Ways to improve properties of high-strength building polymer composites

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Abstract. Ways to improve quality of composite materials, in particular, physical and physico-mechanical properties of nanostructured building polymer composites are described. Applications of polymer additives and superplasticizers for improving technological properties of composites are described. The main tasks of improving polymer composites are determined. The effect of surfactants on the properties of high-strength composites is identified. The dependence of the strength of cement stone on porosity is identified.

1. Introduction

The main building composites are concrete and mortar. In recent years, the success of the cement industry and improvement of the concrete and mortar production technology have improved their quality. M800 – M1200 is used in construction; hardness of concrete and mortar improved. However, further development of the construction industry requires harder building materials. It is necessary to reduce porosity of concrete, apply higher strength components, and increase internal cohesion and adhesion [1].

However, using the traditional concrete production technology, it is difficult to reduce its porosity, since it is necessary to add an excess amount of water. By its nature, cement stone is a porous material, and the volume of neoplasms under normal conditions is insufficient to fill the initial voidness of the solid phase.

2. Methods and materials
Hard cement stone and concrete produced in the laboratory of metals, alloys and composite materials of the IRI n.a. Ibragimov cannot be used [5, 7, 10].

It is difficult to increase the tensile strength of concrete due to the fact that this material has a very heterogeneous structure with a large number of defects, as well as a relatively low adhesion between the components composing the structure, and their low tensile strength.

Reducing the porosity of the concrete composite increases the strength of the materials (Fig. 1).

![Figure 1. The dependence of the strength of cement stone on its porosity: 1 – samples of hot pressing; 2 – samples pressed at normal temperature; 3 – vibrated samples.](image)

Overcoming these difficulties makes it possible to improve quality of composite materials. The latest achievements of the chemical industry can be used. There are various ways of improving the structure and properties of concrete: introduction of new nanostructured components into the concrete composition, the impact on traditional components, a composite mixture, etc.

There are many materials that combine organic and inorganic components, and these materials have high strength and lightness (for example, shells of insects or animal bones). The combination of the organic skeleton of organic nature and astringent inorganic nature into one system and vice versa allows one to produce new building composite materials that have better properties than traditional building composites. Research has already begun at the IRI n.a. H.I. Ibragimov, RAS [2–5, 7, 9, 11].

In the 1980s, polymer concrete was studied by various researchers. Even the term “P-concrete” uniting various varieties of concrete in which polymers are used was introduced. It is necessary to expand varieties of polymer concrete by introducing new terms “nanostructured building polymer composite” or “quasinanostructured composite”, etc.

Currently, there are several ways to improve properties of building composites using polymers [1]:
- introduction of a small amount of polymer additives into the concrete mix (concrete with polymer additives, including superplasticizers, and cement-polymer concrete);
- use of a polymer binder (polymer composites);
- impregnation of finished concrete and reinforced concrete products with special polymer compositions or monomers with their subsequent polymerization in the body of the construction material;
- reinforcement using polymer fibers and microfibres;
- the use of polymeric lightweight aggregates or aggregates modified with polymers;
- introduction of polymer microfillings;
- introduction of polymer ultrafine fillers;
- introduction of composite polymer nano-additives.

Each direction has its own advantages.
The use of various types of polymer additives in concrete is expanding [6]. Superplasticizers are promising. Superplasticizers based on melamine resin, naphthalene sulfonic acids and modified lignosulfonates are widely used.

Superplasticizers are introduced into the concrete mixture in an amount of 0.2–1 % of the mass of cement. Superplasticizers thin the concrete mix while maintaining the proper bonding of the concrete mix and kinetics of cement hydration (Fig. 2). They are a powerful means of changing rheological properties of a mineral binder. It is most advisable to use superplasticizers to produce high-strength concrete or improve the concrete production technology through the use of cast concrete mixtures. In our experiments, superplasticizers were used to produce M500-M600 grade 400 cement and M600-M700 grade 500 cement. The use of superplasticizers in combination with other methods of modifying concrete with polymers, in particular, impregnating hardened concrete with polymeric materials, can increase the compressive strength up to 70 MPa and more.

By introducing additives in the amount of more than 2 % of the cement mass, cement-polymer concrete can be produced [3]. The presence of polymer in concrete affects properties of the material, especially the tensile and bending strength, and the behavior of concrete under operating conditions. Various latexes and some types of resins are used as additives. The effect of polymer additives is measured in tens of percent compared to concrete without additives, however, such additives are promising for mass application in monolithic and precast concrete and reinforced concrete.

Polymer additives and superplasticizers can be used together with other chemical additives as part of complex additives that change properties of composites.

Polymer composites are a separate large group of new composites. There are more than 30 types of polymer concrete. The most widely used are FAM, PN-1 and UKS.

![Figure 2](image)

Figure 2. The effect of the content of D superplasticizer on the properties of concrete and concrete mix: 1 – change in the mobility of the mixture when introducing superplasticizers and constant consumption of cement and water; 2 – increased strength of concrete with constant mobility of the mixture and cement consumption by reducing water consumption; 3 – reduced consumption

Heavy polymer concrete has a compressive strength of 60–120 MPa, a tensile strength of 5–10 MPa, several times lower permeability, high chemical resistance and a number of other positive properties. Light polymer concrete with an average density of 1500–1800 kg/m$^3$ can have a strength of 40–80 MPa, a density of 400–600 kg/m$^3$, and a strength of 20–30 MPa.

Polymer composites have been studied since 1958 under the guidance of Professor S.S. Davydov [1]. There are several plants producing polymer-concrete and steel-polymer-concrete products used in the construction industry, in the chemical industry, non-ferrous metallurgy, hydraulic engineering, etc.

Important tasks are to improve their properties, reduce creep and shrinkage, increase hardness and reduce costs [4].

Polymer fine fibers are used as reinforcement. They are added to cellular, lightweight and gypsum concrete. Increased deformability of concrete contributes to the joint work with polymer fibers which have a very high level of deformability. As a result, the strength of the material increases.
The use of polymeric lightweight aggregates, especially in combination with a polymeric binder, makes it possible to produce light heat-insulating materials that are resistant to moisture and frost and allow the creation of lightweight building structures.

Polymeric materials are used to modify aggregates, for example, to reduce the water absorption of light aggregates by creating a polymer film on their surface or partially impregnating the aggregate with a high molecular weight technogenic compound. These studies are carried out in the laboratory of metals, alloys and composite materials of the IRI n.a. Ibragimov, RAS. Polymeric materials can be used to improve adhesion between the aggregate and the binder, including by grafting the polymer onto the aggregate. However, methods for modifying aggregates with polymers are not used in the construction industry, since the achieved effect often does not compensate for an increase in the cost of the material and the complex technology. In addition, polymeric materials are still scarce and their use is rational only if they can be economically efficient.

The most noticeable change in the properties of a building composite is observed when it is impregnated with special compounds, i.e. in polymer composites. These are new building materials. Treatment of concrete and reinforced concrete products includes drying, impregnation and sometimes radiation.

Impregnation of concrete, asbestos cement and other capillary-porous materials in order to increase their hardness and resistance has been used for a long time. However, due to the small depth of impregnation and insufficient strength of the impregnating composition, it is not possible to change the strength of the composite.

As a result of special treatment of the composite with polymers, the strength of the material increases several times, its hardness and resistance sharply increase when exposed to aggressive media. Table 1 shows some ways to improve properties of the composite when it is impregnated with methyl methacrylate [1].

By changing the structure of the impregnated composite, the impregnating material and the treatment technology, it is possible to produce polymer composites with a wide variety of properties. In particular, it is possible to produce durable light polymer composites, electrical composites, and a number of other special materials.

Table 1. Properties of construction composites and polymer composites

| Parameter                              | Composite polymer | Source composite |
|----------------------------------------|-------------------|------------------|
| Tensile strength, MPa: under compression | 100–200           | 30–50            |
| under tension                          | 6–19              | 2–3              |
| under bending                          | 14–28             | 5–6              |
| The elastic modulus under compression, MPa | 3.5·10^4–5·10^4  | 2.5·10^4–3.5·10^4 |
| Ultimate compressive strain            | 0.002             | 0.001            |
| Adhesion to reinforcement, MPa         | 10–18             | 1–2              |
| Dynamic tensile strength (τ = 103 MPa·s) | 30                | 7                |
| Shrinkage strain                       | 0–5·10^-5         | 50·10^-5         |
| Creep strain                           | 6·10^-3–8·10^-5   | 40·10^-3–60·10^-5 |
| Electric resistance, Ohm               | 10^{14}           | 10^{5}           |
| Water absorption, %                    | 1                 | 3–5              |
| Frost resistance, std. cycles          | 5000              | 200              |
| Corrosion Resistance to Sulphates and Acids | High        | Insufficient    |

Table 2 shows properties of polymer composites [1, 9]. For comparison, the results of polymer impregnation and other building materials are shown. These materials can be combined with polymer composites. The data in Table 2 do not exhaust the variety of materials and properties that can be obtained by combining various mineral structures with polymers.

A composite with increased strength and hardness, as well as other improved properties is promising for producing new durable building structures. Figure 3 shows the change in the
Table 2. Properties of various concrete polymers

| Material                        | Weight gain, % | Compressive strength, MPa | Water absorption, % |
|--------------------------------|----------------|---------------------------|---------------------|
| High strength concrete         | 4              | 76                        | 2100                |
| Expanded clay concrete with an average density, kg/m³: |                 |                           |                     |
| 750                            | 68             | 2.9                       | 33.3                |
| 1400                           | 19             | 15.2                      | 90.3                |
| Perlite concrete               | 58             | 5.5                       | 42                  |
| Gypsum concrete                | 46             | 22                        | 92                  |
| Gypsum cement                  | 13             | 27                        | 52                  |
| Arbolite                       | 18             | 9                         | 48                  |
| Aerated concrete               | 75             | 7.7                       | 75.5                |
| Silicate materials (brick)     | 12.8           | 19                        | 120                 |
| Ceramics (brick)               | 15.5           | 12.5                      | 78                  |
| Asbestos cement:               |                |                           |                     |
| -standard                      | 6              | 2                         | 42                  |
| -pressed                       | 6.2            | 3                         | 70                  |

Figure 3. The effect of the impregnating composition on the stress-strain curves: 1 – methyl methacrylate (MMA); 2 – 90% MMA + 10% butyl acrylate (BA); 3 – 70% MMA + 30% BA; 4 – 50% MMA + 50% BA; 5 – concrete (control samples)

Various initial composites or capillary-porous building materials, conventional concrete or reinforced concrete structures and products produced using traditional methods (from cast mixtures without vibration) can undergo subsequent special treatment. It is possible to treat either the entire volume of concrete, or only its surface or individual zones of the product in order to give them required properties.

There are heavy polymer composites produced on the basis of various types of heavy concrete and having an average density of more than 1800 kg/m³, and light polymer composites produced on the basis of various varieties of light concrete (with an average density of less than 1800 kg/m³).

Depending on the type of impregnated materials, there are polymer composites based on artificial glassy polymers (styrene, methyl methacrylate, etc.); polymer composites impregnated with viscous organic materials such as bitumen, paraffin, etc.; polymer composites impregnated with sulfur, and polymer composites impregnated with water glass and some other special compounds. The concrete impregnation technology has its own peculiarities, often materials impregnated with various compositions are called "polymer composites".

By the nature of the polymerization, polymer composites are divided into materials produced by thermocatalytic or radiation polymerization.
According to the degree of filling of concrete pores with polymer, there are polymer composites with almost complete impregnation of concrete and polymer composites with zone treatment.

It is possible to produce complex polymer composites with a polymer skeleton combined with fibrous polymers introduced in the composite, or with polymer fillers or microfillers [8].

In order to increase the efficiency of using polymers, surface or zone impregnation can be used. With a small consumption of monomer (1.5–3 kg/m$^2$ of concrete), this treatment increases frost resistance, corrosion resistance and improves other properties of structures and products, including those made of a monolithic and lightweight building composite (concrete and reinforced concrete).

The use of secondary products of petrochemicals and oil refining or composite impregnating compositions can reduce the cost of polymer composites.

3. Conclusion
Polymer composites are the most effective materials which lack disadvantages of polymer materials (high cost, aging and creep). Polymer composites do not manifest creep, since the polymer network is combined with a rigid mineral skeleton with low deformability under loading. In polymer composites, the polymer is located inside the material; it is protected from the effects of solar radiation, atmospheric oxygen, and other atmospheric factors, which helps increase its durability.

An advantage of products and structures made of polymer composites is the possibility of gluing and welding them to produce a high strength weld. Some polymer composites can be machined, which is of particular importance for some special applications.

Each material has drawbacks. The disadvantage of polymer composites is their limited heat resistance. By using more heat-resistant polymers, the heat resistance of the polymer composite can be increased, however, these materials must be used for structures that do not have special requirements for heat resistance.

Impregnation of the material with more heat-resistant compositions, for example, liquid metals or other high-temperature melts, can be used to produce more heat-resistant composites.

To ensure the heat resistance of a high-strength composite, high-temperature additives are of great importance. These studies are carried out by the Department of Cementing and Concrete Technology of the Institute of Construction and Architecture of the National Research Moscow State University of Civil Engineering and the Laboratory of High-Molecular Compounds of the IRI named after H.I. Ibragimov of the Russian Academy of Sciences (Grozny).

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