Possibilities for the polymer composites physicomechanical characteristics improvement

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Abstract. A group of composite materials based on a polyvinyl chloride matrix and dispersed industrial wastes is presented. Production of these materials will significantly reduce the anthropogenic burden on the environment by reducing the primary resources consumption. Studies of the new materials physicomechanical properties dependence on the composition and quantity of the dispersed filler are presented. The industrial wastes characteristics influence on the composites structure formation is considered. The data obtained indicate the competitiveness of the developed composite materials and the feasibility of their production.

1. Introduction

The construction industry development leads to the need to expand the nomenclature of tailor-made building materials. Modern researchers have learned to create composites according to given characteristics that satisfy the specific customer needs. However, no less important is the construction industry environmental component, associated not only with impact mitigation, but also with the non-renewable natural resources preservation. That is why today the production technologies of building materials on the basis of or with the content of waste and recyclable materials are widely used.

In turn, the waste use in the production of building materials is accompanied by additional difficulties associated with the need to study the used industrial raw materials safety and its properties. In addition, among consumers, there are still stereotypes associated with the danger of building products containing waste. However, the recycled materials use in production has several undeniable advantages:

- finished products cost-cutting by 30-50%, due to the waste low cost compared to primary resources [1];
- decrease in the consumed primary resources volume by 40%;
- reducing the negative impact on the environment by reducing the accumulated waste volume, reducing the seized land area, reducing the pollutants emission into the air, water and soil, etc.;
- creating the manufacturer benign image that increases the demand for products.

Along with the cost and construction products environmental friendliness, consumers are interested in the material performance, which directly determine its purpose and application scope. Decorative coatings and building mixtures should have adhesion to the surface to be coated, and concrete should be frost resistant and have a slight shrinkage. However, it can be said with confidence that the applicability of most building materials is to some extent determined by their strength.
2. Experimental procedure
In general, strength is a material ability to resist an applied load without breaking. Nevertheless, depending on the applied load nature and direction, many different values can be obtained. This article considers the improving the strength characteristics of composite building materials on the example of determining the static compressive strength, static bending strength and static rupture strength by the breaking strength.

Studies were conducted on the example of the mineral-polymer building composite "Vinizol", developed on the basis of the Irkutsk National Research Technical University. The composition includes a polyvinyl chloride (PVC) matrix, dispersed filler in the fly ash form from thermal power plants and a modifying additives set, which are aimed at improving the mixture processability, reducing friction in the raw materials preparation and processing, as well as to modify the product final properties, in particular, strength and elasticity. The composition is processed by extrusion with obtaining molded building products for construction and finishing purposes [2, 3].

The research was based on the study of changes in the mineral-polymer composite strength characteristics, depending on the filler type and amount. As the latter, dispersed materials of different composition and origin, including man-made materials, were used. The basic composition for all materials remained unchanged: suspension PVC grade SI-64 – 100 pts. wt., modifying additives – 11 pts. wt. The materials composition is presented in table 1.

Table 1. The fillers content in the studied materials

| Composite  | Filler type                  | Filler content, pts. wt. |
|-----------|------------------------------|--------------------------|
| Composite 1 | Vermiculite                  | 40                       |
| Composite 2 | Marble dust                  | 75                       |
| Composite 3 | Marble dust                  | 110                      |
| Composite 4 | Fly ash                      | 65                       |
| Composite 5 | Carbon nanoparticles         | 0.0016                   |
| Composite 6 | Aluminosilicate microspheres | 48                       |
| Composite 7 | Aluminosilicate microspheres | 23                       |
| Composite 8 | Aluminosilicate microspheres | 23                       |

All fillers as dispersed materials have different composition and origin. Marble dust is the marble mining and processing waste - fine white powder with a predominant grain size of 4-30 microns (≈ 75%). The chemical composition is represented mainly by Ca and Mg carbonates. Vermiculite is a layered natural mineral with Si, Mg, Al oxides predominance. Exfoliated vermiculite obtained by mineral rapid roasting, as a result of which the grains are increased up to 15–20 times in volume, was used as a filler. Fly ash is the coal combustion products finest fraction, caught by electrostatic precipitators. Fly ash has a particle size wider distribution - more than 80 % of particles have a 6-200 microns in size. The fly ash composition is mainly represented by Si, Al, Fe, Ca, Mg oxides.

The aluminosilicate microspheres use is of particular interest [4]. Their chemical composition is similar to that of fly ash, however, the grains shape is close to a hollow ideal sphere, which leads to high particle strength, low thermal conductivity and chemical inertness. The microspheres chemical composition peculiarity is the acidic aluminum oxides high content (over 20.0 wt.% Al₂O₃) and silicon (over 62.0 wt.% SiO₂), but low iron content (less than 3.5 wt.% equivalent to Fe₂O₃). Of no less interest are carbon nanoparticles. In this work, nanoparticles (carbon nanotubes) were isolated from silicon dust. The specific surface area is 500-1500 m²/g. The energy dispersive X-ray microanalysis method determined a significant (up to 35%) quartz content and the carbon content up to 12 %.
The conditions for the raw materials preparation (two-stage mixing) were identical for all compositions, and the extrusion processing technological modes were adjusted individually, which is associated with significant differences in fillers that affect the melt viscosity in the extruder chamber [5].

To study the fillers effect on the composite building materials physicomechanical properties, tests were conducted to determine the composites strength characteristics. For all compositions, the maximum load that leads to the sample destruction during compression, rupture and bending was determined. On the basis of this load the ultimate strength was determined. All tests were carried out in accordance with applicable standards - GOST 11262, GOST 4651 and GOST 4648. The test results are presented in table 2. The table also shows the ultimate strength values of the source material Vinizol and the object analogue - wood-polymer composite (WPC), which uses wood flour as a filler.

| Table 2. The composite building materials physicomechanical characteristics study results |
|-------------------------------------------------------------|
| Compressive strength, MPa | Tensile strength, MPa | Flexural strength, MPa |
|---------------------------|----------------------|-----------------------|
| Composite 1               | 42.28 ± 0.46         | 21.81 ± 1.41          | 49.29 ± 3.04           |
| Composite 2               | 45.51 ± 0.42         | 18.14 ± 1.57          | 48.21 ± 3.03           |
| Composite 3               | 46.31 ± 0.3          | 19.61 ± 0.51          | 34.78 ± 1.27           |
| Composite 4               | 42.34 ± 0.83         | 16.31 ± 0.35          | 27.13 ± 1.93           |
| Composite 5               | 35.09 ± 0.72         | 11.54 ± 0.87          | 24.02 ± 2.5            |
| Composite 6               | 40.1 ± 0.65          | 13.69 ± 0.48          | 35.78 ± 0.52           |
| Composite 7               | 35.67 ± 0.39         | 12.55 ± 1.21          | 34.24 ± 0.68           |
| Composite 8               | 30.88 ± 0.52         | 5.91 ± 0.55           | 15.62 ± 6.48           |
| Vinizol                   | -                    | 18.9                  | 35.93                  |
| WPC                       | -                    | 9.0                   | 25.0                   |

From the table 2 it can be seen difference between the obtained values of ultimate strength of various composition materials. At the same time, no single composition surpasses the rest at the same time in all characteristics. However, it can be noted that composites 1-3 have the best strength properties combination and are significantly superior to other compounds, including Vinizol and WPC.

The composite materials properties are largely due to their structure, which is a heterogeneous system. The composites physical and mechanical properties are largely characterized by the matrix-filler bond strength, which in turn depends on many factors: the interface area, the particle size and shape, the wettability of the filler polymer matrix, the adhesion, etc. Consider the studied materials micrographs with the aim of studying their structure and the components interaction nature (figure 1).

As can be seen from figures 1-2, the polymer matrix structure is not changing in relation to the filler composition. However, shapes, particles size and their incorporation nature into the matrix are different. Figure 1c shows a composite 1 micrograph containing 40 weight parts. expanded vermiculite. The figure shows how large the vermiculite particle is (on the right side of image), especially when compared to the filler particles in other photos. It should also be noted that the polymer is tight is tight to the filler particle.
Figure 1. Micrographs of the starting components and materials with various fillers:
a) PVC without filler; b) fly ash; c) PVC and expanded vermiculite; d) PVC and marble dust; e) PVC and microspheres; f) PVC and fly ash.
Figure 2. Micrographs of the materials with fly ash and nanoparticles.

Figure 1d shows a composite 3 micrograph with a content of 11 weight parts including marble dust. The scale bar in the picture allows you to note how small the marble particles are in the composite. The particles shape is closest to that of a prism, the filler is also tightly embedded in the PVC matrix structure. Figure 1e shows the material containing microspheres. The picture shows that the filler particles shape is almost perfect, however, the density of adhesion of the polymer to the microspheres is not the same. The same applies to fly ash in the composition (figures 1f, 2). Ash particles also resemble spheres in shape, but much less regular in shape. The ash particles size varies considerably, which confirms the data on the fly ash particle size distribution.

In general, it should be noted that a filler particles significant amount is present on the studied composites breakdown, which confirms the well-known fact of the primary composites destruction at the interface [6]. Thus, taking into account the results of the study of physical and mechanical properties of composite building materials, it can be assumed that high-strength limit for materials containing expanded vermiculite and marble dust as a filler largely depends on the fillers characteristics. For vermiculite, this is a particles layered lamellar structure, and for marble dust there is a grains dispersion high degree and a prismatic shape.

3. Conclusion
1. Using the technogenic raw materials as a filler allows to improve the composite building material physical and mechanical characteristics, while reducing the primary resources consumption and the final product cost.
2. The best physical and mechanical properties combination have compositions filled with exfoliated vermiculite and marble dust.
3. Composites 1-3 high strength properties are determined by the materials structure and the fillers characteristics: the particles are tightly embedded in the polymer matrix and due to the high specific grains surface and shape form a strong particle-polymer bond.

A detailed study of the properties of the developed materials and the establishment of patterns of changes in the properties of the composition of the composition and characteristics of the filler, as well as the development of a line of highly durable highly filled composite building materials is the subject of further research by the authors.

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