ENVIRONMENTAL SAFETY OF CONSTRUCTION AND MUNICIPAL SERVICES

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ENVIRONMENTALLY FRIENDLY COMPOSITES BASED ON SECONDARY POLYETHYLENE AND PLANT RAW MATERIALS

Statement of the problem. The aim of the paper is qualified recuperation of polymer and organic wastes by obtaining environmentally friendly plate materials on their basis. This is a topical issue due to the necessity of developing the method for obtaining environmental friendly composite materials on the basis of secondary polymer and plant raw materials.

Results. Physical and chemical granulometric properties of polymeric and plant wastes are considered. The technology of plate materials was developed using both the classical methods and experiment planning method for diagrams structure property . In optimal technological modes a number of experimental samples has been made, and their properties which define efficiency of their application as decorative heat-insulated building material are studied.

Conclusions. The effective granulometric structure of initial raw material and its physical and chemical properties are shown. Optimal modes of hot pressing, ratios of components and areas of effective application of the composites in building construction are established.

Keywords: secondary polyethylene, organic wastes, pressed plates, decorative heat-insulation building material.

Introduction

Designing composite materials has been a growing concern lately. This is due to an opportunity to use materials with a very new range of useful properties [1].

In some cases there is a possibility of qualified applications of wastes and secondary industrial materials as composite ingredients. There are as well prerequisites for improving the environmental situation and boosting current industries [2].

Thermal reactives have been much in use in the production of ground wood products [3]. High technological and service performance was observed in binders based on the above resin. E.g., good strength properties and waterproof performance were achieved for ground wood products using carbamide, melamine, phenol-formaldehyde resins [4]. However, in most cases the use of the above resins is challenging due to increasingly rigid environment requirements.

In order to produce products to comply with rigid strength requirements and even more rigid requirements for environmental performance levels (toys, decorative, heat and sound insulation panel, etc.), thermoplastic polymers are used [5]. Along with a high enviromental performance level, thermoplastics are uniquely good for multiple fusion and solidification which makes it possible to use thermoplastics as a waste binder.

The present paper deals with the results of the study into wood polymer composite based on wood wastes and secondary polyethylene that have applications as decorative, heat and sound insulation panels, gaskets, fillers, etc.

1. Study of physical and chemical performance of a filler and binder

Chips are used as wood wastes that occur in most wood processing industries from radial saw machines, log-processing equipment and sawmill machinery, etc. Secondary polyethylene materials in accordance with ТУ 63-476-32-90 Secondary polymer crude materials are no longer used film and film products in agriculture, packing and storage of industrial products and as well as polyethylene bags of mineral fertilizers and fish products.

Homogeneity of composite materials and its service performance levels are dependent on the physical and chemical compatibility of the ingredients as well as its even distribution in a polymer matrix which is affected by the blending quality and the latter is dependent on the disperse composition of the components, i.e. their grinding degree.

Therefore, at the initial stage of the research the objective was to study grinding of polymer components and to evaluate their granular metric composition. If there was no need to grind the chips, polyethylene film was supplied followed by cutting using a filament into a typical grinding mill for film polymer materials. Water was also supplied to the grinding mill which provided dust particles separating from a polymer as well as protection from overheating and the polymer caking into large agglomerates. Further the chips and ground polymer were fractionated using the method of averaging of samples.

The results suggest (Fig. 1) that the main fraction (~38 %) for chips and polyethylene are 1 and 2 mm particles respectively. According to the nature of the curves, composition for wood particles (curve 1) is more homogeneous which is obviously due to the breed composition of wood (pine) and homogeneous sawmill machinery. A wider fraction composition of the ground polyethylene (curve 2) is probably due to a more complex process occurring as thermoplastics are ground: along with mechanic failure (grinding) there is counteracting physical and chemical structuring (agglomeration).

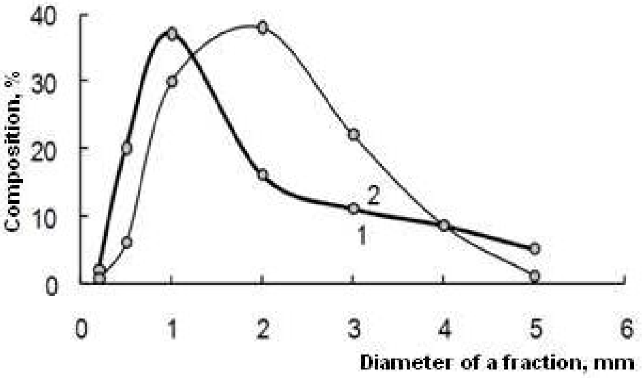

Fig. 1. Fractional composition of the filler and binder: 1 wood particles; 2 polyethylene

Here is the evaluation of some physical and chemical indicators of individual fractions of ground wood and polyethylene (Table 1, 2).

Table 1

Properties of wood particles

Indicators	Fraction size, mm			
	0.25	0.50	1.00	2.00
Apparent density, kg/m^3	86	66	44	30
Humidity, %	5.37	5.15	5.55	5.54
Free formaldehyde, mg/100 g of a sample	3.42	1.02	2.02	2.48

The results suggest (Table 1) that individual fractions of the chip mass have the identical humidity and the same amount of free formaldehyde during a subsequent drop in apparent density with increasing fraction sizes. Free formaldehyde is obviously present due to methyl groups in the cellulose component as well as in the other wood components that are capable of splitting out at high temperatures (in the analysis at t = 70 80^{o}C) resulting in the latter [6].

Secondary polyethylene is a mixture of almost equal amounts of high and low pressure polyethylene. However, the level of the indicators of the secondary polyethylene is a lot higher than LPPE and HPPE.

The above is due to aging of the structure failure material a condition polyethylene product was subjected to during its service in sunlight and heat. Grinding also contributes to that to a certain degree. Ground secondary polyethylene is therefore a polymer with a macrostructure, unlike that of LPPE and HPPE has a more branched chaotic structure as suggested by the physical and chemical indicators (Table 2).

Table 2

Properties of polyethylene

Indicators	Secondary polyethylene	Low pressure polyethylene (LPPE)	High pressure polyethylene (HPPE)
Density, kg/m^3	890-915	940-960	920-930
Fusion temperature, ^{o}C	125-160	120-180	108-110
Compression limit strength, MPa	9.8	22-35	12-16
Water consumption over 30 days, %	0.05	0.03-0.04	0.04

Taking into account a range of differences in the chemical nature of wood and polyethylene as well as the above features of initial wastes, we can speculate about how there is little compatibility of the latter and low likelihoods of their chemical interaction [7].

In order to improve the compatibility of the wood and polyethylene components, the third component - ethylene-propylene rubber is suggested [8].

The production of a composite material included several stages: filler fractionation, treatment of the examined fraction with a ethylene-propylene solution in a non-fraction followed by drying, combination of modified wood particles with polyethylene by prior mixing and heating followed by rolling on a laboratory roll with rollers of 20 mm in diameter and a 1 mm gap between them, pressing of the obtained mass in a hydraulic press ПГ-60 at 130   140°C and pressure of 5 MPa.

According to the above technique of producing composites, the effect of filler fraction on the physical and chemical properties of a composite material was further investigated. It was shown (Fig. 2) that as the size of wood particles increases, there is an improvement of the physical and chemical properties, which is more obvious in the fraction range of 0.25 to 1.50 mm.

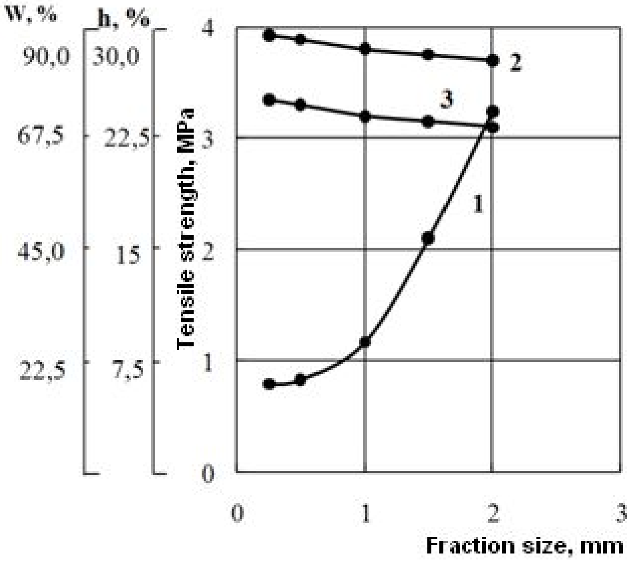

Fig. 2. Dependence of the physical and mechanical properties of composite materials on the size of wood particles:

1 compression limit strength;
2 water consumption W;
3 swelling h

An increase of a fraction size that follows results in a significant change in the properties of a composite.

2. Designing a mathematical model

In order to select the optimal correlation range between the filler (chips), binder (polyethylene) and modificator (ethylene-propylene rubber), the experiment was planned for the Component-property diagram to significantly reduce the amount of problems the experiment needed to address. The study was made into a local area of the diagram which is an irregular simplex with the top coordinates

$$A_1(x_1^{(1)},x_2^{(1)},x_3^{(1)}),\ A_2(x_1^{(2)},x_2^{(2)},x_3^{(2)}),\ A_3(x_1^{(3)},x_2^{(3)},x_3^{(3)}).$$

The examined local area is given by

$$0 \le a_i \le x_i \le b_i \le 1,$$

where a_i, b_i are component constraints.

The experiment to study the properties of composite materials and optimization of the content was planned according to [9].

The content of the components varied as follows:

$$40 \le x_1 \le 100; 0 \le x_2 \le 5; 0 \le x_3 \le 55,$$

where x_1 is the content of the secondary polyethylene, mass fraction, %; x_2 is the content of ethylene-propylene rubber, mass fraction, %; x_3 is the content of wood particles, mass fraction, %.

In order to define a regression equation, a third order simplex-lattice design for a three-component mixture in relation to a pseudocomponent z_1, z_2, z_3 that were obtained from x_1, x_2, x_3 by recalculating the formula

$$x_i^{(u)} = x_i^{(1)} + z_2^{(u)} \cdot (x_i^{(2)} - x_i^{(1)}) + z_3^{(u)} \cdot (x_i^{(3)} - x_i^{(1)}),$$

where $x_i^{(u)}$ is the content of the components in any u-th point of the design; $z_i^{(j)}$ is the content of the pseudocomponents in any u-th point of the experiment.

Considering the above constraints and dependencies, we have an experiment design with the tops of the simplex lattice in the x_i coordinates: $A_1(100, 0.0)$, $A_2(40; 5.55)$, $A_3(45; 0.55)$ as shown in Table 3.

The response function to determine an optimal area of the composite composition was the following properties of composite materials: compressive strength limit, MPa; water consumption, %; swelling, %. Implementing the design enabled us to present the response function as regression equations:

$$Y = \beta_1 z_1 + \beta_2 z_2 + \beta_3 z_3 + \beta_{12} z_1 z_2 + \beta_{13} z_1 z_3 + \beta_{23} z_2 z_3 + \gamma_{12} z_1 z_2 (z_1 - z_2) +$$
$$+ \gamma_{13} z_1 z_3 (z_1 - z_3) + \gamma_{23} z_2 z_3 (z_2 - z_3) + \beta_{123} z_1 z_2 z_3.$$

The experimental data that was used to obtain the coefficients of the above polynomial is in Table 4.

Table 3

Design matrix for a third-order polynomial

Number of the experiment	Coordinates of the pseudocomponents			Coordinates of the components		
	z_1	z_2	z_3	x_1	x_2	x_3
1	1	0	0	100.0	0.0	0.0
2	0	1	0	40.0	5.0	55.0
3	0	0	1	45.0	0.0	55.0
4	2/3	1/3	0	80.2	1.6	18.2
5	1/3	2/3	0	60.4	3.3	36.3
6	0	2/3	1/3	42.2	3.3	54.5
7	0	1/3	2/3	43.9	1.6	54.5
8	2/3	0	1/3	81.8	0.0	18.2
9	1/3	0	2/3	63.7	0.0	36.3
10	1/3	1/3	1/3	62.1	1.6	36.3

Table 4

Properties of composite materials based on industrial wastes

Physical and chemical properties	Experiment number in the design matrix									
	1	2	3	4	5	6	7	8	9	10
Compressive limit strength, MPa	8.50	1.88	2.77	4.83	3.77	2.84	2.33	7.12	4.15	3.08
Water consumption, %	0.0	1.9	22.5	1.9	8.5	17.3	18.5	1.7	6.0	3.9
Swelling, %	0.0	20.1	19.1	1.2	10.0	15.3	15.5	1.0	4.2	2.5

The polynomial coefficients that were calculated using a specially developed software were applied to design isolines of the properties of composite materials (Fig. 3). The feasibility of the equation was proved by the experiments in the control points.

The comparative analysis of the isolines allowed determination of the optimal composition of composite materials in all the response functions.

a) b)

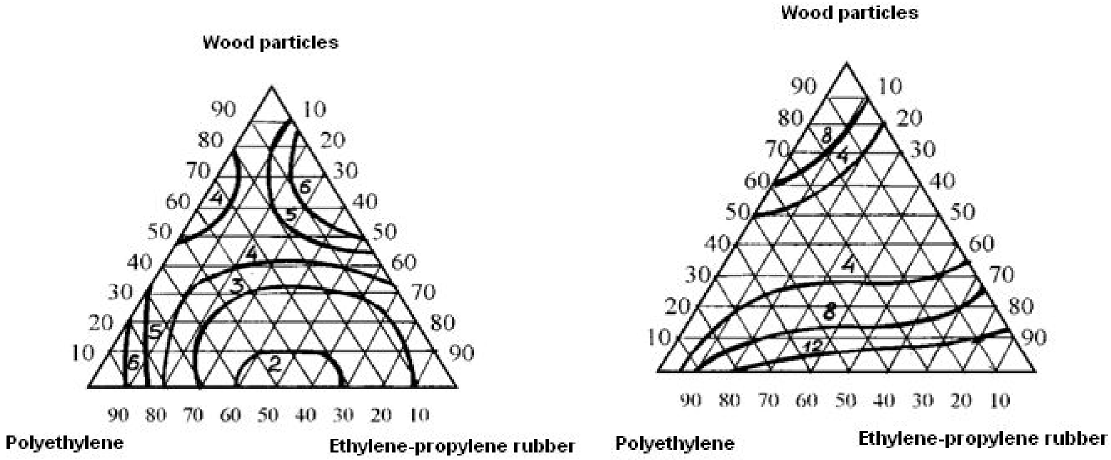

Fig. 3. Isolines of the properties of composite materials:
a) compressive limit strength, MPa; b) swelling, %

The largest value of compressive limit strength (excluding the area close to the top x_1 of the triangle, which is secondary polyethylene with no other components) as well as the smallest value of water consumption and swelling were those of the following composites: secondary polyethylene 41 48 mass fractions, %; wood particles 49 55 mass fractions, %; ethylene-propylene rubber 3 4 mass fractions, %.

It is obvious that further studies into possibly obtaining composites in the following way need to be made regarding the optimal composites. It should be noted that extrusion method is currently regarded the most promising way of recycling this kind of composites as it allows a higher mixture ratio with the content of the wood filler of up to 75 85 % and more depending on the capacity of an extruder. The compositions suggested by us may prove efficient in the long run in case of extrusion as well.

Conclusions

1. A granular metric composition of the ingredients was investigated and it was found that fractions of pine chips and ground polyethylene of 1 2 mm that make up the most of the standard secondary polyethylene and equipment chips are easy to work with during flat pressing and dry mixing of ingredients.

2. The method of designing an experiment for the composition-property options was helpful in obtaining the regression equation coefficients whose response functions were compressive limit strength, water consumption and swelling and the variables were secondary polyethylene, pine chips and modificator (ethylene-propylene rubber) which provided better compatibility of the main components.

The comparative analysis of isolines allowed determination of the optimal composite: secondary polyethylene 41 48 mass fractions, %; wood particles 49 55 mass fractions, %; ethylene-propylene rubber СКЭПТ 3 4 mass fractions, %.

3. In the optimal composition we can expect to obtain the highest indicators of the strength and service properties of the examined plate polymer composite materials.

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