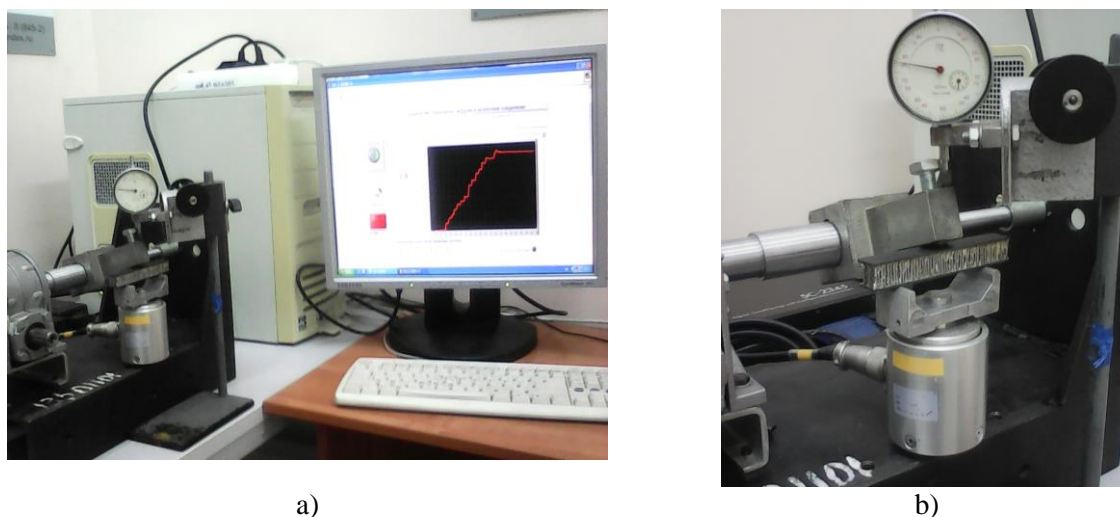
The purpose of the research was to study the effect of processing carbon plastics with embedded cellular metal elements for their resistance to bending deformations in the microwave electromagnetic field.

## **3. Research methods and equipment**

The aim of the experiments was to study the samples representing plates made of a cured composite reinforced with carbon fibre of the VKU type with cellular elements of aluminium alloy located between them. The length of the samples was 117.0 mm, width and height, respectively, 15.5 and 15.0 mm. The thickness of PCM plates was 1.5 mm, the thickness of the walls of cellular elements was 0.3 mm. The experiments were carried out using special microwave "Zhuk-2-02" installation (LLC "AgroEkoTekh", Obninsk, Kaluga region) with a horn-type radiator. The installation was upgraded by placing in the working area of a three-coordinate subject table for fixing and a fixed change in the position of the samples relative to the radiating horn. The frequency of the electromagnetic field was

2450 MHz, the magnetron power was 1200 watts. The distance from the plane of aperture of the horn to the outer surface of the sample was 200 mm, which ensured an energy flux density of  $(17-18) \times 10^4 \mu\text{W} / \text{cm}^2$  in the working area. The exposure time of the microwave electromagnetic field was 1 minute, taking into account the small thickness of the PCM plates in order to avoid their overheating. The levels of microwave radiation reflected from the surface of the samples and transmitted through the sample were estimated from the energy flux density using an electronic P3-33M instrument with an exposure of 1 minute. In the process of measurements, the antenna of the device was installed on a tripod at the level of the axis of the radiating horn in the front and rear zone at a distance of 2 m from the opening plane.

Samples were tested on a computer laboratory stand with LabWiev software (Orel). The stand is equipped with strain gauges and a worm loading mechanism. The specimen was loaded perpendicular to the plane of the PCM plates with a step of 0.01 mm to achieve a total strain of 0.2 mm. The magnitude of the loading force at each step was read from the monitor screen of the installation, the strain value was determined from the readings of a dial gauge with a scale value of 0.01 mm. The modulus of elasticity and the value of stresses were calculated on the basis of the experimental data obtained from the known dependencies of the mechanics of composite materials. One of the test moments is presented in figure 1.

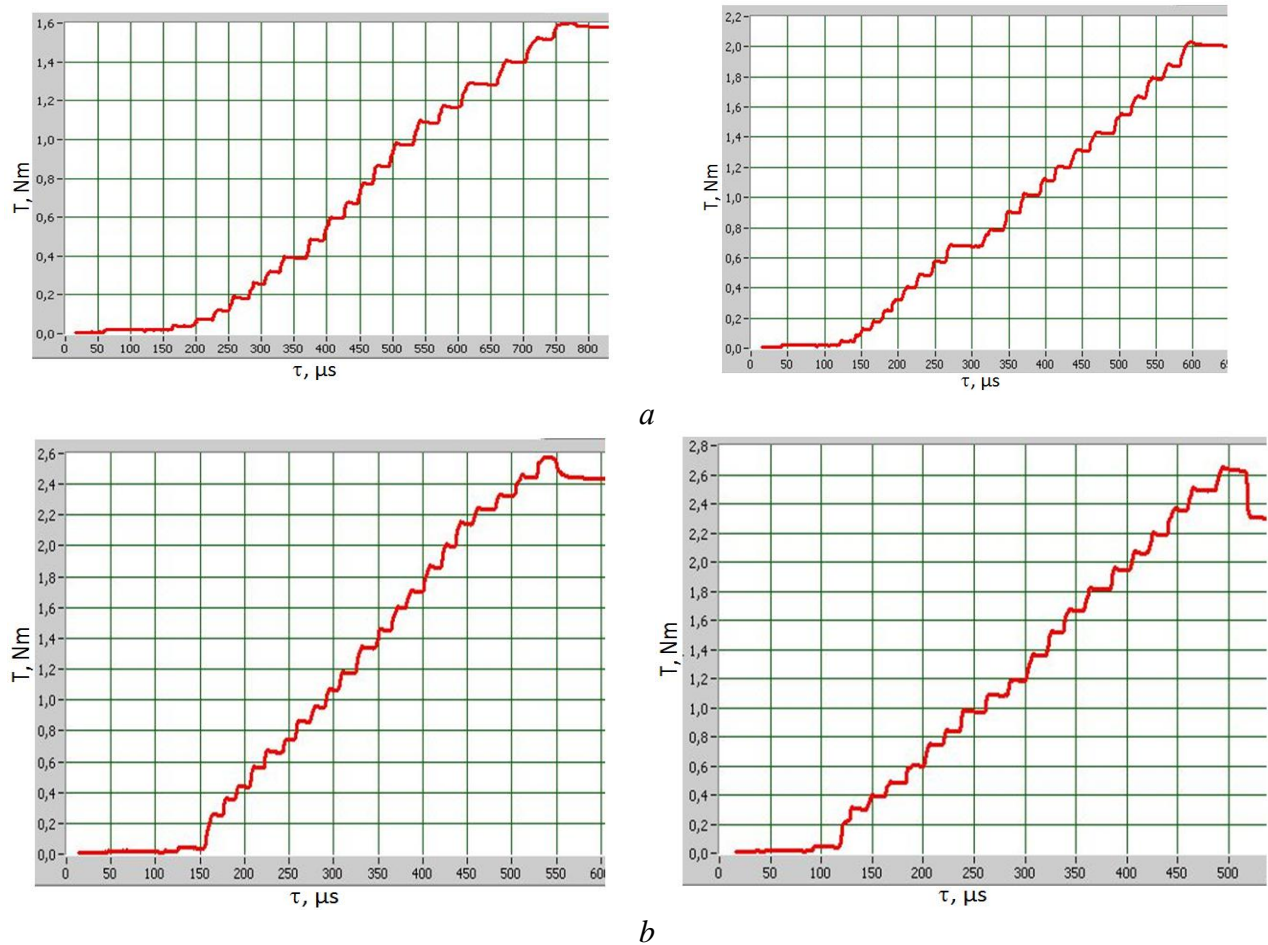


**Figure 1.** Laboratory installation at the time of testing (a), the sample in the working area of the installation at the time of loading (b).

#### 4. Results and discussion

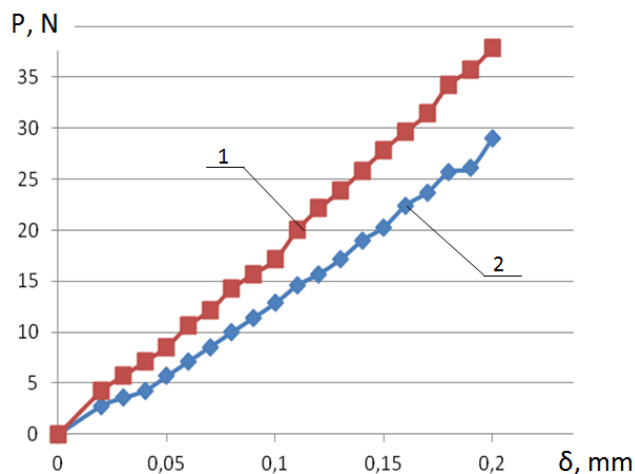
Comparing the density of the reflected flux of energy of the microwave electromagnetic field, it has been established that for hardened CFRP carbon fibre its share is 9.9%. Less than 1% of the microwave energy flow is reflected from the structure with the honeycomb element located between the two plates of the cured CFC plastics. At the same time, the microwave energy flow that passed through the barrier is, respectively, for carbon fibre and cellular construction (85-86) % and (75-76)%. The difference in the levels of reflected and absorbed energy fluxes for monolithic CFRP and CFRP with cellular elements is most likely associated with a complex pattern of re-reflection of the flow through the relatively thin outer PCM layer in the honeycomb metal cells, resulting in the predominant distribution of the latter in a kind of cavity chamber formed by two layer carbon fibre. Thus, there is practically no danger of the reflected energy flow into the magnetron and the implementation of the process of microwave processing of samples with cellular internal structures is possible.

Screen shots from the monitor of the laboratory stand, showing a stepwise increase in the load on the control and processed samples are shown in figure 2



**Figure 2.** The magnitude of the load until reaching the maximum deformation control (a) and processed (b) samples.

The dependencies of deformations and loads (figure 3) for the control and processed samples are almost straightforward, which indicates the predominantly elastic nature of the deformations at a given level and the ability to apply computational methods for determining the elastic modulus and internal stresses.



**Figure 3.** Dependence of deformation and loading force for the processed (1) and control (2) samples.

Processing of the test results allowed us to obtain the average values of the elastic modulus for the control and processed samples, respectively 29.2 and 38.5 GPa. Tangential stresses were 84.4 and 111.0 MPa. Thus, the processing of structures from carbon fibre reinforced PCM with distributed embedded cellular metal structures is possible and provides a significant increase in their strength in the field of elastic bending deformations.

## 5. Conclusion

The presence of embedded metal cellular elements in the construction of carbon fiber-reinforced PCM does not lead to an increased reflection of the microwave electromagnetic field, but, on the contrary, it is less than that observed with conventional PCM structures. This allows for strengthening quasi-structuring.

Processing for 1 minute in a microwave electromagnetic field with a frequency of 2450 MHz with an energy flux density of  $(17-18) \times 10^4 \mu\text{W}/\text{cm}^2$  solidified PCM with integrated cellular structures allows increasing the elastic modulus and ultimate normal stresses by 31.8%, shear stresses by 29.4%, which, accordingly, can contribute to improving the reliability and durability of the supporting structures and shells of modern and advanced aircraft. The results obtained are significantly higher than the previously obtained increase in the modulus of elasticity of 16% reinforced with carbon fibres PCM without embedded metal structures.

Additional theoretical and experimental studies are appropriate to identify the physical mechanism that explains the results.

## Acknowledgements

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