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UTILIZATION OF FIBER COMPOSITE PRODUCTS

The method for processing of fiberglass plastic is proposed for deriving of the fiber constituent, applied as reinforcing filler for producing secondary composite materials. It is proved by theory and experiments the influence of modes of shock-centrifugal mill to produce a fibrous component with the highest content of fibers with a length of more efficient. The obtained analytical regularities can be used to develop the design of the elements of the mill, as well as for the optimization of the grinding process.

Introduction. The fibrous composite materials based on glass fibers and the polymer matrix have a high strength, resistance to elevated temperatures and chemicals, water and atmospheric agents; thus they have found wide application in the manufacture of vehicles, constructions and other products for constructional purposes. But the same properties being positive for the use of products, make it difficult to recycle waste production. Taking into consideration environmental requirements, the problem of recycling is becoming more urgent due to expanding volume of output and the use of products made of fiber composite materials.

In terms of economy and ecology, the most attractive recycling technology of composite materials is to provide for recycling of components. Primarily reinforcing high-strength fibers as a filler of thermoplastic polymers to obtain secondary composite materials are of great interest. These materials are applicable for the manufacture of structural composite by one of the common ways – by injection molding, pressing, extrusion, etc.

The purpose of research is to strengthen the secondary composite material obtained as a result of the disposal of products by optimizing the grinding process and obtaining a high share in the crushed product of fibers with a length of more than efficient.

Main part. The following scheme is proposed to utilize the products of the fiber composite material: recyclable product is cut into pieces (size depends on the performance of the mill, but not more than 100 mm), then they are treated in the shock-centrifugal mill with reflectors; fibrous fraction separated from the crushed product is combined with crushed waste thermoplastic polymers, in particular polyethylene, polypropylene, polyamide, polyethylene terephthalate or their mixtures; the product is formed from prepared in the extruder plasticized stock (secondary composite material).

It is known [1] that the reinforcing fibers fully implement its strength in the composite material only in the case if the length L is not smaller than the so-called effective length determined by the ratio:

$$L \geq (\sigma_f d) / (2\tau), \quad (1)$$

where σ_f – tensile strength fibers; d – average diameter of the fibers; τ – adhesive bond strength between the fiber and the matrix polymer in the secondary fiber composite, determined experimentally, for example by the method of fragmentation [2].

Glass fibers linked by input matrix polymer and forming particles of uncertain shape lose reinforcing ability, and as a result, the strength of the secondary composite material appeared to be poor. The length of the fibers in particulate mass is less effective and therefore not sufficient to implement the full strength in the secondary fiber composite material due to intense mechanical impact on pieces of disposition product in the mill.

Low and heterogeneous high adhesive bond strength of the reinforcing fibers with thermoplastic polymers also prevents from obtaining durable recycled materials, thereby reducing the efficiency of the recycling process.

To erase the matrix material (and the link between fibers) kinetic energy of the matrix particles in the moment of impact in shock-reflector centrifugal mill should exceed the specific fracture energy of this component. The fibers must not break down, so their kinetic energy should be less than the specific energy of brittle fracture.

At the speed of the rotor radius R in shock-speed centrifugal mill v velocity of piece when hit the reflector is $\pi nR / 30$, the kinetic energy per unit volume of the matrix is $\rho_m v^2 / 2$, and the kinetic energy per unit volume of the fiber – $\rho_f v^2 / 2$.

Specific energy of brittle fracture per unit volume of the matrix material [1], having Young modulus E_m and destructive tensile stress σ_m is $\sigma_m^2 / 2E_m$. Specific energy per unit volume of brittle fracture of a reinforcing fiber is respectively $\sigma_f^2 / 2E_f$ [1].

These formulae give approximate relation between the indices of the components and the rotor speed n in shock-centrifugal mill, which provide matrix destruction, but the fibers do not break down, namely:

$$30\sigma_m / (\pi R\sqrt{E_m \rho_m}) \leq n \leq 30\sigma_f / (\pi R\sqrt{E_f \rho_f}). \quad (2)$$

The structure of the fibrous composite material is heterogeneous and indices of component properties have variation, therefore, it is preferable to set the rotational speed of the rotor approximately equal to the average value of the boundaries identified in (2), namely:

$$n = 15\left[\sigma_m /(\pi R\sqrt{E_m \rho_m}) + \sigma_f /(\pi R\sqrt{E_f \rho_f})\right], \quad (3)$$

where σ_m – fracture stress in tension of the matrix; E_m, E_f, ρ_m, ρ_f – Young's modulus and density of the matrix (the subscript "m") and reinforcing fibers (subscript "f") in utilizable product from fiber composite material, respectively.

If the condition is fulfilled (2), the grinding process creates the most favorable conditions for the separation of the fiber fraction of the matrix are set while grinding, i.e., the impact energy exceeds the energy of the brittle fracture of the matrix polymer, but not enough to break the fiber. This increases the fiber volume fraction of greater length in the grinding product. High proportion of long fibers in the secondary composite material provides its higher tensile strength, bending and compression [1].

Applying formula (3) simplifies the task of rotor speed necessary for the initial crushing of the raw composite material maintaining the maximum length of the fibers and reducing the time required for testing of suitable modes.

To test the proposed solutions defective products from fiberglass of contact molding based on polyester resin PN-1 were recycled. The density of the glass is 2.5 g/cm^3, the Young's modulus E_f = = 70 GPa. The average fiber diameter d is 6 microns, the mean failure stress in tension in the fibers σ_f is 2.5 GPa. Matrix density ρ_m = 1.2 g/cm^3, Young's modulus E_m = 3 GPa, the average value of tensile strength σ_m = 35 MPa. These indicators are given in reference books and textbooks, if necessary, they can be refined while testing by known methods [2].

Mixed waste products of polypropylene and ABC-plastic which were formed while replacing of the material in the cylinder of the molding machine are used as matrix for secondary composite material. Adhesive bond strength τ between such matrix and glass fibers found by the method of fiber fragmentation [2] is ≈ 1 MPa. The effective length of the glass fibers in the secondary composite, calculated by formula (1), and its mean value obtained by the method of fragmentation are about 4 mm.

Waste of contact molding fiberglass were prepartitioned into pieces with dimensions of 20–30 mm, exceeding the above value of the effective length of the fibers in the secondary composite.

Grinding pieces of glass was performed in a shock-centrifugal mill with a rotor diameter of 450 mm (R = 225 mm). Length booster blades was 150 mm, length of reflectors were 100 mm.

From ratio (2), under the above terms of properties, it follows that the operating speed of the rotor is in the range of 750 min^{-1} ≤ n ≤ 2,850 min^{-1}, and the average value calculated by the formula (3) is 1,800 min^{-1}.

For experimental mode testing of grinding regimes rotary speed was set at six points in the specified range and, in particular, equal to the average value. Grinding of pieces of glass fibre plastic of one set was done for each of the received frequency value. Obtained product was dissipated on the laboratory sieves, separating fiber fraction. Mass of fibers was determined while weighing the fraction, the average length of which exceeds the effective length (4 mm).

As follows from the results of the experiment, P is a portion in the crushed product of fibers having length L more than effective, and it essentially depends on the rotor speed mill. It is significant the availability of its maximum value in the range of values previously calculated taking into account the properties of the components.

A significant proportion of unground pieces is in the product obtained in shock-centrifugal mill at rotor speeds less than 750 min^{-1}, i.e. less than lower limit in ratio (2). Therefore, the proportion of the fibers obtained from this product is less than 10 wt %. At a speed of 750 min^{-1} proportion of fibers the length of which are more than effective, was 12 wt %.

When a rotor speed is 2,850 min^{-1} i.e. greater than the upper boundary in ratio (2), small fraction fines are prevailed in ground product as product in a mixture of short fibers and matrix polymer particles, but the proportion of fibers whose length is more than efficient, is also small (less than 10%).

If the value n = 1,800 min^{-1}, calculated by formula (3), the proportion of fibers P, the length of which exceeds an efficient is close to the maximum (about 0.5) for the product obtained from the recycled product.

The components of the secondary composite material (ground waste obtained after processing of pieces in shock centrifugal mill without classification; matrix polymer – a mixture of polypropylene and ABC-plastic) were combined in a disk extruder (the diameter of disk is 200 mm, the speed is 100 min^{-1}, melting point is 280°C). The degree of filling in the compositions is set constant and equal to 40 wt % regardless of the mode of grinding fiberglass.

Product (its dimensions are 250×250 mm) was pressed in the form of box from the resulting composition From the flat bottom of the product (4 mm thick) specimens were cut for bending test (5–6 for each variant). The table shows data on the proportion of fiber fraction and obtained secondary composite material.

Indicators of the structure and strength of the secondary composite

Indicator	Rotor speed, min^{-1}						
	750	1,200	1,600	1,800	2,000	2,400	2,850
Fiber fraction, the length of which is more than effective, wt %	12	34	46	51	48	38	16
Flexural stress at breaking, MPa	24	36	42	45	41	39	28

The table shows that the secondary fiber composition obtained by the proposed method, contains the largest (from the number of investigated variants) portion of fibers (51 wt %), the length of which exceeds efficient, and its flexural strength is the highest (45 MPa).

Conclusion. The proposed analytical method for determining the mode of grinding process solves the problem of choosing the preferred parameters of the mill performance, depending on its size and functional properties of the components in the secondary fibrous composite material. The dependence of fiber length in the crushed product from the impact energy is theoretically proved and confirmed by experiments. The maintenance of the length of fibers in the ground enables to double the strength characteristics of the secondary composite. The analytical dependence of rotor speed on the properties of the primary components of the composite material and the geometry of the mill enable to eliminate the time-consuming experimental studies to test the grinding modes.

The results can be used at the enterprises manufacturing products from fibrous composite materials, in particular GFP by contact molding at JSC “Osipovichsky Zavod Avtomobilnykh agregatov”, JV “Liplast”, LLC “Belkarplastic”, JV “SMIavtotrans”, etc.

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