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The effect of filler modification on the properties of sulfur-polymer composite materials

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Abstract: This article investigates the effects of modified dispersed and fibrous fillers on the mechanical and operational properties of sulfur-based concrete, as well as determines the optimal time and method of modification. The obtained results were compared with the M450 grade heavy concrete currently used in the production of reinforced concrete sleepers for railway transport.

Key words: Sulfur concrete, modification, glass fiber, dispersed filler.

INTRODUCTION.

Currently, research is being conducted both abroad and in our country on new compositions of composite materials operating in various conditions and industries, as well as methods of chemical, physical, and mechanical modification to improve their mechanical properties. In this context, an urgent issue is the study of how modification methods depend on structural components, production technology, and other related factors, in accordance with the characteristics of the molecular structure and formation of interlayer structures in thermoplastic materials. This research aims to create new energy-efficient, environmentally friendly, and durable materials that take into account operational conditions. Additionally, it involves testing these materials in real operating conditions to determine their durability and to assess the impact of dynamic loads on the material's mechanical strength and reliability for practical applications.

Concrete, a mixture of materials such as gravel, sand, crushed stones, Portland cement, and water, has been used by humans for nearly ten centuries. The concrete production industry has been developing over the years.

To date, several modified types of concrete have been created, including polymer concrete, cement concrete, reinforced concrete, lead concrete, and sulfur concrete. Among the aforementioned types, sulfur concrete stands out from other types of concrete due to its operational, mechanical, and physical properties in aggressive environments.

Sulfur concrete is a modern composite material that incorporates inert aggregates and fillers which perform structural strengthening functions. Composites based on sulfur, including sulfur concrete, are considered thermoplastic materials. Taking into account the reactive properties of sulfur and based on the study of physicochemical processes between the filler and binder during structure formation in the polymerization process, it is possible to obtain high-strength structures, materials with thermal insulation properties, and materials resistant to highly aggressive environments from this material.

Despite the high functional capabilities of the sulfur element, the possibilities of obtaining materials from it have not been fully explored by scientists to date. According to the results of scientific research conducted by European scientists, modified sulfur concrete possesses a number of advantages over ordinary concrete. Accordingly, sulfur polymer concrete modifier exhibits superior properties such as friction resistance, compressive strength, and flexural strength compared to Portland cement. In comparison to ordinary concrete, it is more fatigue-resistant and durable under repeated loads. Sulfur polymer concrete modifier has been widely used for nearly 50 years in agriculture and food processing plants, as a coating material, as a means of supporting pipeline systems, and in various industrial applications.[1]

In research conducted by Uzbek scientists, sulfur, which is formed as a secondary raw material in oil and gas enterprises, was used as a binder in the production of sulfur concrete and compared to Portland cement-based concrete. The results showed that the average density of the new sulfur concrete composition is 4-5% higher than that of Portland cement-based concrete, while its compressive strength is 2-2.5 times higher, and its flexural strength is 1.5-2 times higher. Sulfur-containing concrete has enabled the production of cost-effective and highly efficient concretes and products that are no less effective than those based on Portland cement binder [2].

These scientific studies indicate that the use of modified sulfur as a base improves the mechanical properties of the material. However, the type of modification and the influence of modification parameters on material properties and structure formation processes have not been studied.

A review of literature sources indicates that materials with improved mechanical properties based on gas processing waste (sulfur) are widely used in various fields. The increasing demand for such materials remains promising, especially in areas related to their performance, resistance to various aggressive environments, as well as water impermeability. The use of sulfur-containing organomineral polymer composite materials, which can be obtained from the large amounts of sulfur released during gas purification at gas processing and gas-chemical plants, can solve several important problems [3]:

- supplying the country's construction market with high-strength products;
- increasing operational reliability while reducing the cost of materials that ensure the product's design;
- reducing the cost of structures by increasing their resistance to mechanical loads and aggressive chemical environments;
- reducing harmful effects on the environment through the utilization of technical sulfur.

The production of structures from organomineral composite polymer materials leads to a 40% reduction in CO_2 emissions compared to the production of structures from traditional ceramic composite materials. This allows for the redirection of energy used in converting mineral limestones into cement, which results in the release of large amounts of carbon dioxide. Furthermore, a temperature of 140°C is sufficient to obtain organomineral composite materials, whereas cement production requires a temperature of 1400°C. For cement production, a temperature of 1400°C is required.

1. Research Methodology

The mechanical and operational properties of sulfur concrete samples enriched with modified fillers, obtained as a result of research, were compared with the types of heavy concrete of M450 grade currently in use.

A vibroplanetary activator was used to increase the surface activity of the dispersed fillers used in sample preparation. The difference between this vibroplanetary activator and existing analogues is that it has the ability to better activate the surface areas by simultaneously applying Coriolis force to the filler particles in different directions. Active dispersed particles incorporated into the material composition as fillers improve the structural bonding in the heterosystem by forming secondary Van der Waals and hydrogen bonds during the mechanical activation process.

An "IN-test" MLA-20 mixing device was used to mix mechanically activated fillers and sand-gravel mixture together with sulfur at a temperature of 140-160 °C.

The fluid mixture was stirred in an MLA-20 mixer at a temperature of 160°C for 15 minutes, then poured into molds measuring 100×100×100 mm, and air-dried for 24 hours. The mechanical load resistance properties of the obtained samples were determined using a press.

2. Results

For the research, a mixture of fine and coarse sand in a 1:3 ratio, granulated technical sulfur according to O'z DSt 127.1-93, and waste generated during the copper production process at the

"Almalyk Mining and Metallurgical Combine" containing 60.68% [4] silica were used as modifiers.

The sand-gravel mixture was heated at 170°C for 15 minutes to remove moisture from the mixture, then modifying silica was added and mixed until evenly distributed throughout the volume. After lowering the temperature to 150°C, sulfur was added to the mixture and stirred until a liquid phase was formed. Once the mixture became fully fluid, samples were obtained by pouring into standard molds. Several samples were prepared by varying the quantities of the components that make up the material in this manner. Table 1 presents the quantitative indicators of the constituent components in the obtained samples.**1 - table.**

Results of physical and mechanical tests on sulfur concrete samples under laboratory conditions

Sample No.	Charge composition, wt. %				Density, g/sm^3	Water absorption, wt. %	Load, MPa
	Sulfur	Sand	Gravel	Kremnezim			
№1	30	60	10	2	1,262	0,0006	22,006
№2	50	10	35	5	2,028	0,0004	18,953
№3	30	15	50	5	1,577	0,0006	32,679
№4	30	20	45	5	1,420	0,0006	43,087
M450 concrete (GOST 26633-2012)					2,5	< 0,038	44,95

Discussions Studies have shown that in the process of obtaining organomineral sulfur polymer composite material, when fillers are heated to 150-170°C to remove surface moisture and activated sulfur powder is added in a vibro-planetary activator, the sulfur initially transitions into a liquid state. During the mixing of components, when the temperature exceeds 170°C, sulfur polymerization occurs, and the mixture is observed to thicken. Samples 1 and 2 presented in Table 2 are samples that were poured into the composition in a liquid state before the polymerization process began. Samples 3 and 4 were heated to 180°C and poured into molds after the composition had transitioned to a thick state.

The addition of 5% silica as a filler to the composition allows for a high degree of filling due to the specific surface area of the filler particles. Moreover, it improves the rheological properties of the modified compositions, provides high electrical insulation (due to low contamination), and enables the achievement of high mechanical properties in the modified compositions [5-10].

The water absorption property of the material depends on the amount of binder in its composition, and we can observe that it changes inversely proportional to it.

Conclusion

Based on an in-depth scientific analysis of the obtained results and experimental studies, it can be concluded that the compressive strength of a composite material containing 30% sulfur binder, 20% sand, 45% crushed stone, and 5% kremnezim is close to the strength of M450 grade cement. Therefore, temperature plays a significant role in obtaining a sulfur-based composite material, and the materials obtained after the initiation of polymerization in the mixture have a relatively higher strength.

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