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Magnesia Composites Formation as a Result of Furniture Production Wood Waste Processing

Olga MIRYUK*

Rudny Industrial Institute, 111500, Rudny, Kostanay Region, Kazakhstan

***Abstract* – The article outlines the problem of accumulation of short-fibered waste generated during chipboard sawing. Intense impact on the material determines a high level of technological availability of wood waste. The research objective is to create magnesia composite materials for various purposes based on chipboard processing waste. Moulding sands containing caustic magnesite, fly ash, aluminosilicate ash microsphere, wood waste and magnesium chloride solution have been studied. Change in the ratio of moulding sands' components provided production of finely dispersed composite material, and granules of cylindrical and spherical shapes. Composite materials of coarse-pored structure have been developed on the basis of magnesia granules and hybrid magnesia-ash binder. Combination of layers of finely dispersed and coarse-pored materials has been proposed to form composites of variotropic structure with density 780–840 kg/m^3 and strength 9.7–11.9 MPa. Combined structures' stability is achieved due to the high adhesive ability of magnesia binders and genetic commonality of various layers.**

***Keywords* – Building composites; caustic magnesite; unburnt pellets; wood chipboard**

1. INTRODUCTION

The construction field is a major consumer of materials, fuel and electricity. High rates of construction work irreparably deplete natural resources. The problem of expanding the raw material base for the production of building materials is topical. To provide the construction industry with raw materials, it is necessary to search for available materials of the technogenic origin. On the other hand, it is crucial to develop resource-saving technologies for the production and use of building materials.

Wood-based materials are effectively used for the manufacture of products and structures for various purposes. Wood combines high strength and low density; it is easily machined and provides comfortable indoor conditions. Along with natural wood, waste in the form of wood particles of various shapes and sizes is widely used in the technology of sheet goods.

Particle board is sheet material, for example, 3500×1750×15 mm in size, which is made by thermal pressing of a mixture of wood shavings and sawdust with the addition of synthetic resin. The composition of substances for gluing wood particles contains formaldehyde.

The improvement of manufacturing technology, the possibility of regulating the structure of the product, high-quality physical and mechanical properties and affordable cost ensure that particle board is widely used in the realisation of construction projects, as well as furniture manufacturing.

The technology of manufacturing structures provides for format pruning and calibration of particle board. This process is accompanied by the formation of waste, the volume of which

* Corresponding author.
E-mail address: psm58@mail.ru

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is 12–15 % of the mass of the processed material. Another source of waste is obsolete physical elements of buildings and furniture, the accumulation of which has become a problem at an international level [1]–[4]. There are various ways to dispose of waste generated during particle board cutting. The most primitive way is to take the waste to a landfill. Rotting of wood-chip waste without oxygen access often results in the formation of toxic gases. Incineration of waste in landfills is dangerous for the environment, which is polluted by substances formed during thermal exposure to formaldehyde and other binders [5], [6]. Often, the particle board sheets are crushed and the resulting fine mass is pressed into fuel briquettes. There are methods proposed for burning fuel briquettes and waste in special furnaces without releasing formaldehyde into the environment, for example, in pyrolysis plants [7], [8]. However, this method of disposal requires strict control of emissions into the atmosphere, which is not always ensured during thermal process planning [9].

A wealth of experience has been accumulated in the use of fibrous waste of plant origin in the technology of building materials to obtain effective products. Fibrous wood particles can serve as filler in concretes and other composite materials with heat-shielding properties [10]–[19]. Consequently, wood waste is a valuable raw material for the production of construction materials. Incineration of waste generated during particle board furniture production is irrational and creates environmental problems.

The processing of the chipboard waste wins technological properties, providing possibilities and advantages of their use in moulding sands for various purposes as a result of the intense mechanical and thermal exposure. The purpose of the study is to develop magnesia composite materials based on chipboard processing waste.

2. METHODS AND METHODOLOGY

The current study researched materials obtained using the waste left after sawing particle board (hereinafter referred to as PB waste). The waste is generated in the cabinet furniture workshops. Wood waste is a loose mass with a bulk density of 175–180 kg/m^3. A significant part of the waste is formed by small particles the size of which does not exceed 0.315 mm (Table 1). The predominance of dust-like particles distinguishes the waste under study from sawdust formed during the processing of natural wood. Fine-dispersed waste from the processing of particle board can be designated as ‘sawn sawdust’. Another feature of the waste under study is the presence of the thinnest films of hardened resin on the particles, which bond the wood particles in the structure of the sheet tissue. The content of solidified binder fragments in the waste can reach 10–12 %.

TABLE 1. PB WASTE CHARACTERISTICS

The size of the sieve holes, mm	The remainder on the sieve, %	Appearance
2.5	0.9	
1.25	3.2	
0.63	14.2	
0.315	41.3	
0.14	79.8	
Less than 0.14	100.0	

Caustic magnesite and hybrid magnesia binder were used to combine wood waste into a monolith. Caustic magnesite of the PMK–87 brand contains 85–90 % MgO, characterized by a specific surface area of 310 m^2/kg. Hybrid magnesia binder was obtained from caustic magnesite and fly ash formed during the process of coal combustion (Ekibastuz, Pavlodar region). Chemical composition of fly ash, %: SiO_2 36–48, Al_2O_3 10–25, Fe_2O_3 2–6, CaO 12–15, MgO 1–3, R_2O 1–3, SO_3 2–5, l.o.i. 3–15.

Intensive hardening and high strength of magnesia materials is ensured by the use of salt closures. To seal the moulding mixtures, a solution of magnesium chloride with a density of 1230 kg/m^3 was used. This protects wood waste from rotting.

Aluminosilicate ash microsphere was used to regulate the structure and properties of magnesia composite materials. Alumosilicate ash microsphere is a loose material consisting of hollow spherical particles with a diameter of 100–350 microns; it is formed as a light fraction of ash from solid fuel combustion. The bulk density is 400 kg/m^3. Chemical composition, %: SiO_2 65–70; Al_2O_3 1–2; Fe_2O_3 2–4; CaO up to 10. It is formed by burning coal at the Troitskaya thermal power plant.

Moulding mixtures were prepared by thoroughly mixing magnesia binder with wood particles and waste from heat and power engineering. The properties of composite materials were determined using samples sized 40×40×160 mm.

Various methods were used to prepare granular materials. The granular material in the form of cylindrical briquettes was pressed on a special installation by pushing the moulding mixture through the cells of a metal matrix (Fig. 1 and Fig. 2). A drum-type laboratory installation was used to obtain pellets by the pelletizing method. The rotation of the metal drum ensured the transformation of the moulding mixture into spherical granules with a size of 5–15 mm (Fig. 3).



Fig. 1. Granulator.



Fig. 2. The matrix and the rollers of the granulator.



Fig. 3. Drum-type laboratory installation.

Granulated and composite magnesia materials were hardened in the open air at a temperature of 20–25 °C. Testing the samples on a hydraulic press determined the strength of the materials. The modernized diffractometer *DRON-3M* was used to determine binder's phase composition. The microstructure of the materials was examined using a scanning electron microscope.

3. RESULTS

3.1. Fine Composite Materials

The combination of PB waste and caustic magnesite provides composite materials, the properties of which can be adjusted by changing the content of the wood component (Table 2).

TABLE 2. BASIC PROPERTIES OF MAGNESIA COMPOSITE MATERIALS FROM PARTICLE BOARD WASTE

Caustic magnesite, %	**PB waste, %**	**Composite density, kg/m³**	**Tensile strength, MPa**	
			when bending	during compression
100	0	1930	15	44
80	20	1520	15	38
75	25	1240	13	31
70	30	1030	11	27
65	35	980	9	21

As the fibrous waste of particle board increases, the density of the composite decreases; this improves the thermal protection properties of the material. At the same time, the strength characteristics of magnesia composites have very high values necessary for the manufacture of sheets and plates. The strength properties of materials based on caustic magnesite are reduced in high ambient humidity. Mineral additives are introduced to add water-resistance properties to magnesia composites [20]. Combination of caustic magnesite with fly ash provides hybrid waterproof binder. Mechanical activation improves the strength of magnesia-ash binder (Table 3). The hardened stone of the hybrid binder is characterized by reduced density and increased water resistance.

To create composite materials with increased porosity of the structure, it is advisable to use a combined filler. The combination of particle board waste and ash microsphere improves the technological properties of moulding mixtures. Due to the spherical shape and smooth surface of the hollow particles of the microsphere, the homogenization of the moulding mass improves, and the uniformity of the structure increases. With an increase in the content of the microsphere to 10 %, the hardening of the material by 15 % is observed. Regulation of the

composition of the moulding mass with a combined filler makes it possible to obtain composites with a wide range of properties (Table 4).

TABLE 3. COMPARATIVE CHARACTERISTICS OF MAGNESIA BINDERS

Type of binder	**Consumption of magnesium chloride solution, %**	**Properties of the hardened binder**		
		Density, kg/m³	Compressive strength, MPa	Softening factor
Caustic magnesite	50.3	1930	44	0.45
Hybrid binder (50 % caustic magnesite + 50 % fly ash):				
– obtained by mixing the components;	41.7	1840	41	0.72
– obtained by mechanical activation	40.7	1830	52	0.75

TABLE 4. CHARACTERISTICS OF MAGNESIA COMPOSITE MATERIALS BASED ON A COMBINED FILLER

Filler content, %		**Composite density, kg/m³**	**Tensile strength, MPa**	
particle board waste	ash microsphere		when bending	during compression
100	0	1030	11	27
95	5	1010	11	29
90	10	980	14	31
85	15	870	12	24
80	20	750	8	18

To achieve the highest strength indicators of composites, moulding masses with a 30 % filler content are preferred with the predominance of particle board waste in it. The microstructure of combined composites is characterized by dense packing of components, and strong adhesion of the binder stone with filler particles (Fig. 4).

The preferred method of the moulding mass preparation is the initial preparation of a suspension from a magnesia binder and a salt sealer, the subsequent addition of an ash microsphere, then the introduction of particle board waste.

3.2. Granular Materials

Granular materials produced without the use of high-temperature processes along with the porous fired filler for concrete [21], [22], are being used in the modern production of lightweight concretes [23], [24]. Technologies of unfired fillers provide for the production of composite granules in which filler particles are bonded with an astringent. Particles forming porosity are used as fillers [25]. Increasing requirements for the construction and technical properties of lightweight concrete necessitates the expansion of the raw material base due to available sources.

Existing moulding methods make it possible to obtain granular material of various configurations. Wood particle board processing waste is often recycled by converting the finely ground mass into fuel briquettes on granulators (Fig. 1 and Fig. 2).

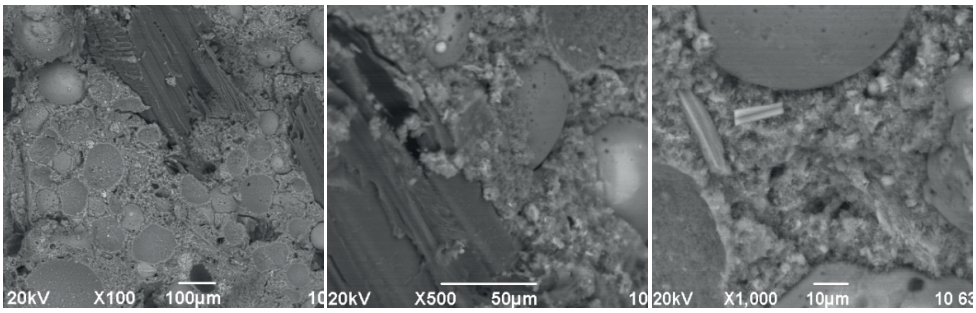


Fig. 4. Microstructure of magnesia composites with a combined filler.

The moistened wood pulp enters the matrix through the loading funnel and is squeezed out of the matrix holes in the form of briquettes with a diameter of 5–8 mm under the pressure of rollers 1000–1200 kg/cm^2. Pressing ensures the stability of the shape and the strength of the briquettes. The average bulk density of the briquetted mass is 285–350 kg/m^3, which corresponds to the indicators of the filler for light concrete – thermal insulation backfills. However, due to the presence of toxic formaldehyde, such use of particle board waste is unacceptable. Magnesia binder allows to offset harmful components in particle board waste. Magnesia oxychloride hardening binder ensures the resistance of the material to mould and fungi and eliminates the release of harmful gases.

Moulding sands containing magnesia binder (30–40 %), chipboard waste (40–45 %) and ash microsphere (24–25 %) were used to manufacture granulated material. A directed change in the content of solid components and magnesium chloride's solution allows you to control the density, hardening rate and the strength of granular materials. Magnesia pressed briquettes and granules of spherical shape, obtained by pelletizing in a drum machine, hardened in the open air (Table 5). The granules were tested for strength by squeezing on a hydraulic press after 28 days of hardening.

TABLE 5. CHARACTERISTICS OF MAGNESIA GRANULAR MATERIALS

Moulding process	**Pressing**	**Pelletisation**
Appearance		
Bulk density, kg/m³	300–370	340–360
Strength, MPa	3.8	2.7

Magnesia granular materials of various configurations can be used as filler for lightweight concretes, as heat-insulating and sound-absorbing backfill, for example, for flooring and building envelopes insulation, as fine-grained expanded clay replacement.

3.3. Composite Materials Based on Granular Aggregate

Lightweight concretes on porous aggregates serve as a promising composite material for energy-efficient construction. The characteristics of the porous aggregate make it possible to regulate the structure of composite materials, and determine the thermal and physicomechanical properties of light concrete.

The current study presents compositions of composite materials based on the obtained magnesia granules and the developed hybrid magnesia binder. Optimization of the composition of moulding mixtures was carried out using the method of mathematical planning of the experiment (Table 6). The factors characterizing the material composition of moulding mixtures are taken as the studied ones: the ratio between large and small granules; the ratio between magnesia binder and filler. The large filler consisted of grains with a size of 10–15 mm, and the small filler consists of grains with a diameter of 5–10 mm. After statistical processing of experimental data, mathematical models in the form of regression equations were obtained.

Eq. (1) is a mathematical model that shows the dependence of the density of magnesia composites, ρ (kg/m^3), on the studied factors:

$$\rho = 757.15 - 5.395 \cdot x_1 + 0.05 \cdot x_1^2 + 141.13 x_2 - 29.15 \cdot x_2^2. \quad (1)$$

A geometric illustration of the function is shown in Fig. 5.

The dependence of the compressive strength of magnesia composites at the age of 28 days, *R* (MPa), on the composition of the moulding mass is obtained in the form of a regression equation of a complete quadratic model:

$$R = 9.17 + 0.03 \cdot x_1 - 3.79 \cdot x_2 - 0.16 \cdot x_2^2 + 0.03 \cdot x_1 \cdot x_2. \quad (2)$$

The geometric image corresponding to Eq. (2) is shown in Fig. 6.

TABLE 6. CONDITIONS OF THE EXPERIMENT

Factors		**Levels of variation**				
Natural appearance	Encoded view	−1.41	−1	0	+1	+1.41
The proportion of large granules in the filler, %	X_1	0.0	14.5	50.0	85.5	100.0
Binder/Filler	X_2	0.25	0.31	0.45	0.59	0.65

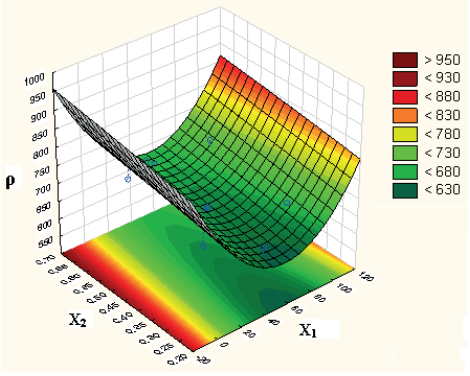


Fig. 5. The response surface of the dependence of the density of magnesia composites on the composition of the moulding mass.

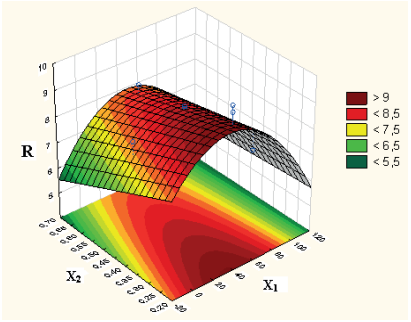


Fig. 6. The response surface of the dependence of the strength of magnesia composites on the composition of the moulding mass.

The analysis of mathematical models indicates the ratio between binder and filler has the determining influence on the density of magnesia composites. With an increase in the content of magnesia binder, the density of composite materials increases due to a reduction in the volume of the porous filler. The influence of the size of the granular aggregate is less significant. It is expressed in a decrease in the density of the composite as the large grains of the aggregate increase. An increase in the content of large granules contributes to the increase in the strength of magnesia composites.

The established mathematical dependencies help to determine the compositions of mixtures for the production of composite materials with a density of no more than 850 kg/m^3. To ensure this, the content of large granules should not be less than 20 %, with a ratio of 'binder: filler' not exceeding 0.40. Considering the requirements for the strength of magnesia composites (at least 7.5 MPa), the area of preferred compositions of moulding mixtures is specified: the proportion of large granules is 40–80 %, the ratio 'binder: filler' is 0.27–0.40.

The mathematical model of the composition of magnesia materials corresponds to the results of numerical studies of the packing of granules in the structure of composites. A comparison of various schemes of granular aggregate packaging showed that minimal stresses and deformations in the magnesia composite material are characteristic of a two-component system that contains 55–75 % of the aggregate. At the same time, the content of large granules in the filler is 50–70 %.

The physical and mechanical characteristics of composite materials are determined by the nature of the adhesion of filler granules to the magnesium matrix. The state of the contact zone between the magnesia stone and the surface of the granules, as well as the nature of the destruction of the samples during testing, indicate the strength of the adhesion of the components (Fig. 7). The filler grains are securely held by the magnesium matrix. The fracture occurs both along the stone of the binder and along the grain of the filler (Fig. 8). The strong adhesion of the matrix and the filler is achieved due to the high adhesion of the magnesia binder.

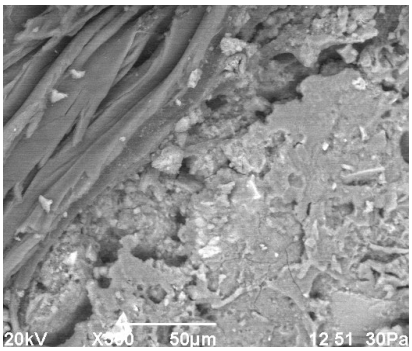


Fig. 7. Microstructure of the contact zone of the composite.



Fig. 8. The chip of the composite sample (in the centre of the granule).

Magnesia materials favourably differ because of increased tensile and bending strength that is ensured by the formation of magnesium pentahydrooxychloride in the hardening stone·$5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$ (Fig. 9). Fibrous crystals $5Mg(OH)_2 \cdot MgCl_2 \cdot 8H_2O$ perform a reinforcing function in composites and provide intensive hardening and strength of the stone (Fig. 10).

The high strength and adhesive ability of the magnesia binder make it possible to minimize the matrix content and form a coarse-pored granular structure of the composite (Fig. 11). The diversity of the composition and structure of the developed magnesia materials determines the possibility of their combination in variatropic composites.

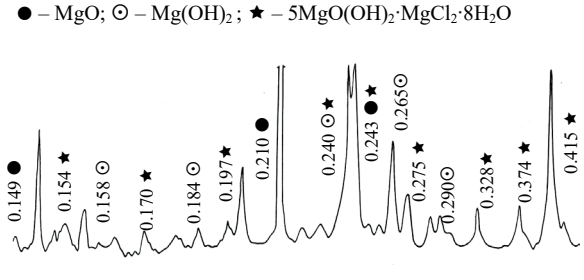


Fig. 9. Radiograph of magnesia stone.

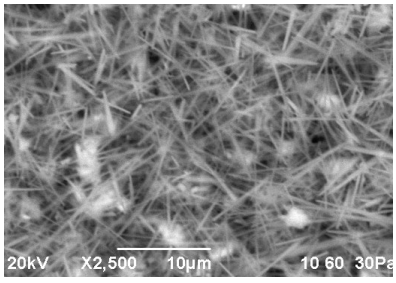


Fig. 10. Microstructure of magnesia stone.

Variatropic structures differ in variable values of density and strength in the cross-section of the material. The combination of layers of different compositions and structure makes it possible to obtain composites with adjustable characteristics. For example, a magnesia composite of variable structures contains a central coarse–porous layer with a density of 450–500 kg/m^3, the surface layers are made of fine-fibre material based on particle board waste with a density of 980–1030 kg/m^3 (Fig. 12). The ratio of layers in the structure of a variatropic composite is 25 % – upper, 55 % – central, and 20 % – lower (Fig. 13). The density of the composite of the combined structure is 780–840 kg/m^3.



Fig. 11. Coarse-pored granular composite.



Fig. 12. Thin-fibre composite.



Fig. 13. Variator composite.

In terms of strength, magnesia composites are not inferior to cement light concretes of comparable density. Compressive strength of the three-layer composite material is from 9.7 MPa to 11.9 MPa. The hardening of magnesia composite materials does not require heat exposure. At the age of 3 days, materials acquire up to 70 % of the design strength.

4. CONCLUSION

The result of this research is the development of magnesia composite materials containing fine-dispersed waste of wood particle board sawing. The high adhesive ability of the magnesia binder oxychloride hardening ensures the immobilization of environmentally hazardous waste components. It also makes it possible to obtain effective construction composites of various structures and purposes.

The authors presented the compositions of finely dispersed moulding sands for manufacturing plate products containing magnesia-ash binder, chipboards sawing waste and aluminosilicate ash microsphere.

It has been established that during the process of hardening of hybrid magnesia-ash binder containing 50 % of technogenic component, a stone of the reduced density and the increased water resistance has been formed. Hybrid binder's mechanical activation provides the 18 % increase in the strength compared to caustic magnesite.

High manufacturability of magnesia moulding sands with wood waste served as the basis for obtaining unburnt granular material of various configurations. The technogenic fibrous component forms a finely porous structure of magnesia granules.

Using the method of mathematical modelling, the authors have substantiated that the preferred compositions of magnesia composite materials contain granular filler.

Feasibility of creating composites with a variotropic structure, consisting of layers with different densities, has been proved. Regulation of layers' thickness makes it possible to obtain composite materials with density 780–840 kg/m^3 and strength 9.7–11.9 MPa.

Reliable coupling of components guarantees the stability of combined structures, also due to the genetic community.

The development of composite materials is aimed at the rational disposal of industrial waste, the development of resource-saving construction technologies, and the formation of a circular economy in industrial regions.

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