Components of solid municipal waste in construction compositions

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Abstract. The effectiveness of chemical, thermal, mechanical and complex methods of disposal of polymer waste was analyzed. The results of studies aimed at the development of the composition of a thermoplastic binder using polymeric municipal waste, taking into account the sample sizes of various components in waste sorting complexes, are presented. The binder is filled with mineral powders and shredded wood waste. Received compositions are used for the manufacture of construction products with a long life cycle. Standard methods for determining the properties of products for constructional purpose, the parameters of the fillers were used. Compositions for the manufacture of polymer-mineral composite building materials are offered. The optimal parameters of filling and dosage of functional additives are established.

1. Introduction
Such positive tendencies of the XX-XXI centuries as the growth of industrial production, an increase in population and life expectancy, an improvement in the quality of life also have their negative consequences. This includes the rapid increase in the amount of industrial and household wastes. The practice of handling municipal waste most acceptable today for the Russian Federation is transporting them by municipal services to waste sorting complexes\textsuperscript{[1-6]}. The main task of such complexes is to reduce the volume of garbage. The efficiency of the complexes increases due to the extraction of useful components from the garbage, such as: glass, metal, paper and cardboard, textiles, wood, plastic. The number of extracted components is not so great. This number is about 10\% of the total mass of garbage. The remaining 90\% is reduced in volume by grinding. The resulting mass is to be disposed of at special landfills.

It is obvious that there are various plastic such as different packaging, broken household items, toys, etc in a large volume of municipal waste. If we consider plastic by type of polymer, then polyethylene terephthalate (PET) is most successfully removed by waste sorting complexes. PET beverage bottles are easily identified and removed separately - transparent, green, brown, white; PET bottles are also separated from the oil. Polyolefins (low and high pressure polyethylene (HDPE, LDPE), polypropylene (PP)) are also successfully extracted in the form of containers from household chemicals, canisters, containers from food products, disposable tableware, transparent and colored bags. Communal waste also contains quite a lot of polystyrene (PS), because this polymer in foam form (press-free - EPS) is widely used as protective packaging for household appliances, various goods and products. EPS is also one of the most popular types of thermal insulation, and accordingly it is a component of construction waste. However, the sampling of EPS from waste is difficult, and it is extracted in small quantities. Thermosetting polymers and polyvinyl chloride (PVC) are difficult to identify, and therefore are almost
completely disposed of. Such a variant of polymers, like rubber in automobile tires due to the increased hazard class, is not allowed on waste sorting complexes, and should be disposed of by specialized methods. In this way PET plastic and plastics as HDPE, LDPE, PP are a mass commercial products of waste sorting complexes. According to Waste Management JSC, PET is about 70% of all recoverable plastic and 30% is polyolefins.

The effectiveness and applicability of various methods for the processing of polymeric waste, depending on the type and properties of the polymers, the volume of education, the degree of pollution and other specific factors, are reflected in domestic and foreign surveys and monographs [7-10], as well as in numerous Russian studies (Karpov Institute of Non-Ferrous Metallurgy [11], K. Berkunov State University named after Kh. M. Berbekov [12], VGU named after Stoletov [13], KuzGTU named after TF Gorbachev [14], MSTU named after G.I. Nosov [15, 16], Peter the Great St. Petersburg Polytechnic University [17], SSTU named after Gagarin Yu. A. [18, 19]), European [20], American [21, 22] and other [23-25] scientific schools.

It is known that chemical methods for processing PET waste, such as transesterification [26], hydrolysis [13, 14, 26, 27], glycolysis [25, 21, 24, 28], algolysis [26], methanolysis [13, 21, 29], and others, with obtaining valuable low-molecular products, or destructive decomposition to produce sorbents [15, 18, 22], are complex in technological design, durable and often energy-intensive. Methods for processing PET waste based on thermal exposure to produce low-molecular products (pyrolysis, thermolysis [30]) are also associated with technological difficulties and significant energy costs. Thermal processing, which is aimed at obtaining energy, is ineffective, because the calorific value of polymers is commensurable with that of, for example, wood or coke [31], and the cost of polymer fuel is much higher (the reason for this is the cost of collecting and sorting waste).

Due to the relative simplicity and low energy consumption thermomechanical methods of processing polymer wastes are the most possible. Polymer waste is ground by cutting in high-performance shredders. The resulting crushed material is heated to the softening temperature or to the temperature of melting and then on the special equipment loose agglomerate is received. More common technology is in melting polymers and extruding a melt, followed by cutting the material into bulk granules. The technologies of mechanical processing of PET-waste into flexs are also quite common. The resulting semi-finished products - agglomerate, granulate, flex - are subject to further processing into products and can serve as a substitute for the primary polymeric raw materials.

Examples of successful processing of polymeric waste in building products include the production experience of the companies of OOO Prompolymer (Kirov), Skolkovo Mechanical Plant (Samara Region), Pstile (Bashkortostan), and others.

Using polymer semi-finished products in the form of granules and flexes for the manufacture of building products, having a cost lower than the cost of primary raw materials (approximately 20-30%), but still quite tangible, leads to increased prices for products. Often polymer-mineral building products are not in demand, due to the fact that they are competing with similar products based on cement, which are inferior in properties, but significantly cheaper than polymer-based products.

Therefore, the aim of the work was to develop compositions for the manufacture of construction products based on polymeric waste, using waste without prior cleaning and processing into semi-finished products.

2. Materials and Methods
Polymeric waste PET, HDPE, LDPE, PP, obtained by sorting municipal waste, were studied. Wastes were crushed into particles up to 5 cm.

Mineral powder materials obtained by drying, crushing and grinding samples of regional rocks (quartz sand, limestone, chalk, clay, and flasks) were investigated as fillers. In order to reduce the density of products, as a filler we studied wood waste obtained by grinding wood components of municipal waste, such as elements of old furniture and construction products made of wood that were out of circulation. Crushed wood waste was pretreated with sodium silicate solution, and then dried.
Standard methods for determining the properties of products for constructional purpose, the parameters of the fillers were used.

3. Results and Discussion

The possibility of manufacturing building products based on PET waste by heating at 270 °C for 1 hour in forms of compacted composition from a mixture of PET-waste with particle sizes up to 1 cm and quartz sand, without using melting and mixing equipment is shown (Table 1).

Table 1. Properties of samples made by pressing mixtures % with following heating based on PET waste.

| The content of the PET, % by weight of the composition | Average density, kg/m³ | Compressive strength, MPa | Bending strength, MPa | Water absorption, % by weight |
|------------------------------------------------------|------------------------|---------------------------|----------------------|----------------------------|
| 15                                                   | 1890                   | 11.8                      | 1.6                  | 10.0                       |
| 20                                                   | 1920                   | 18.0                      | 2.0                  | 5.0                        |
| 30                                                   | 1970                   | 22.4                      | 1.6                  | 3.0                        |

The resulting products have satisfactory compression strength at 20-30% binder content in the composition. It is necessary to increase the time for keeping samples in the mold at a temperature of 270 °C with an increase of PET waste in the composition. But this leads to an increase in technological energy consumption. It should be noted that the samples obtained by this method have a low flexural strength, the noticeable surface porosity and low decorativeness of the samples.

The possibility of manufacturing building products based on PET waste with the preparation of a mixture of PET waste with particle sizes up to 5 cm and quartz sand in a melting and mixing unit at a temperature of 250-270 °C is also shown. The technology involves laying the hot mixture into molds and pressing the mixture for 2 minutes, holding it for 5 minutes with following remove the sample from the mold (Table 2).

The strength of the samples obtained by this method is significantly higher. The highest value of the strength parameters is observed at 30% content of PET waste in the composition. In this way to obtain high-quality products, it is necessary to completely melt the PET waste.

Table 2. Properties of the Samples Made by Pressing of Hot Mixtures Based on PET-Waste.

| The content of the PET, % by weight of the composition | Average density, kg/m³ | Compressive strength, MPa | Bending strength, MPa | Water absorption, % by weight |
|------------------------------------------------------|------------------------|---------------------------|----------------------|----------------------------|
| 15                                                   | 1813                   | 10.0                      | 4.0                  | 7.0                        |
| 20                                                   | 1935                   | 22.5                      | 5.6                  | 2.7                        |
| 30                                                   | 1961                   | 76.4                      | 17.4                 | 0.3                        |
| 40                                                   | 1838                   | 65.8                      | 13.9                 | 0.3                        |
| 50                                                   | 1720                   | 61.7                      | 9.0                  | 0.3                        |

Additionally, samples were made according to the technological variant of the preparation of the composition in the melting-mixing unit, with the only difference that other mineral fillers of various degrees of dispersion were used. It was established that with the introduction of coarse carbonate chips (limestone with a particle size of 0.315-5 mm) into the composition, the properties of the samples become close to the properties of samples filled with quartz sand. The usage of finely dispersed fillers with a specific surface area in the range from 1000 to 8000 cm²/g, regardless of the chemical and mineralogical composition of the filler (finely divided flasks, montmorillonite clays, limestone, chalk), decreases in physical and mechanical properties of the samples.

This indicated the need to change the composition of the binder, the need to introduce polyolefins into the composition. It is also necessary to use modern additives-bearers in the composition. This modern additives facilitate the processes of mixing thermoplastics among themselves and with mineral fillers. Also they contribute to enhancing the adhesive interaction at the level of the interfacial layers. Compositions have been developed [19, 32]. The binder is a complex of PET-waste, waste of polyolefins
(preferably PP), additive additives (copolymer of ethylene and vinyl acetate Etatilen EVA-g-GMA), filled with fine mineral powders, to obtain high-quality durable building products with strength at compression up to 70 MPa and frost resistance over 200 cycles.

The possibility of introducing wood waste into the compositions was considered. On the one hand, such a filler will reduce the density of products, on the other hand, it will effectively utilize the wood components of municipal waste. The properties of samples made by pressing from hot mixtures based on a binder (including PET-waste, PP-waste, the addition of Ethatilene EVA in a ratio of 70% : 25% : 5% by weight) filled with mineral powders and chopped wood waste are investigated. The binder content in compositions, filled with mineral powders only, was 70% by weight. Shredded wood waste was introduced by replacing the volume of mineral filler with an equivalent volume of wood filler. Volumetric parts of the fillers for the convenience of analysis transferred to the mass parts (Table 3).

The decrease in the density of the obtained samples with an increase in the content in the compositions of shredded wood waste leads to a regular decrease in strength. However, the resulting strength indicators are at a fairly high level. This allows the usage of the developed compositions for the manufacture of construction products for structural purposes.

### Table 3. Properties of Samples Made by Pressing from Hot Mixtures, Based on a Binder (from PET-Waste, PP-Waste, Auxiliary Additive), Filled with Mineral Powders and Crushed Wood-Waste.

| Binder content, parts by weight | Filler content parts by weight | Average density, kg/m³ | Compressive strength, MPa | Bending strength, MPa | Water absorption, % by weight |
|-------------------------------|-------------------------------|------------------------|---------------------------|----------------------|------------------------------|
| 100                           | 233                           | 1900                   | 39.6                      | 10.3                 | 0.2                          |
| 100                           | 160                           | 1610                   | 35.9                      | 16.1                 | 0.5                          |
| 100                           | 120                           | 1572                   | 34.7                      | 14.7                 | 0.5                          |
| 100                           | 40                            | 1389                   | 34.2                      | 9.4                  | 0.5                          |
| 100                           | -                             | 1110                   | 25.1                      | 6.2                  | 2.7                          |

### 4. Conclusions

Studies have shown the possibility of manufacturing construction products based on polymer waste, using waste without prior cleaning and processing into semi-finished products. It is advisable to combine in one composition PET-waste and waste polyolefins, preferably PP-waste. The optimal content of the polymeric binder in the filled composition was established. It is 30% by weight of the composition. The possibility and expediency of introducing wood components of municipal waste into the compositions is shown.

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