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STRUTURE AND PROPERTIES OF COMPOSITE MATERIALS FROM FIBREGLASS WASTES AND THERMOSETTING BINDER

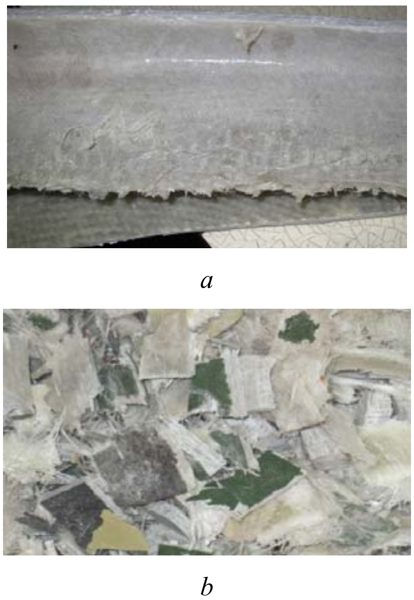
The possibility of the use of ground fibreglass wastes as fillers and thermosetting resins as binders to manufacture the articles for household and constructive use have been studied. Parameters of the mechanical properties of materials with different fraction composition have been determined. Influence of the mechanical action on particle size has been studied. Experimental test for checking the possibility of component combination has been carried out. Quality of materials has been examined. Recommendations for the use of the existing technologies in the manufacture of articles have been worked out. The obtained results can be used in developing product design, in determining the areas and conditions of their effective application as well as in choosing technologies for their processing.

Introduction. The increasing demands for economic effectivity, energy and labour intensity of mass-production articles as well as for the utilization of overage materials and articles cause constant search for new solutions in the sphere of composite materials (CM) and the technology of molding [1].

Technological wastes and wastes from overage articles are formed in the process of mechanical treatment of fibreglass articles. This also concerns articles which came out of action or are not applicable for further use and need reprocessing.

The aim of the research was to consider the possibility of the use of ground fibreglass wastes as fillers in certain technological processes.

Study of the fibreglass waste structure. Article off-cuts produced by contact molding at JSC Osipovichi Automobile Units Plant were used as basic material for the research (Fig. 1).



a

b

Fig. 1. Basic material:
a – off-cuts; *b* – cut fragments

Different types of fibreglass fillers are used for the production of articles by contact molding method, such as: fabrics, linen, roving. Thermosetting polymers are used as a binding component.

Following grinding and reduction [1, 2], the material changes into the mixture of fibrous (chiefly fibreglass) and dispersed (resin) mass.

In terms of the increase of the compound operational characteristics including rigidity, hardness and strength, the fibrous glass content with the fibre length more than 2mm is of great interest.

Classification of the base mixture of fibrous wastes was done in the trommel with the cell size of 2 mm to separate fibrous and dispersed fines. Ground wastes pre and post classification are shown in Fig. 2.

The composition of post classification materials is more homogeneous. Dependence of the separation factor of the base mixture and its components on the particle size is shown in Fig. 3. Diagrams are constructed by summing up the percentage for each fraction. Following classification, the fibrous fraction with the average fibre size of 8–12 mm reaches 55 wt % of the base mixture, the fibreglass content in the obtained material being 75–80 wt %. The residue contains a large amount of the dispersed ground binder component and milled fine fibres, the average size of which is 0.5–1.0 mm. The glass component in such fibres is not less than 25 wt %. The content of the polymer compound was defined by burning.

The combining of the components results in the force action on the filler particles and consequently on the size changes during processing.

The efficiency of the mechanical action on the ground material was modelled by generating compressive pressure, that is by linkage deformation in a closed mould (50 mm in diameter) under compressive load. Density dependence on the applied pressure is shown in Fig. 4.

Base mixture Fibrous fraction Residue

Fig. 2. Fibrous wastes pre and post classification

The compaction degree for fibreglass wastes depends on the polymer fraction content and fibre size. The larger the amount of polymers and the smaller the fibre size (this is characteristic for wastes post screening), the higher the compaction density due to lesser rigidity of the given particles.

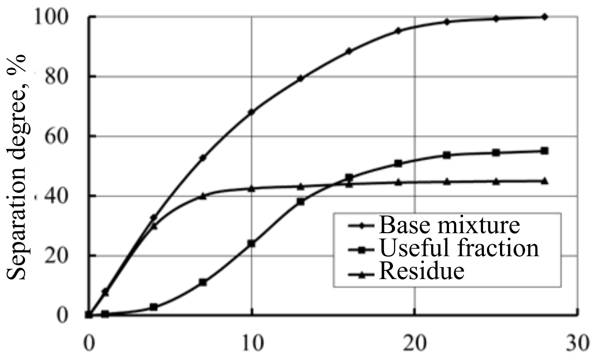


Fig. 3. Dispersed composition of the base mixture and its constituents

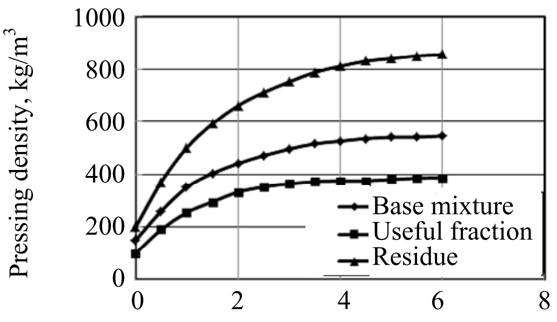


Fig. 4. Density pressing dependence on applied pressure

Classified wastes (fibrous fraction) are characterized by lower polymer content (two- or threefold) and longer fibres in relation to the base mixture, and consequently by greater rigidity of the inner structure. The compaction density of such a structure is much lower (Fig. 4).

Parameters of the compaction process are expresed by the equation of regression

$$\rho = \rho_{max} - (\rho_{max} - \rho_0) \cdot \exp(-p/B_п),$$

where ρ – density under pressure p; ρ_{max} – maximum density equal to experimental maximum compaction pressure; ρ_0 – initial (smear) density; $B_п$ – parameter characterising resistance to compaction.

Parameters of the compaction law are shown in Table 1.

Table 1

Compaction process parameters of the fibreglass filler

Material	Parameters of the regression equation		
	$B_п$, MPa	ρ_0, kg/m^3	ρ_{max}, kg/m^3
Initial mixture	1.58	120	545
Useful fraction	1.77	85	390
Residue	1.59	185	860

The pressure to develop required density was determined by the above given equation using the least squares in semilogarithmical coordinates method. Compound density reaches its experimental limiting value under pressure p and is considered to be minimal molding pressure.

The degree of fibre damage due to the applied compression force was determinined from the study of the structure before and after the mechanical action. As a numerical criterion of damage it is advisable to use the ratio value of the average size fibres before and after compaction – the degree of fibre reduction and breaking. The highest degree of breaking occurs when the fibre fraction compaction is 2.5–3.5 and the carcass consists of fragile fibres. After classification the degree of reduction in the base mixture and in the residue is almost the same and equals to 2.0 and 1.6 respectively. Shortening of the fibre length results in the physico-mechanical deterioration of properties of materials and articles.

To get the useful fibre length in the compound (not less than 2 mm) a separating screen (hole size more than 3 mm) for the classification of fibrous wastes was used.

Study of the properties of materials from fibreglass plastic and thermoreactive binder wastes. Resilience and strength properties of the compounds with different composition have been examined to determine the influence of waste particle size of fibreglass plastics on physico-mechanical characteristics.

The basic material used for the manufacture of samples is polyester binder. The composition of the binder contains cold-curing resin NORPOL M888 and curing agent "Butanox". A filler (content 30–50 wt %) consists of the ground fibreglass plastic wastes.

All the components of the initial material were loaded in the mixer manually. The sequence of loading is as follows: 50% of the filler were charged into the resin; the resultant material was being mixed for 3 min.; some more 30% of the filler were charged into the mixture; the resultant material was being mixed for 3 min.; the curing agent and the filler residue were added to the mixture; the resultant material was carefully mixed till the formation of a homogeneous mixture. It was important to avoid bubbling and overheating of the compound. The time of mixing is not more than 10 min.

Casting into the mould was done manually. The uncured contents filled the whole mould cavity but didn't go beyond the edges.The article was being cured within 24 hours at room temperature (full cure). To enhance strength and reduce inner stess the articles were being treated by heat at 120ºC within 1 hour.

Viscosity of the compound was defined by the Khepler viscosimeter. When 50 wt % of the filler is added, the compound viscosity changes 3.5–10.0 times in contrast with the base mixture depending on the fraction type. The larger the content of the dispersed polymer material, the higher the mixture viscosity. It depends on the resin particle absorbing capacity. The time of gelation changes but little if the filler is added (about 10%).

At the present stage of research samples with the required degree of filling at a certain pilot compressive pressure have been obtained.The basic properties of the obtained materials are shown in Table 2. Sample appearance with different fillers is shown in Fig. 5.

The results of the preliminary studies show the necessity of waste classification for the manufacture of high-tension and stiff compounds. However, only 50% of the whole bulk of wastes is used, and it is not economical.

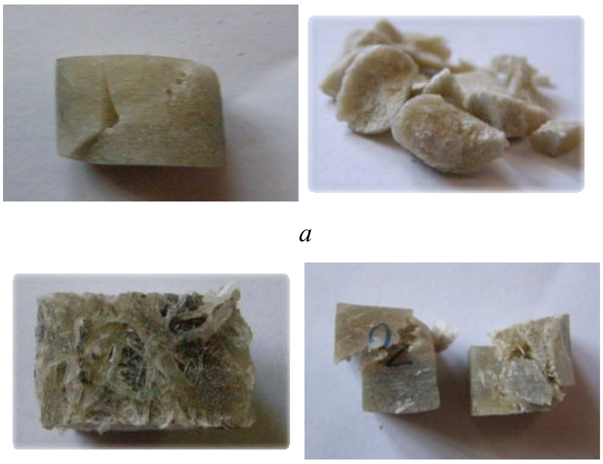
The operational characteristics of the resultant compound are not high. The classification residue considerably degrades the technological characteristics of the compound. All the above mentioned significantly limits the range of the applied technologies.

Table 2

Physico-mechanical characteristics of compounds prepared by compression method

Parameters	Filler content, wt %			
	30	40	50	20 (analogue)
Density, g/sm^3	1.25	1.27	1.29	1.4–2.4
Tensile strength, MPa	25	18	15	20–60
Bending strength, MPa	79	65	60	70–140
Tensile modulus, GPa	2.8	3.1	3.2	–
Bending modulus, GPa	6.0	7.5	7.6	8–15
Porosity, %	6	11	20	–

Processing methods. There are three main technological processes for the manufacture of articles from the fraction components of all types (Fig. 6).



a

b *c*

Fig. 5. Sample appearance:
a – waste material; *b* – useful fraction; *c* – base mixture

Direct compression. During the process the preliminarily prepared viscous mixture or fluid prepreg in the closed moulding tool is compressed (Fig. 6, *a*).

Any type of a thermosetting polymer, including that with gelling agents or the one in a certain degree of gelation can serve as a binder. In this case semi-finished materials (premixes) can be manufactured.

All groups of reduced wastes are used for the manufacture of articles. It must be considered that the component combination intermidiate phase means an intensive mechanical action on filler particles in the mixer, and consequently results in a considerable change of fibrous fraction length and decrease of physico-mechanical characteristics of the material (Table 2).

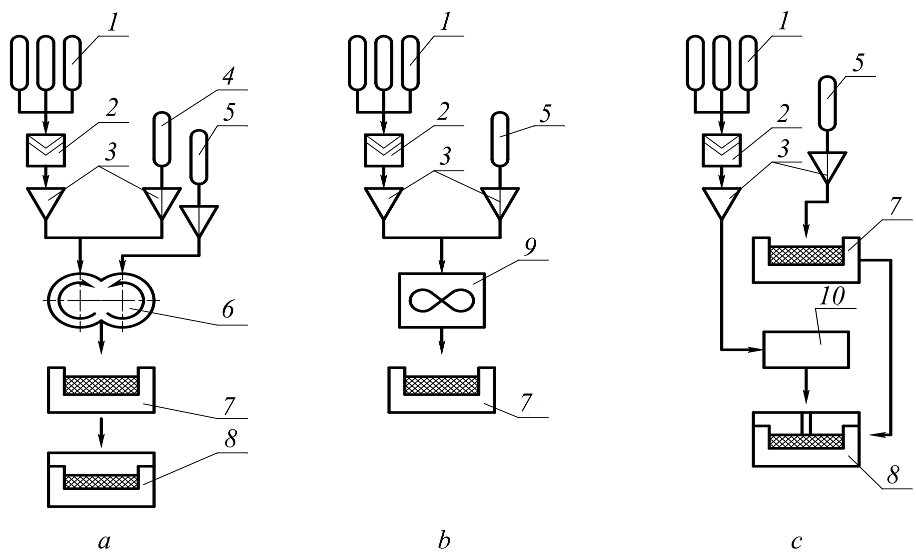


Fig. 6. Technological scheme of the article manufacture:
a – compression moulding; *b* – potting; *c* – injection moulding;
1 – binder components; *2* – mixer; *3* – dosing unit; *4* – mineral filler (if necessary);
5 – reduced wastes; *6* – screw mixer; *7* – moulding cavity; *8* – compression;
9 – paddle mixer; *10* – jet blower

Due to low flow index, compresion force is determined by the requirements to the quality of materials and article surface. Mold cavity filling criterion is not considered when determining compression force. Because of the maximum density of the article material it is possible to use minimal pressure while choosing the optimal value of the compression force (Table 1).

The article material is characterised by a high degree of homogeneity and minimal porosity. The article surface is smooth all round. The size accuracy is high.

Paddle or screw mixer, hydraulic press and press mold are necessary for the implementation of the above mentioned technology

Resin transfer moulding. The technology is based on filling the working cavity with the fibrous material having been compressed to a certain degree. The pilot compression degree of the fibrous mixture determines the degree of filling for CM.

Due to the particle dense packing in the screening and weak mechanical bonding between them, the use of this fraction for the article manufacture is problematic. The method results in washing out the filler and its localization in the compacted structures. All these factors influence the material operational characteristics and make the article appearance worse (Table 3). The lack of the pilot mixing stage maintains the required fibre length in the fibrous fraction.

The articles produced by this method are characterised by high quality of side surfaces without additional mechanical processing. They have a well-developed form and contain embedded elements. The availability of the open or closed-type moulding tool and the compressed fluid binder feeding system are necesaary to perform the technology.

Gravity die casting. Molding differs from compression molding by lack of the additional force action on the component mixture. This enables to avoid further reduction of the fibrous fraction.

Table 3

Physico-mechanical characteristics of a compound prepared by the impregnation method

Parameters	Glass mat			Reduced wastes		
Filler content, wt %	30	40	50	30	40	50
Density, g/sm^3	1.35	1.43	1.55	1.26	1.31	1.35
Tensile strength, MPa	76.3	82.3	88.6	15.9	19.7	34.1
Bending strength, MPa	110	165	220	49.1	54.8	58.6
Tensile modulus, GPa	5.8	7.0	8.2	5.8	7.8	–
Bending modulus, GPa	4.2	5.4	6.6	4.2	4.6	5.6

For example, available and pour density at a minium compression pressure for fibrous fraction CM is 2.5 times lower than that for the screened CM. This eleminates differences in the operational characteristics of the articles.

Any type of reduced wastes may be used as a reinforcing component. However, to control parameters of the physico-mechanical properties at the expense of fibre length variability is somehow problematic. First of all it is determined by the rigidity of the filler structure, and consequently by the density of the article material.

The obtained material has sufficient strength and rough surface. Using this method it is possible to obtain only one quality surface without any additional mechanical processing provided that a decorative layer of the moulding tool is applied to the form-building surface. Analysing the spheres of application of the examined compounds it's better to focus on bulky articles made of artificial stones and the like.

Availabilityof paddle and screw mixers as well as open-type moulding tools of simple construction are necessary for the implementation of the technology.

Conclusion. The materials on the basis of the thermosetting resins which are made of ground fibreglass plastic wastes meet the requirements applied to composite materials. The data about the properties of these materials are shown in Table 4.

Table 4

Basic properties of materials from fibreglass plastic wastes and polyester binder

Parameter	Fibrous fraction			Base mixture	Residue
	Filling degree, wt %				
	30	40	50	30	30
E_b, GPa	2.62	3.40	4.30	2.46	2.39
σ_b, MPa	39.5	50.7	71.4	30.9	21.3
E_t, GPa	3.05	3.27	3.43	2.57	1.66
σ_c, MPa	44.0	–	–	40.0	36.0

Methods of the manufacture of articles have been examined. The possibility of using the existing technological processes has been tested. Researches are exploratory.

References

1. Двустадийная технология совмещения волокнистых отходов стеклопластика и смешанных отходов термопластов для формования изделий / В. П. Ставров [и др.] // Труды БГТУ. Сер. IV, Химия, технология орган. в-в и биотехнология. – 2010. – Вып. XVIII. – С. 99–103.

2. Калиновская, В. Г. Основные направления использования отходов стеклопластиков / В. Г. Калиновская. – М.: Химия, 1982. – 130 с.

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