The Ultrasonic Impregnation of Polymer Composite Materials

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***Abstract* – The article is devoted to the study of impregnation of polymer composite materials under the unfluence of high-intensity ultrasonic vibrations. The advantages of ultrasonic impregnation and possibilities of its practical realization are described. It was designed ultrasonic technological equipment used for ultrasonic impregnation in practice.**

***Index terms* – Ultrasonic impregnation, polymer composite material, fiberfill, polymer binder.**

I. INTRODUCTION

POLYMER composite materials and the goods made of them have a number of unique properties. It determines their wide application in different branches of modern production complex: from space-system engineering and articles of cosmic branch to production of goods used in private life.

The requirement to provide specified strength of material at the production of polymer composite articles can be met only at the realization of qualitative impregnation of fiber glass with binder (resin).

II. PROBLEM STATEMENT OF THE STUDY

Insufficient impregnation of fiberfill with polymer binder at the production process leads to the decrease of operating characteristics and premature failure of the articles made of polymer composite materials.

Moreover the formations of air cavities during the impregnation worsen strength of the articles made of polymer composite materials especially at interlaminar shift [1].

In this connection to increase quality and strength of the articles made of polymer composite materials it is necessary to enhance the efficiency of impregnation process, i.e. provide the conditions, which ease the penetration of the binder into interfibrillar space of fiberfill.

III. THEORY

Polymer composite materials on the base of fiberfills (fiber glass, organofiber or carbon fiber), epoxy binder and the articles made of them have a number of unique properties. One of the main stages at the production of the articles from polymer composite materials determining quality of finished articles is an impregnation of fiberfill with polymer binder.

There are different processing methods, which makes easier the penetration of polymer binder into the fiberfill. They are reduction of motion speed of fiberfill through the bath with polymer binder, evacuation of the binder, wringing of impregnated fiberfill, physical modification of polymer binder and change of its viscosity making for essential improvement of wettability of fiberfill. The modification of the binder can be realized under the action of electric and magnetic fields, by the vibration of fibers of the fill, influence of intensive ultrasonic vibrations on fibers of the fill and polymer binder.

Reduce of the speed or increase of the duration of drawing of fiberfill through the bath with polymer binder greatly decrease process productivity, as the speed of drawing is higher tahn the speed of capillary impregnation. The provision of evacuation of impregnation process is technologically complicated. The most effective method of improvement of wettability of fiberfill and easing of penetration of polymer binder is physical modification of polymer binder under the influence of high-intensity ultrasonic vibrations [2,3].

The most important advantege of ultrasonic modification is possibilty of reduction of viscosity of polymer binder in tens of times. Due to it the penetration of the binder into interfibrillar space of fiberfill is made easier. As a result change of physical properties of the articles made of polymer composite materials after their polymerization takes place. Moreover under the influence of cavitaion streams better penetration, activation, accompanied by intensive degassing in the zone of impregnation with polymer binder, takes place. Ultrasonic degassing leads to considerable decrease of the amount of air gas cavities in the articles made of polymer a composite material, which increases its quality and strength.

IV. INVESTIGATIONS OF ULTRASONIC IMPREGNATION OF POLYMER COMPOSITE MATERIALS

Besides carried out investigations of the intensification of impregnation process it is known, that the application of mechanical vibrations of high-intensity ultrasonic frequency allows to intensify other stages of the technological process at the production of articles made of polymer composite materials, e.g. calibration of external diameter of the rod, activation of resin used for glueing of fiberglass articles.

At working-off of the glueing technology of load-bearing element with resin activated by ultrasound it was determined essential increase of joint strength (up to 70% of strength of main material).

Moreover during the investigations carried out in different years (2000 – 2005) it was ascertained, that the application of

mechanical vibrations of ultrasonic frequency of low intensity allowed to organize and realize quality control of obtained production made of polymer composite materials. The parameters of ultrasonic control were determined experimentally.

During the production of flexible connector fiberglass armature for thickening of the rod from polymer composite material at the stage of its formation inset element of cylinder form with pointed end is placed. Originally inset element is made of similar rod made of composite material of required diameter. From known results of tests on strength it follows, that flexible connector fiberglass armature as a rule breaks down in the place of thicknening. It is evident, that it is determined by insufficient impregnation with the binder of fibers of unpolymerized material, entry of insufficient amount of the binder on the surface of inset element, absence of resin activation for strength increase of glued joint with inset element.

In this connection there is a need in practical application of ultrasonic influence for increase of strength of the articles in the places of thickening due to intensification of impregnation and resin activation processes. Practical realization of the method allows to carry out investigations and determine optimum modes (intensity) and conditions (duration) of ultrasonic influence.

V. ULTRASONIC TECHNOLOGICAL EQUIPMENT

Earlier (2000 – 2002) the device for ultrasonic impregnation of fiberglass in impregnating bath was proposed and practically realized. The device (see Fig. 1) allowed organizing at the production of “Biysk Fiber glass plant” ultrasonic impregnation of the articles made of polymer composite materials constituting whole fiberglass rods with the diameter of 2 to 10 mm.

Fig. 1. The equipment for qualitative ultrasonic impregnation.

Carried out laboratory tests and tests of the articles made of polymer composite materials show, that the application of designed device is suitable for efficiency increase of impregnation. The content of the binder in the rods increases in 30–4% and it is 23.7–24.2 %, strength of finished product rises in 20% and its chemical stability rises in 17%.

As ultrasonic vibrations intensifies the impregnation process and activates resin, for solving of stated tasks ultrasonic technological equipment was developed and designed.

Ultrasonic equipment (see Fig. 2) for the application of mechanical vibrations on the die for broaching of rod – the diameter of the die will be chosen according to the diameter of thickening (5.6 mm, 7.7 mm and 10.5 mm).

Fig. 2. The appearance of ultrasonic technological equipment.

The same ultrasonic equipment with removed die (see Fig. 3).

Fig. 3. The appearance of the ultrasonic technological equipment with removed die.

Threaded rod allows to install ultrasonic vibrating system at any structural component (preliminary flat with the diameter of no less than 30 mm and threaded hole in the center M16x2 with the depth of no less than 18 mm should be made) of technological line of the formation of articles made of polymer composite materials. The application of mechanical vibrations is practical in the contact zone of metal surfaces with impregnated fiberglass in the zone of rod formation and inset placement.

VI. THE FACILITY FOR ULTRASONIC IMPREGNATION

For elimination of disadvantages of existing devices for ultrasonic impregnation of fiberfill combined ultrasonic device for impregnation was designed (see Fig. 4).

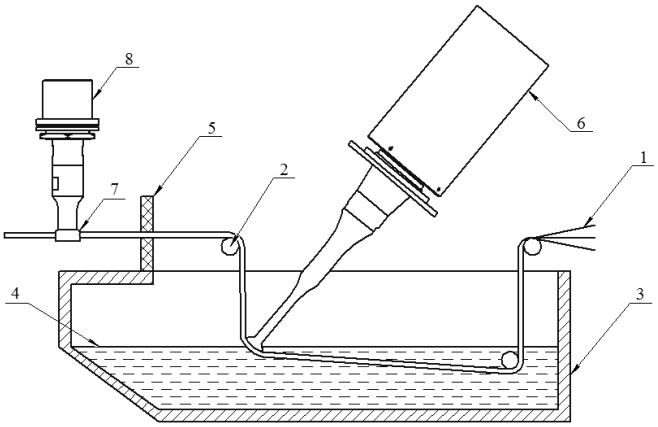

Fig. 4. The scheme of combined ultrasonic equipment for impregnation of polymer composite materials.

Proposed device of ultrasonic impregnation of fiberfill operates in a following way. Reinforcing fiberfill 1 consisting of plenty of continuous fibers is formed into the bundle and with the help of pressure rollers 2 it comes and it is drawn through the bath 3 with the binder 4 up to the output device 5, which provides removal of surplus of the binder. During the impregnation reinforcing fiberfill 1 is influenced by high-intensity ultrasonic vibrations generated by ultrasonic equipment 6. After the output device 5 reinforcing fiberfill 1 goes through the die 7 of ultrasonic equipment 8 for additional ultrasonic processing, thereby impregnating fiberfill in the zone of inset placement.

The main advantages of the use of such device for ultrasonic processing during the impregnation are decrease of impregnation duration and reduction of air cavities in polymer composite materials and possibility of total process automation [4]. In proposed device the ultrasonic vibrating system is located at an angle to fiberfill. At that the part of working tool is placed into the binder, and another part is out of it providing impregnation and removal of remained air.

Such embodiment is caused by the fact, that ultrasonic processing of fiberfill coming out of the binder (in air) increases impregnation effciency and makes for even distribution of the binder and removal of gas bubbles [5].

The part of working tool immersed in the binder provides processing and degassing of polymer binder in all volume because of the absence of elastic clamping material. Clamping is carried out due to the choice of form of radiating surface of working tool. Lower wall of the bath in the zone of placement above it of working tool of vibrating system is made at an angle to the sutrface of the binder in bath, which is perpendicular to acoustic axis of vibrating system. The distance from the surface of working tool to the bottom is chosen equal to half of wave length of ultrasonic vibrations in the binder at operating frequency of vibrating system. The performing of bath wall in the zone of processing parallel to working surface and providing of resonant amplification of ultrasonic vibrations due to the choice of the distance between radiating surface and wall equals to half of wave length allow to increase vibration amplitude in the processing zone and near the bath wall.

The rise of vibration amplitude near the bath wall lets increase efficiency of processing of binder saturated with air returned after wringing in the bath. Chosen placement of vibrating system and working tool excludes ingress of gases liberating during the processing into processed binder. Air bubbles will emerge in front of the part of working tool, which is not immersed into the binder.

The embodiment of proposed device allows excluding disadvantages of existing nowadays ultrasonic devices for impregnation of fiberfill with polymer binder.

To provide the conditions of appearing of developed cavitation in polymer binder intensity of ultrasonic vibrations should be 2 – 3 W/cm^2 [6]. To provide such intensity special construction of ultrasonic vibrating system will be developed and produced. It will consist of three packets of piezoelectric transducers with reflecting cover plates and concentrator of ultrasonic vibrations ending with working tool of knife type.

As a binder is a liquid with high coefficient of viscosity, to provide cavitation mode of ultrasonic influence developed device will provide amplitude of vibrations on radiating surface of no less than 50 μm.

VII. CONCLUSION

The application of mechanical vibrations of high-intensity ultrasonic frequency allows intensifying technological process of impregnation of the articles made of polymer composite materials.

To increase quality and strength of the articles from polymer composite materials the device providing essential improvement of wettability of fiberfill, facilitating penetration of the binder into interfibrillar space of fiberfill was developed. Ultrasonic technological device is a combination of two devices for ultrasonic impregnation of the series “Nadezda”.

Such embodiment of proposed device is caused by the necessity to intensify impregnation process at different stages. The initial stage of impregnation of polymer composite material is carried out in impregnating bath, where fiberfill gets impregnated with the binder with simultaneous reduction of gas occlusions in polymer composite materials. The next stage of impregnation of polymer composite material is carried out by drawing of rod of polymer composite material through the die of ultrasonic vibrating system removing surplus of the binder and impregnating polymer composite material in the zone of inset placement.

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