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Experimental results of increasing the bending strength of construction glass after microwave radiation exposure

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Abstract. The analysis of the scientific and technical literature and trends in the development of transport and energy technology showed that advanced plastic complexes and fiberglass plastics are widely used in promising aviation complexes and ground-based robotic complexes for various purposes. The promising point of application of the effects of microwave radiation (microwave electromagnetic field) on the formation of enhanced strength properties of products made of glass-reinforced plastics, especially in terms of bending stresses and interlayer shear, is shown. Experimental studies of the effect of microwave electromagnetic field with a frequency of 2450 MHz on the microstructure of hardened laminated fiberglass and their flexural strength have been performed. A 60% increase in the flexural strength of the samples was achieved after exposure to microwave radiation of an average power level for 2 minutes compared to the control ones. With shorter and longer time of processing, the increase of strength was less pronounced. The reason of hardening is an increase of the solidity of the structure by increasing the contact points of the matrix and fibers during the formation of the characteristic "star" structures. The fact of embrittlement of samples processed at maximum radiation power with an increase in exposure time was revealed.

1. Introduction

The development and introduction of advanced transport systems, aircrafts in particular, require the advanced creation of new high-strength and lightweight materials and the improvement of the shaping technologies for the their structural elements. Analysis of scientific and technical literature, materials of conferences and exhibitions testifies to the intensive development of the production of composite materials based on carbon-glass- and aramid fibers and their widespread use in the aviation, automotive, shipbuilding industry, rocket production and space technology in various objects. Among them are the elements of supporting structures, the plating of heavy transport vehicles, the construction of light and ultra-light unmanned and remotely piloted aircraft, including multicopters [1, 2]. The nature of the destruction of fibrous compositions under tension depends on the type and volume content of the fibers and the matrix, as well as on the ratio of their deformations to failure. The orientation of the fibers also has a decisive influence on the mechanical properties of the composition. Composites have a different mechanism for fatigue failure under cyclic loads than homogeneous materials. The complex macrostructure provides a considerably lower than that of metals, the sensitivity of composites to stress concentration and a low rate of propagation of cracks. This provides increased durability of structures made of these materials [3-7]. The use of carbon plastics is especially effective in various structural elements. According to the company, MarketsandMarkets, the global market for carbon-fiber plastics will rise to \$ 35.74 billion by 2020. Carbon consumption can rise from 68 thousand tons at present to



130 thousand tons in 2020 [9]. This indicates an increased demand in the present and in the future high-tech industries for polymer composite materials.

2. Relevance of research

Despite the noticed increase in demand for carbon fiber, there is still a need to use composites based on fiberglass and glass fabrics. Synthetic fiberglass is widely used to create non-metallic composites - fiberglass. With a relatively low density, they have high strength, low thermal conductivity, heat, chemical and biological effects resistance. Especially important is the property of radio transparency, which determines the need to use glass-reinforced plastics in the design of radomes for radars, shells of radio receiving and radio transmitting devices of aviation robotic complexes [9, 10]. The use of fiberglass is determined here by a significantly lower tangent of dielectric loss angle compared to carbon plastics: 0.02- 0.05 and 0.17- 0.42, respectively, with a higher dielectric constant: 3.8- 8 and 3.3- 3.5. At the same time, fiberglass plastics have worse mechanical characteristics as compared with carbon plastics. In particular, the modulus of elasticity is on average 69- 80 GPa, while, as in carbon plastics, it is 120- 130 GPa with comparable tensile strength: 1920 and 1800 MPa, respectively [11- 13]. The requirement of uniform strength of the structure, for example, an airframe of an aircraft, necessitates the reinforcement of fiberglass elements, which is carried out, as a rule, by constructive methods by increasing the layers and changing the reinforcement scheme. However, this is accompanied by an increase in the weight of the structure, which is an undesirable factor for aircraft technology. Weight growth is also associated with a large proportion of fiberglass as compared with carbon plastic [11].

Consequently, one of the main tasks of creating promising technology and, mainly, aviation, is to develop design and technological methods to improve the strength characteristics of parts made of structural glass-reinforced plastics without significantly increasing the weight of the structure.

3. Problem statement

Recently, alternative methods have been developed to increase the strength properties of polymer composite materials and, in particular, glass-reinforced plastics. A method of creating so-called self-reinforced plastics is being developed, according to which the product is pressed from glass fibers without the use of a binder and heated to temperatures that cause activation of the micro melting of the surface of the fibers. In this case, their connection is carried out by bonding the fibers through this molten layer, which replaces the matrix of ordinary PCMs. This reduces the weight of the composition, since there is no additional matrix material, and the strength even rises a little [14]. However, this method is difficult to implement due to the complex controllability and uniformity of heating of the peripheral zone of the fibers. The change in existing technology and equipment is required. The “technological heredity” of subsequent operations and transitions influences the final set of properties. Obviously, it is more expedient to impact the final product made of hardened material.

For local control of the structure and strength properties of a three-dimensional or two-dimensional object of non-metallic materials one of the most effective methods is the use of microwave radiation (microwave electromagnetic) field. However, the majority of studies of these electrotechnological processes concerned the effects on the process of synthesizing components or curing the composition [15- 17]. Practically there is no information about the mechanism of the effect of microwave radiation on the cured structure of the finally formed product. At the same time, the use of this impact on composite materials in the process of their formation is not always advisable because of the need to make changes in the streamlined and complex technological process of component synthesis, laying out the composite layers, hardening and finishing. Previously we have obtained positive results on microwave hardening of pultruded carbon and layered carbon plastics [18, 19]. However, the influence of microwave radiation on fiberglass requires additional study due to the substantial dependence of the process of interaction of microwave radiation with PCM on their composition, including the type of fibers and the matrix material.

The aim of our research is to determine experimentally the possibility of strengthening microwave modification of the finally formed and hardened structure of structural composite fiberglass in modes that do not lead to material heating above 35- 40 °C.

4. Research methods and equipment

We carried out studies of the effect of microwave processing on the physicomachanical and protective properties of samples formed from 24 layers of aramid fiber TSVM-DJ article 56319A with a binder-Glue 88. While preparing samples, each layer was impregnated with a layer of glue, placed under a press and held for 24 hours after the composition was cured, one part of the samples was left as a control, and another part was placed in a microwave electromagnetic field of average power density for 3 minutes. The treatment was carried out using the installation "Zhuk-2-02" with a horn radiating antenna manufactured by LLC AgroEkoTech (Obninsk, Kaluga region). The power of the installation magnetron is 1200 W, the frequency is 2450 MHz. The distance to the plane of the aperture of the horn was 150 mm, which corresponds to the average power level. According to our earlier studies [9], it is the average microwave power that provides the greatest efficiency in increasing the bending stresses of aramid filaments. Three specimens were made with dimensions of 60 x 60 mm (Figure 1).

5. Theoretical part

At present, the mechanism of microwave radiation on polymeric and composite materials is described as follows [15, 17, 20, 21]. The standard frequency for microwave ovens and industrial microwave installations is 2450 MHz. This is the frequency of resonance absorption for water molecules. Under the influence of physical vibrational effects, as with heating, the mobility of the structural elements of the polymer increases. It means that such effects are equivalent to an increase in temperature. The greatest effect from the use of vibrational effects should be expected when the frequency of external exposure coincides with the natural frequency of the structural elements of the macrochains [20]. When using microwave radiation at the stage of hardening, there is an intensification of diffusion processes that promote the formation of bonds in a shorter period of time and provide greater strength of interaction between the components.

On the other hand, the performed analysis suggests that oscillatory processes in the microstructure of solidified PCMs can lead to its restructuring, changes in the number and nature of mechanical and intermolecular bonds in the matrix-fiber system and, as a result, lead to an increase in local and general strength properties subject to the avoidance of thermal destruction.

6. Results and discussion

We have investigated samples of laminated glass-reinforced plastics in the form of plates with dimensions of 80.0 x 15.0 x 2.0 mm. In the experiments, the microwave setting "Zhuk-2-02" produced by "AgroEkoTeh", Obninsk, Kaluga Region, with radiating antenna horn type was used. The device generates an electromagnetic field of 2450 MHz with an output power of 1200 W. Three modes of microwave power were used: low P_I , medium P_{II} , and high P_{III} . Because of the patenting of the method of modifying at the present time, specific technological regimes are not indicated. The processing time was set equal to 1, 2, 3 minutes at different power levels. Tests of samples before and after processing were carried out on an installation equipped with strain gauge force sensors and a worm loading mechanism. Processing the results of the measurement of the load applied to the sample was carried out using a special program installed in the program (LabVIEW, Orel) and allowed to obtain load graphs (torque on the drive) in the dynamics from the moment of application to failure. According to known dependencies, the mechanics of materials calculated the bending stresses. The surface of the deformation zone was studied using a Digital Microscope 2.0 MP 1000X digital microscope (GAOSUO, China) at x500 magnification with display on a laptop screen.

According to the results of processing the experimental setup, graphical dependencies were obtained (Figure 1).

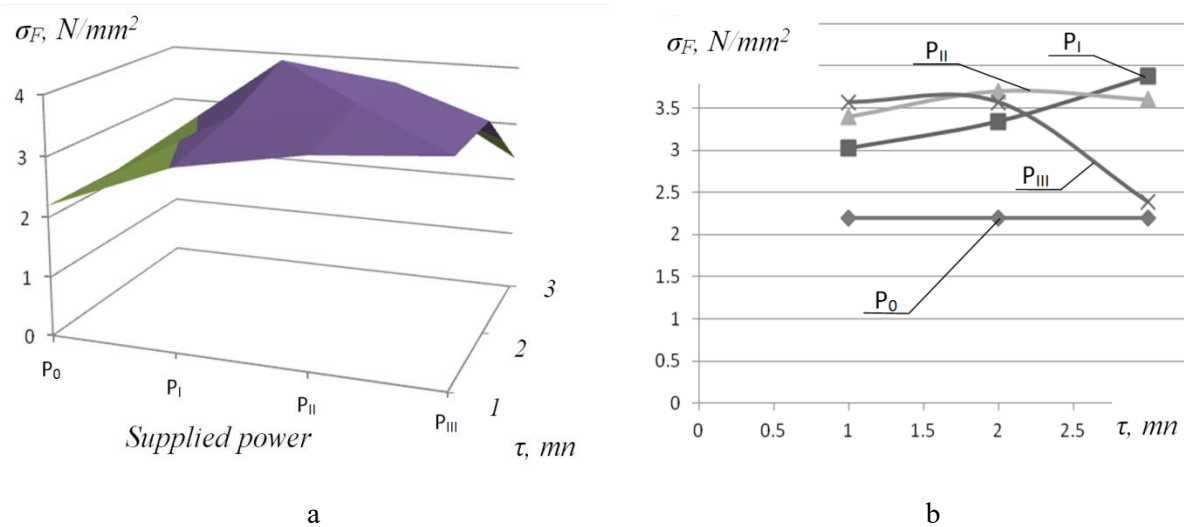


Figure 1. The effect of microwave processing time on fiberglass on bending stresses σ_F at different supplied power

With a short exposure time, a steady increase in the specimen strength is observed with an increase in the input radiation power, which is determined by the limiting bending stresses; with an increase in time, the specimen strength increases, but tends to decrease with increasing power. Finally, at the maximum of the investigated range of exposure time and low power, the maximum hardening effect is achieved. The effect of hardening on bending stresses in this case is more than 60 % and exceeds that previously achieved for CFRP. The hardening effect at medium power decreases when the exposure time exceeds the level of 2 minutes. At the maximum of the investigated power range, the hardening effect sharply decreases with increasing time. The strength of the sample remains almost comparable with the control. The study of the microstructure of the sample deformation zone (Figure 2) showed the following.

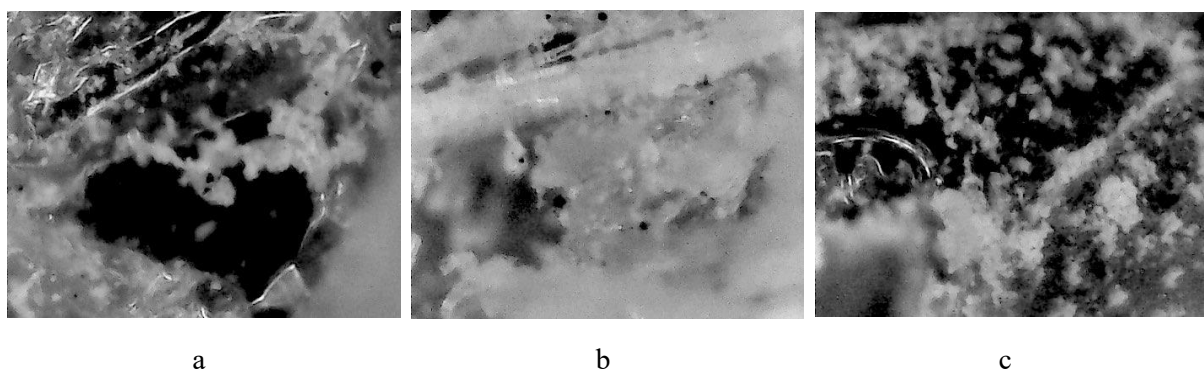


Figure 2. The microstructure of the control sample of fiberglass (a) and processed with medium (b) and high (c) microwave power x500

In the fracture zone of the control sample (Figure 2a), fiber breaks and particles of the crumbling matrix are visible. The structure of the sample processed at low power is characterized by solidity; the fibers are interconnected by "star-shaped" matrix structures having a developed contact surface. When processed at medium power for 2 minutes (Figure 2b), individual fibers are visible, separated from each

other, although with preserved "star-like" formations on the surface. After exposure for 3 minutes at high power, the sample looks completely destructed (Figure 2c). The fibers are separated; the particles of the matrix are split and are not connected to each other. In general, this structure resembles the structure of control samples.

The results obtained can be explained as follows. Over time, at a low power level, the processes of formation of additional cross-links gradually develop, both in the matrix and between the matrix and the reinforcing fibers, as well as between the fibers themselves, which form conglomerates (welded strands). Due to the formation of such a maximally connected structure, the material acquires maximum strength. With increasing radiation power supplied to fiberglass, the heat generation increases, which on the one hand accelerates the hardening process (maximum occurs after 2, not 3 minutes), on the other hand, as the exposure time increases, it leads to dehydration and embrittlement of both the matrix and the reinforcing fibers, which manifests itself in reducing strength. At maximum power, this mechanism is manifested to a greater degree; therefore, an increase in the exposure time causes heating of the material, which adversely affects the adhesion of the components and also the cohesive interaction of the structural formations of the matrix. Accordingly, the resistance to the action of loads decreases and reaches a minimum during long-term processing at the maximum of the investigated power range.

7. Conclusion

It was experimentally shown that the effect of microwave radiation on structural elements of hardened fiberglass for 1-3 minutes allows to increase the strength of bending stresses by 60 %. At the same time, the greatest effect is achieved when processing with a minimum power level for 3 minutes or with an average level for 2 minutes.

The reason for the increase in strength may be an increase in the points of interaction of the fibers with the matrix and the fibers between themselves (with the formation of compacted bundles and "star" structures) due to local thermal effects in the interfacial zones.

Acknowledgments

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References

- [1] Koshkin R 2015 *Scientific Bulletin of the State Civil Aviation Institute of Civil Aviation* vol. 10 pp 16–25
- [2] Kiva D 2014 *Aerospace Engineering and Technology* **6** 5
- [3] Kablov E 2012 *Bulletin of the Russian Academy of Sciences* **82** 520
- [4] Ahmad A, Abdalla M and Gurdal Z 2010 *Journal of Aircraft* **47** 775
- [5] Brinkmann S et al. 2006 *International Plastics Handbook the Resource for Plastics Engineers Ed. Hanser* p 920
- [6] Bunakov V, Vasiliev V and Gurdal Z 1999 *Optimal Structural Design USA : Technomic Publishing* pp 207–246
- [7] Karbhari V et al. 1998 *ECCM-8 European conference on composite materials «Science, technologies and applications»* **2** 35
- [8] Avrasin A, Borodin M and Kiselev B 1982 *Aviation industry* **8** 80
- [9] Preobrazhensky A 2010 *Chief Mechanic* **5** 27
- [10] Vasilyev V, Protasov V, Bolotin V and others 1990 *Composite materials: Reference book Moscow Mashinostroenie* p 512
- [11] Kurnosov A, Melnikov D and Sokolov I 2015 *Proceedings of VIAM* **8** 08
- [12] Davydova I and Kavun N 2012 *Glass and Ceramics* **4** 1–7
- [13] Sevostyanov D, Doriomedov M, Daskovsky M et al. 2017 *Proceedings of VIAM* **4** 104

- [14] Arkhangelskiy Y 2011 The reference book on the microwave electrothermies: a reference book *Saratov: A scientific book* p 560
- [15] Kolomeitsev V, Kuzmin Y, Nikuiko D and Semenov A 2013 *Electromagnetic Waves and Electronic Systems* **18** 12 25
- [16] Estel L, Lebaudy Ph, Ledoux A, Bonnet C and Delmotte M 2004 *Proceedings of the Fourth World Congress on Microwave and Radio Frequency Applications* **11** 33
- [17] Zlobina I, Bekrenev N and Muldasheva G 2016 *International Conference on Advanced Materials with Hierarchical Structure for New Technologies and Reliable Structures* **1783** 020236-1
- [18] Zlobina I, Bekrenev N and Pavlov S 2017 *Bulletin of the Chuvash State Pedagogical University. AND I. Yakovlev. - Ser .: Mechanics of ultimate state* **3** 42
- [19] Komarov V 2010 *Physics of wave processes and radio engineering systems* **13** 4 57
- [20] Studentsov V and Pyataev I 2014 *Effect Russian Journal of Applied Chemistry* **87** 3 352