Composite materials based on non-recyclable polyethylene

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Abstract. In this paper, the possibilities of creating composite materials based on cross-linked polyethylene (XPE) were investigated. The environmental benefit of recycling such polyethylene is to free up space for buildings that are now occupied by landfills. The influence of polyethylene, previously considered non-recyclable, on the strength characteristics of concrete is shown. In the course of the work, waste from the existing chemical industry was used, with varying particle sizes (0.5-15 mm). The analysis of patent information on the utilization of polyethylene in construction materials. Using mathematical planning methods, the compositions of composite materials are optimized. The volume of solid waste of non-recyclable plastic is more than 1.3 billion tons. Its decay period in the natural environment is more than 400 years. There is no world experience in the use of such waste, so the problem of its disposal is more than relevant. Thanks to the results obtained, it is possible to significantly reduce the degree of environmental pollution by waste of chemically cross-linked polyethylene, and get a new composite material for construction, a wide range of applications. The economic justification of the developed technology being introduced into mass production is presented.

1. Introduction

The problem of sustainable development of the global construction industry is closely related to the environment and the use of modern building materials with improved physical and mechanical properties. These materials include polymer-modified concrete. There is no world experience in the use of cross-linked (non-recyclable) polyethylene. This may indicate the difficulty of identifying the polymer and the imperfection of its processing methods. Environmental pollution from various non-biodegradable wastes not only poses a danger to the environment, but can also lead to serious consequences for human life. In this work, the authors proposed the use of non-recyclable waste cross-linked polyethylene cable industry in the production of building composite materials.

The mechanism for adding cross-linked waste is similar to the methods for the production of building composite materials with the addition of fiber from a polymer material, such as PET [1]. The fundamental difference lies in the chemical composition of the modifying substances, which does not allow recycling of cross-linked material by classical methods of processing secondary resources. Many scientists have noted that dispersed reinforcement of concrete with polyethylene particles has a number of advantages compared to traditional nets and frames [2–6]. Recently, the processing of polyethylene terephthalate (PET) is actively developing. Primary PET makes a large number of bottles and food containers. The annual production of this plastic is millions of tons. However, even with modern recycling methods for recycled PET, the percentage of recyclable waste is very small, which,
in turn, provokes the appearance of large dumps of unprocessed plastic, which has been decomposing for more than 400 years. Therefore, the issue of using plastic waste in industry, including in construction, is becoming increasingly important [7]. Scientists around the world are gradually solving the problem of recycling: there are two successful examples of the use of such materials in building structures [8]. The positive effect of the addition of PET fibers on the strength of concrete was proven by researchers from Italy and Malta [9]. They studied the effect of various types of straight and curved fibers. The resulting samples had higher cracking strength, lower shrinkage and increased tensile strength. Also, Portuguese scientists found that the addition of waste in the form of hard flakes increases the cracking limit of the samples under compression, and the tensile and bending strengths are directly proportional to the compressive strength [10]. Researchers from Malaysia worked with concrete containing 0.5%, 1.0%, and 1.5% PET fiber. They noted a slight increase in strength [11]. Employees at Baba Gulam University Shah Badshah (India) also studied the behavior of various types of concrete grades B20, B25 and B30, with the addition of a certain amount of PET fiber (2%, 3%, 4% and 5%). Mechanical properties, such as compressive strength, were compared with conventional concrete grades. The optimum compressive strength of concrete was achieved by adding 3% PET fiber [12]. The use of crosslinked polyethylene particles (SPE) as a filler in concrete partially solves the problem of recycling, and it also opens up the possibility of obtaining new composite materials with improved mechanical properties.

The purpose of this study is to develop a technology for producing composite building material based on non-recyclable cross-linked polyethylene.

2. Methods
The work uses waste chemically cross-linked polyethylene (XPE), which are formed in the production of cable braid. Polyethylene is crosslinked with dicumyl peroxide [13]. The structural difference of crosslinked polyethylene from the initial one is shown in Figure 1. During the curing reaction, transverse bonds form between the macromolecules, which, in turn, prevent the material from melting, so it cannot be recycled. Residual peroxide residues may also be present in the composition of the material: acetophenone, dicumyl peroxide in amounts of <0.05% [14].

![Figure 1. General view of the formula of uncrosslinked (a) and crosslinked (b) polyethylene](image)

The properties of XPE compare favorably with the linear one: it becomes less susceptible to UV rays, acquires oil and benzo resistance, and the softening temperature rises. The density of the material varies from 920 to 980 kg/m³. The particle length is within 10 ± 5 mm.

The authors proposed to study the effect of the XPE filler on the strength characteristics of concrete on various binders (Portland cement, Sorel cement, lime, gypsum and clay). Table 1 shows the composition of composite materials based on Portland cement and Sorel cement. The study of the properties of concrete mixtures with the addition of XPE was carried out in several stages:
- sample preparation, with different concentrations of waste, on all types of binders;
- determination of strength characteristics and density of samples;
- analysis of the results and conclusions.
Table 1. The compositions.

| Name of composite | Components, mass. % |
|-------------------|---------------------|
|                   | Cement  | Sand    | Waste  | Water  | Sorel cement | Bischofite |
| SC-10             | 21.7    | 65.3    | 0      | 13     | -            | -          |
| SC-20             | 19.5    | 58.8    | 10.0   | 11.7   | -            | -          |
| SC-30             | 17.3    | 52.4    | 20.0   | 10.3   | -            | -          |
| SC-40             | 15.2    | 46.5    | 30.0   | 8.3    | -            | -          |
| SS-10             | -       | 51.8    | 0      | -      | 17.2         | 31         |
| SS-20             | -       | 46.6    | 10.0   | -      | 15.5         | 27.9       |
| SS-30             | -       | 42.0    | 20.0   | -      | 13.2         | 24.8       |
| SS-40             | -       | 37.3    | 30.0   | -      | 11.4         | 21.3       |

XPE was added in an amount from 0 to 30% of the total mass, reducing the amount of sand introduced. The length of the introduced fiber was in the range of 0.5 - 15 mm. (standard length, when crushing waste by industrial methods).

Recipe samples were prepared as follows: in a deep container, all components were thoroughly mixed using a ZUBR MP-1050-1 hand mixer, then the resulting mixture was poured into a silicone mold, placed on a PE-6700 vibrating stand for compaction, and then sent to a Climcontrol M climate chamber 0 / 100-1000 KTV for curing. The obtained samples (see Figure. 2) after 7 and 28 days were examined for physical and mechanical characteristics.

Figure 2. Appearance of samples on a magnesian binder (a) and on Portland cement (b)

To determine the strength of the samples, the IPS-MG4.03 device was used. This type of device is designed to determine the strength of concrete by the shock pulse method in accordance with GOST 22690.

The density of concrete was determined in accordance with GOST 12730.1 Concretes. Density determination methods. Density was determined in the air-dry state. Before testing, the samples were aged 28 days. During the test, the dimensions of the samples were measured with an accuracy of 0.5 mm. Then, the mass of the samples was measured and their density was calculated.

3. Results and Discussion
The results of studies of physical and mechanical properties are shown in table 2. As can be seen from table 2, replacing sand with crushed polyethylene can double the strength of Portland cement compositions by introducing 30% filler (SC-40).
Table 2. Properties of synthesized polymer concrete

| Name of composite | Properties | Density, g/cm³ | Strength, MPa |
|-------------------|------------|---------------|---------------|
| SC-10             |            | 2.16          | 5             |
| SC-20             |            | 2.08          | 3             |
| SC-30             |            | 1.96          | 3.5           |
| SC-40             |            | 1.91          | 9.7           |
| SS-10             |            | 1.85          | 10            |
| SS-20             |            | 1.83          | 54.6          |
| SS-30             |            | 1.80          | 46.5          |
| SS-40             |            | 1.78          | 34.8          |

Moreover, with the introduction of 10% of waste (SC-20), a decrease in strength is observed. These results are correlated with studies on the modification of magnesian concrete [15]. The large difference in the strength indices for Portland cement and magnesian binder can be explained by a decrease in adhesion between the polymer particles and the concrete matrix. This is more apparent when using a magnesia binder. This problem is found in many works [16–20]. But according to the results of our research, it can be said that when using Sorel Cement as a cementing agent, high strength indicators for materials can be achieved for potential use in building structures and foundations. The specific strength of the control sample on cement without the addition of XPE is 5 MPa. Compositions on a magnesian binder show a much greater initial strength and can increase it by more than 5 times with the addition of 10% waste (SS-20).

It is worth noting that the ground XPE with all binders achieved good adhesion without adding any binders. This will save money in the production of material for industrial purposes. The internal distribution of aggregate in the sample volume is shown in Figure 3.

Based on the obtained experimental data, we constructed diagrams of the dependence of concrete strength on the concentration of added XPE.

As can be seen from Fig. 4 (a), a decrease in strength is observed with the addition of XPE in an amount of up to 10% on Portland cement, and then there is an increase in strength up to 30% filling. In the case of a magnesian binder (compositions of SS) - strength characteristics increase to 10% of the input of XPE. A further increase in its concentration leads to less hardening, but the SS-30 and SS-40 samples nevertheless have a significant increase in strength compared to compositions without XPE (SS-10). Thus, the range from 8% to 28% can be considered optimal concentrations of waste addition. The strength stock of these samples is enough to ensure their use in the construction industry. Due to the large difference in the density of sand and XPE, the addition of waste in an amount of more than 30% affects the miscibility of the composition. As a result, there is a decline in physical and mechanical properties. Therefore, it was decided to use, within the framework of this work, concentrations not exceeding 30% of the XPE.
Figure 4. The dependence of the strength of the composition on the concentration of XPE on Portland cement (a) and Sorel Cement (b)

4. Conclusion
In this paper, recommendations are given on obtaining high-strength polymer-cement compositions for the construction industry, which can be used as facing and other finishing materials. The maximum strength of the samples (54.6 MPa) was achieved when using 10% of waste XPE on a magnesian binder, and 30% when using Portland cement (10 MPa). The introduction of a polymer additive in the composition of concrete allows to reduce the density of the composition (3 ~ 5%), which helps to alleviate the total weight of the structure. The results obtained are in good agreement with the experiments on the use of waste [16-18], which are related to recyclables. This is the fundamental difference between the proposed technology and the generally accepted ones, since cross-linked polyethylene (XPE) is currently considered to be non-recyclable waste.

The results of the work are the beginning of a series of studies on the production of polymer concrete with inorganic binders used in the synthesis of building compositions.

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