

# The use of ultrasonic exposure for the modification of synthesized composite materials

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**Abstract.** To provide more effective process of the ultrasonic influence while pressing powder materials, it's necessary to increase the strength of natural vibration frequency of the acoustic system transfer devices to the change of a technological load. Solving this task allows one to design a new ultrasonic technology of solid-phase synthesis of polymer composite materials. The technological load value on waveguide system was determined as the research result and the dependence of the frequency stability index of amplification coefficient was found. The rational parameters of ultrasonic exposure during the synthesis of PCM were defined.

## 1. Introduction

The service life of modern machines and mechanisms is largely depends on the mechanical and tribological materials properties of friction units. The details of friction units made of different metals and alloys have been gradually replaced by polymers and polymeric composite materials, particularly on the basis of polytetrafluorethylene for the last few years [1-3]. The main properties of the polytetrafluoroethylene (PTFE) allow one to use it in the friction units without lubrication. However, the lack of durability of PTFE in operation at high specific loads and sliding velocity requires the development of new ways and methods of increasing the mechanical and tribological properties [4, 5].

To achieve the essential increase of mechanical and tribological properties of polymer composites, it is possible to create improved technologies for their production, in the direction of raising the level of the external energy deposition impact and activating the components directly during their synthesis [6]. Modification of the polymers released by the industry can be carried out by physical methods, both at the stage of their receiving and in the course of their processing. Physical methods of modification can be divided into a number of forms:

- thermal influence (low-temperature or thermochemical processing);
- vacuum and compressor processing (pressure, vacuum, explosive loading);
- periodic deformation (vibration or ultrasonic processing).

From the above mentioned methods of external energetic influence on polymeric materials the most attractive method is appending the energy of ultrasonic vibrations directly while pressing the product, therefore in polymers a number of the physical and chemical phenomena leading to an intensification of a manufacturing process, decrease in the equipment energy intensity, quality improvement of ultimate products are observed. [7, 8].

However, the intensification of pressing process of the polymeric composite materials (PCM) of the ultrasound energy restrains by low effectiveness of ultrasonic sending devices (wave guides). So, the waveguide system design considering the influence of technological loading is an actual task. Its decision allows us to create a new solid-phase technology of obtaining (synthesis) polymeric



composite materials. In this connection, acoustic parameters of the waveguide system and their influence on modification of PCM structure were researched.

## 2. Study subject and methods of research

The study subject was modified polytetrafluoroethylene: 8% - cryptocrystalline graphite, 6% - carbon fiber, 2% - molybdenum disulfide (F4SKG8 UV6M2).

A special installation on the basis of a hydraulic press was developed to research the influence of ultrasonic vibrations while pressing powders of polymeric composite materials [8]. The ultrasonic installation consists of two parts: a power part and a vibratory part. The power part of installation includes a hydraulic press MT – 50, with the maximum pressing effort of 500 kN.

The samples were exposed to heat treatment (agglomeration) at the temperature of 360 ° C after ultrasonic pressing. To observe the same modes of agglomeration, for comparison, samples without impact of ultrasonic vibrations on the pressed composite material were made.

The assessment of the tensile strength limit of samples was performed with the tensile testing machine R 0.5 at the strain rate of 20 mm / min in accordance with State Standard GOST 11262-80.

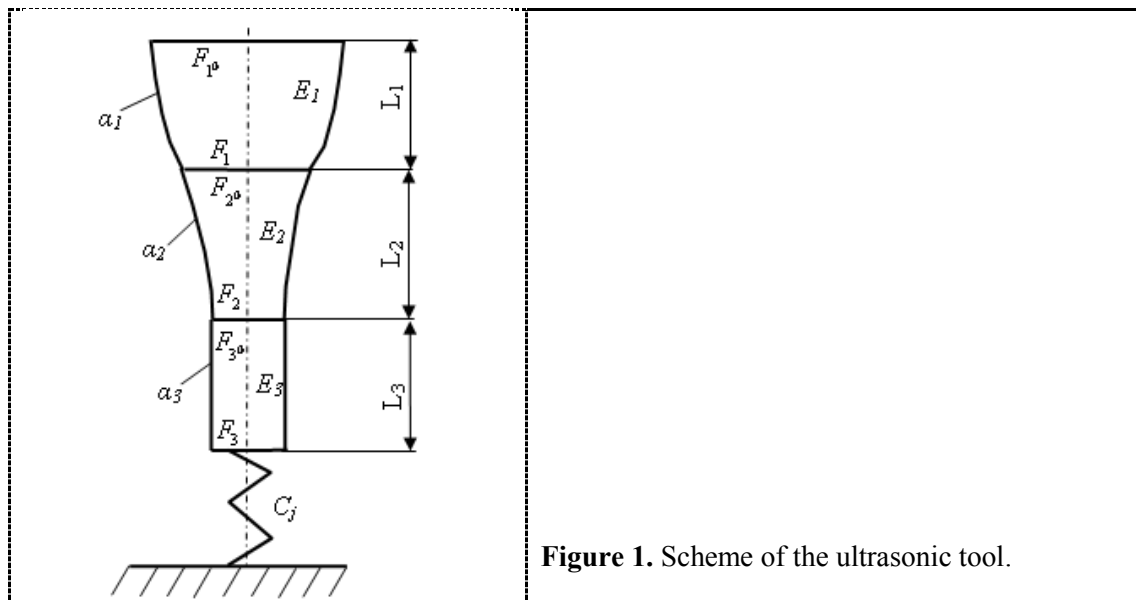
The tribological testing of samples was carried out on a special stand [9], the sliding velocity was  $V = 0,75 \text{ m / s}$ , at the pressure of  $P = 2 \text{ MPa}$  without lubrication.

## 3. Results and discussion

For increasing the pressing process efficiency it is essential to fulfill the following requirements which are imposed on the waveguide system:

- 1) the ultrasonic tool should provide necessary vibration amplitude for a given output tool area;
- 2) the dynamic voltage should not exceed an endurance limit of the system material;
- 3) the ultrasonic system should work in the mode of a steady resonance under the technological loading change in the process of ultrasonic pressing.

The ultrasonic waveguide tool represents a resonant half-wave core (fig. 1) or set of cores with the adjusted law of changing cross-sectional area on its axis making longitudinal vibrations.



**Figure 1.** Scheme of the ultrasonic tool.

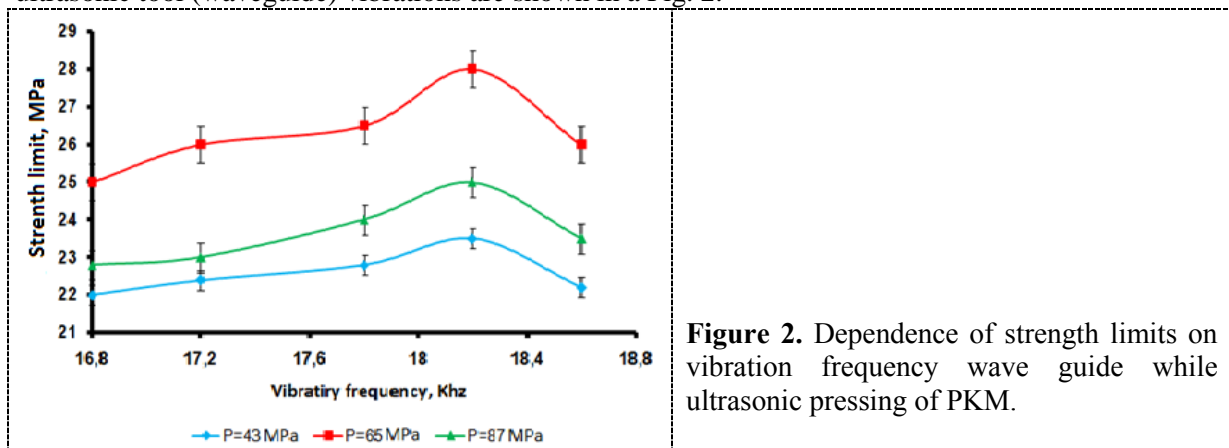
Calculation of this waveguide system is the complex task being solved relative to two opposite options: the maximum frequency stability at the specified amplification coefficient and the maximum amplification coefficient at the specified frequency stability.

The index of sustainable natural frequency of vibrations to loading change was determined by a formula:

$$\Omega = \left\{ \frac{\left[ \frac{(EF)_{i-1}}{E_i F_i} \Delta \Psi_{i-1} + \alpha_i \right] \left[ \left( \frac{\alpha_i}{\beta_i} \operatorname{tg} \beta_i L_i + 1 \right) - (\alpha_i - \beta_i \operatorname{tg} \beta_i L_i) \right]}{1 - \frac{l}{\beta_i} \left[ \frac{E_{i-1} F_{i-1}}{E_i F_i} \Psi_{i-1} + \alpha_i \right] \operatorname{tg} \beta_i \lambda_i} \right\} \frac{f}{\Delta f}, \quad (1)$$

where  $\lambda_i = 2\pi f/c$ ,  $\beta_i = \sqrt{1 - \frac{\alpha^2}{\lambda^2}}$ ,  $E$ - Yung module,  $F$ - cross-sectional area of the waveguide,  $\alpha$ - indicator of exponent,  $L$ - sector length,  $i$  – sector number .

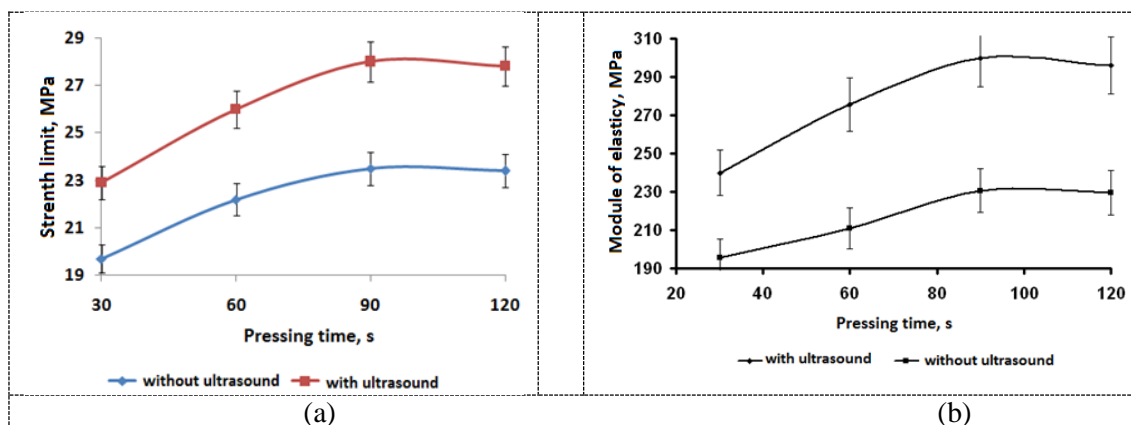
The offset frequency of  $\Delta f$  was defined experimentally on the ultrasonic installation, while the frequency of vibrations of the acoustic system changes in the range 16,8 – 18,8 kHz. The vibration amplitude of the ultrasonic tool (A) and pressing time (t) were fixed (A=14 microns, t=90 c). Besides, ultrasonic pressing of powder composition materials was carried out under different pressures (P) within the range of 43–87 MPa. The obtained dependences of strength limit on the frequency of ultrasonic tool (waveguide) vibrations are shown in a Fig. 2.



**Figure 2.** Dependence of strength limits on vibration frequency wave guide while ultrasonic pressing of PKM.

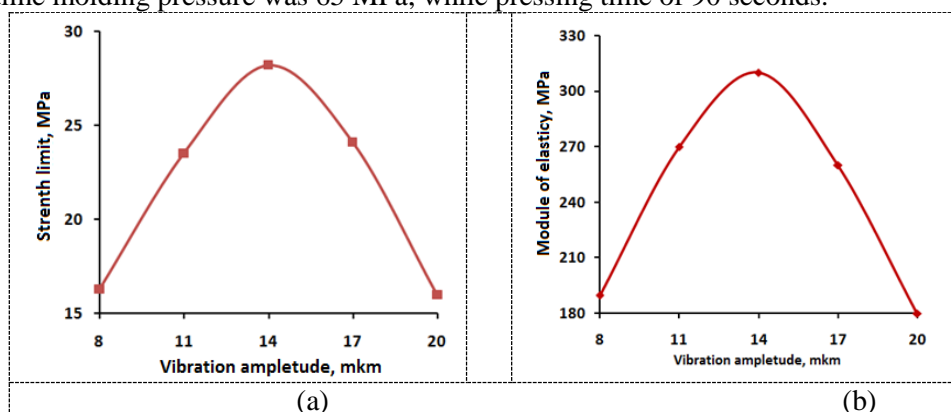
Follows from the achieved results that influence of technological loading in the process of ultrasonic pressing causes essential change in resonance vibration frequency of the acoustic system ( $\approx 400$  Hz), and the most optimal pressure of ultrasonic pressing makes 65 MPa. With molding pressure increase over this value strength limit while extending decreases by 10%. This is due to the fact that pressure grows with increasing load acting on the acoustic assembly, which in turn causes a reduction in the vibrations amplitude of the waveguide in the ultrasonic pressing process.

As a result of the mechanical tests it was found that the optimal pressing time is 90 seconds (Fig. 3). At the same time, the samples produced by ultrasonic pressing the tensile strength higher by 16% and the elastic modulus by 23% in comparison with samples made by the technology without ultrasound use. Further increase of pressing time does not alter the tensile strength and modulus.



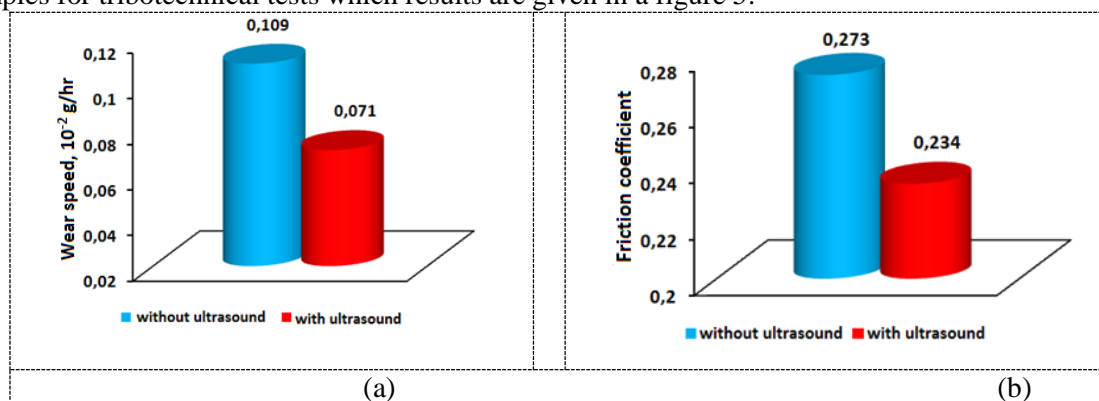
**Figure 3.** Dependence of strength limit (a) and module of elasticity (b) on pressing time.

Influence of vibration amplitude of a wave guide punch on strength and elastic modulus of composition material has pronounced extremal character with a maximum of 14 microns (fig. 4). At the same time molding pressure was 65 MPa, while pressing time of 90 seconds.



**Figure 4.** Dependence of strength limit (a) and module of elasticity (b) from vibration amplitude of a wave guide punch.

On the basis of the above explained researches results rational parameters for the mode of ultrasonic influence while pressing (vibration amplitude of a wave guide punch of 14 microns, extrusion pressure of 65 MPa, time of pressing of 90 seconds) are set. On these parameters were made samples for tribotechnical tests which results are given in a figure 5.



**Figure 5.** Tribotechnical characteristics of the received materials:

a – wear speed; – friction coefficient.

As a result of the carried-out tribotechnical tests it is established that the use of ultrasonic pressing allows to decrease wear speed on 34,8%, and friction coefficient on 14,3%.

During ultrasonic processing polymers essentially facilitated occurrence and plastic development deformation of the powder particles, is carried out the activation of dislocations occurring as a result of the absorption of acoustic energy in the areas of crystal lattice defects and other structural imperfections. Consequently, in a short time, local heating occurs around these absorption material sources, the increase in molecular mobility that determines the improvement of mechanical and tribological properties of the produced composite material.

#### 4. Conclusion

As a result of the carried out researches the size of technological load of the waveguide (acoustic) system is determined. Dependence of an indicator of frequency stability on strengthening coefficient was established.

Rational parameters of ultrasonic influence at synthesis of PKM are determined. The conducted researches have shown that the use of ultrasonic pressing allows to increase strength by 16%, the elasticity module by 23%, at the same time the speed of wear decreases by 34,8%, and friction coefficient by 14,3%.

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