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# RESEARCH PHYSICAL AND MECHANICAL PROPERTIES AND DURABILITY OF SULFUR CONCRETE


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**Abstract**: The article presents the physical and mechanical properties of sulfur concrete based on the modifier sulfur-PEM (maleic anhydride and polyhydric alcohol). The research resulted in the development of a new type of concrete. This innovative concrete was produced using sulfur-PEM modification and aggregate components. The resistance of concrete to freezing, durability, and elastic modulus of the studied sulfur-containing concrete were studied.



**Keywords:** Elasticity, sulfur concrete, durability, concrete, modifier, filler, module.


**Introduction.** Sulfur composite materials refer to special types of building materials, in the production of which technical sulfur is used as a binder in any form - powder, liquid, lump, polymer or sulfur-containing waste (sulfur content of at least 30%; with a lower sulfur content, the waste is enriched with technical sulfur). Sulfur composite materials, as a rule, have a composite structure, which is determined by the boundaries of the “sulfur - dispersed phase” phase interface. Therefore, sulfur composites are obtained by mixing molten sulfur with filler and special additives [1]. Sulfur with some additives that reduce viscosity is used only for impregnation of construction products in order to increase their operational resistance [2].

Sulfur, due to the high ability of its atoms to connect with each other to form ring or chain molecules, has a large number of different allotropic modifications. As a rule, the physical and chemical properties of sulfur samples are largely determined by its allotropic composition [3].

Sulfur-based concrete was originally invented in the United States, and many research works have been carried out to develop sulfur-type concretes. Research has confirmed that sulfur concrete is a safe material in building materials [4]. Sulfur is a compound present in crude oil and gaseous products. The cost of sulfur is also very low compared to other major products. The main role of sulfur in concrete is as a binder. Sulfur concrete was primarily used in offshore structures, dams and underground utility systems. The reason for this use is that it has high strength, high density and low porosity. In the construction industry, Portland cement concrete has been a widely used material [5]. However, Portland cement concrete had some disadvantages. For example, the high porosity of the structure of Portland cement concrete affects its freezing properties; as a result, concrete was destroyed in winter or in conditions of high humidity [6].

**Experimental part:**

Preparation of concrete based on sulfur-PEM modifier

The sulfur-PEM modifier was heated at 150°C for 4 hours. Next, the liquid modifier sulfur-PEM was combined with prepared aggregates (crushed stone, sand and ash) in a volume ratio of 1:2.5. The resulting mixture was then heated at 140-160°C for 30 minutes. At the last stage, the heated mixture was allowed to cool to room temperature, resulting in modified sulfur concrete.

**Results and discussions.** Physical and mechanical properties and durability of sulfur concrete

Before assessing elasticity, deformation and strength, samples of concrete modified with sulfur-PEM were prepared in the form of cylindrical pieces 20 cm high and 10 cm wide. These samples were stored for three days before assessing their elasticity and durability. To effectively measure these parameters, a 1500 kN SATEC™ Series 1500 HDX instrument (Norwood, MA, USA) was used.

The concrete formulation based on the sulfur-PEM modifier included recycled coarse natural filler and fine filler. The main physical and mechanical properties of these fillers were determined, the results are presented in Table 1. The analysis shows that the recycled coarse fillers used have a lower density and increased water absorption compared to natural coarse fillers. Natural crushed litters consist of coarse litters with maximum sizes of 25, 19 and 13 mm. The maximum sizes of recycled coarse filler and natural fine filler are 25 and 10 mm, respectively.

The tensile, compressive and splitting strengths of concrete based on the sulfur-PEM modifier were examined and the results are presented in Table 2. Five variants of the sulfur-PEM modifier were used in this analysis. concrete based on a modifier depending on the size of the filler. Observations showed that concrete sample 5 exhibited superior compressive strength, 82 MPa, and increased splitting strength, 5.5 MPa, compared to the other samples. This particular concrete sample was prepared using 25mm aggregate.

**Table 1.** Properties of the units used in the tests.

| Characteristics | | Units | | |
|---|---|---|---|---|
| | | Recycled coarse litter | Natural coarse litter | Fine litter |
| Absolute dry density (g/mm 3 ) | | 1,62 | 2.29 | 1,24 |
| Absorption (%) | | 2.28 | 0,45 | 1.16 |
| Abrasion (%) | | 15.9 | 11.8 | - |
| Absolute volume (%) | | 32 | 35 | 31 |
| Passage through sieve 0.08 mm (%) | | 0,4 | 0,1 | 1.2 |
| Alkaline cumulative reaction | | Harmless | - | - |
| Amount of clay mass (%) | | 0,9 | 0,07 | 0,2 |
| Stability (%) | | 5.2 | 3 | 4,2 |
| Impurity content (%) | Organic impurities | Less than 1.0 (volume) | - | - |
| | Inorganic impurities | Less than 1.0 (weight) | - | - |

The smaller size of the filler in concrete based on the sulfur-PEM modifier contributes to a higher density, 2354 kg/m3. The density of the concrete gradually decreased as the aggregate size increased.

**Table 2.** Ultimate compressive and splitting strength of concrete based on a gray PEM modifier.

| Samples | Density, (kg/m3) | Compressive strength, (MPa) | Tensile strength, (MPa) |
|---|---|---|---|
| № 1 | 22 32 | 45 | - |
| № 2 | 2254 | 55 | - |
| № 3 | 22 62 | 66 | - |
| № 4 | 2314 | 75 | 5.4 |
| № 5 | 2354 | 82 | 5,5 |

The elastic modulus of concrete based on sulfur-PEM modifier was also investigated and the data obtained are presented in Table 3. The results demonstrate the elastic modulus and strain at peak stress for sulfur-PEM. Concrete based on polyester maleate modifier. The results showed that the average strain of the analyzed concrete ranged from 0.0021 to 0.0049, indicating that the strain characteristics of this concrete were superior to those of conventional concretes.

**Table 3.** Modulus of elasticity of concrete based on sulfur modifier – FEM.

| Samples | Strain at maximum stress | E exp (GPa) | Code E (GPa) | E exp /E code (%) |
|---|---|---|---|---|
| № 1 | 0,0034- | 36,5 | 38,6 | 86 |
| № 2 | 0,0049 | 20.9 | 29,9 | 60 |
| № 3 | 0,0021 | 47,6 | 37,8 | 120 |
| № 4 | 0,0031 | 33,4 | 39,4 | 84 |
| № 5 | 0,0030 | 34,4 | 41,6 | 82 |

**Concrete resistance to freezing.**

The stability of concrete under freezing conditions was studied in an aquatic environment. Prismatic concrete samples measuring 100 x 100 x 400 mm were prepared in accordance with ASTM C666. The relative dynamic modulus of the samples was measured at intervals of 50, 100 and 300 cycles. Each cycle lasted at intervals of four hours and was carried out in a temperature range from 4°C to -18°C, repeated up to 300 times. The study ended after 300 cycles and therefore the cycle stability factor was determined.

Freezing of concrete is a crucial aspect in determining the effectiveness of concrete. The freezing stability values of concrete based on the sulfur-PEM modifier against freezing were assessed for 50, 100 and 300 cycles, and the collected information is presented in Table 4. As can be seen from the results, the freezing stability values of concrete based on the sulfur-PEM modifier were close to 1.0 , which confirms the high resistance of this concrete to negative temperatures. Therefore, the concrete under study is recommended to be used at low temperatures. The low porosity and high sulfur content of concrete based on the new sulfur-PEM modifier contribute to its exceptional hydrophobic properties. As a consequence, interactions with water molecules were significantly reduced. The minute pores on the surface of this concrete are minimal, which also leads to increased stability. It has been established that the frost resistance of concrete depends on various aspects, such as sample size, type and amount of filler, water saturation conditions, cycle time, type and amount of modifier, freezing temperature and other factors.

**Table 4.** Values of resistance of concrete based on sulfur-PEM modifier to freezing.

| Freezing temperature, T | Cycle stability coefficient | | |
|---|---|---|---|
| | 50 | 100 | 300 |
| -18 $^0$C | 0,98 | 0 . 96 | 0,91 |

**Conclusion.** In research, a new modifier, sulfur-PEM, has been developed. The properties of sulfur concrete were determined, leading to the following key findings: Smaller aggregate sizes resulted in a denser concrete of 2354 kg/m 3 The density of the concrete gradually decreased with increasing aggregate size. The average strain of the tested concrete was 0.0021–0.0049, indicating superior strain characteristics compared to conventional concretes.

The frost resistance coefficient of sulfur-PEM modified concrete was approximately 1.0. Thus, a polymer based on sulfur-PEM is the most effective modifier in the production of sulfur concrete.

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# CONTENTS

## PRIMARY PROCESSING OF COTTON, TEXTILE AND LIGHT INDUSTRY

## ADVANCED PEDAGOGICAL TECHNOLOGIES IN EDUCATION



## ECONOMICAL SCIENCES