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Is Sulfur an "Eco-friendly and Low-carbon" Material for Permanent Structures of Transport Infrastructure? Experience and Prospects

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Abstract

In the Russian Federation, the positive balance of production/consumption of technical sulfur is increasing, which contributes to the consideration of the use of sulfur as a low-carbon binder in the production of large-tonnage building materials and products. The successes achieved in the modification of technical sulfur [5] not only make it possible to produce high-strength chemically and moisture-resistant products from it, but also to start developing materials for road surfaces. Moscow Automobile and Road Construction State Technical University (MADI), after successfully conducting pilot tests of sulfur modification processes and the production of road slabs from modified sulfur concrete and composite reinforcement, is preparing a pilot industrial production of sulfur concrete mixtures. This opens up wide opportunities for the creation and testing of innovative technologies for the production of sulfur concrete road surfaces, making the most of the advantages of grey concrete as a thermoplastic material. Such a promising technological direction is the heating of pre-prepared sulfur concrete mixtures at the installation site using microwave induction installations and additives developed for the repair of induction-susceptible asphalt concrete coatings [3]. The article provides an analysis of the results achieved in the development of appropriate modified sulfur binders and samples of sulfur concrete based on them, as well as the formulation of research and technological tasks related to the development of compositions and structures of coatings from modified sulfur concrete mixtures specialized for the technology of their microwave heating and laying directly "on the road". The successful solution of these tasks can ensure the creation of a new highly efficient technology for the construction and repair of modified road concrete pavements with a minimum carbon footprint throughout the entire life cycle. The thermoplastic nature of the sulfur binder, which opens up the possibility of its reusable repair and recycling, allows us to hope for the most important prospects for its joint use with microwave induction technologies as the main type of binder for the Arctic territories.

Keywords: Sulfur concrete; Sulfur concrete mixture; Modified sulfur binder; Road pavement; UHF induction

Introduction

In the Russian Federation, technical sulfur (Fig.1) it is produced as a by-product of gas chemistry, oil refining and metallurgy enterprises, and is used for the production of mineral fertilizers (2.3 million tons), in the chemical (0.14 million tons), metallurgical (0.06 million tons) and pulp and paper (0.05 million tons) industries. The excess of 3.5 million tons is sold for export. By 2030, the surplus of sulfur production may reach up to 19 million tons per year and requires the search for areas of effective application.

Figure 1: Dumps of technical sulfur at an industrial enterprise.

This creates the urgency of searching and exploring new applications for large-tonnage volumes of sulfur.

Currently, the number of publications is increasing [1] on the use of sulfur as a binder in such large-tonnage segments as the production of structures and products made of sulfur concrete [2, 4].

At the same time, in comparison with other types of binders, sulfur is a "low carbon and green" binder in terms of energy costs and carbon emissions. Thus, the production of 1 ton of Portland cement in Russia consumes more than 3.4 gigajoules of energy and emits more than 0.8 tons of greenhouse gases, and about 10 kilojoules of energy is spent on the modification of technical sulfur.

At the same time, the instability of the composition and physico-chemical parameters of technical elemental sulfur creates a number of technological and operational risks, which can lead to injuries and burns due to emissions of hydrogen sulfide or sulfur dioxide when heated during the production process of building mixes or composites from it, or, for example, accelerated corrosion of reinforced concrete materials, made with a sulfur binder [6]. Accordingly, for the large-scale use of materials and structures made of sulfur-concrete mixtures, these risks must be taken into account and offset by the necessary measures of the technological process.

Materials and methods

Materials

To study and mitigate the above risks, degassed granular sulfur was selected from various types of sulfur, a technology for its modification for the production of sulfur concrete was developed and technological modes of production and application were determined, which made it possible to eliminate the emission of hydrogen sulfide and sulfur dioxide.

As a result, the elimination of hydrogen sulfide and sulfur dioxide emissions in the production of sulfur-containing mixtures and composites from them is ensured by the use of modified Sulfotex-SB sulfur (Fig.2) in compliance with the temperature conditions of production and application (Fig.3).

The temperature regime is determined by the range, on the one hand, of reactions leading to the formation and emission of gases (hydrogen sulfide and sulfur dioxide) from the binder at temperatures above 1600C (Fig.3), and on the other hand, by the temperature of sulfur crystallization and, accordingly, solidification of the mixture.

Figure 2: A sample of modified sulfur “Sulfoteks-SB” for the production of sulfur concrete [5].

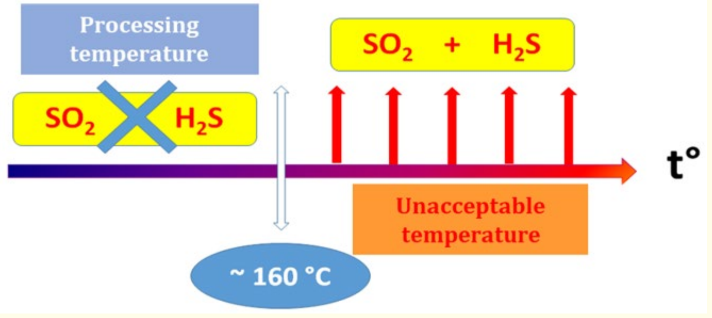

Figure 3: The scheme of acceptable and unacceptable temperature conditions for the production of materials from modified sulfur.

Equipment

Protected by the patent for invention RU 2,554 585C2 [5], the molten sulfur modification process takes place in the reactor of the MADI sulfur modification plant (Fig.4) at a temperature of 120-135 ° C when mixed with ammonium and/or potassium salts in an amount from 0.001 to 0.005 wt.% by weight of sulfur for 5-10 minutes, followed by the introduction of 5-ethylidene-2-norbornene in an amount from 0.08 to 0.1 wt.% by weight of sulfur and additional stirring for 20-50 minutes.

Applications for patents of the Russian Federation have been submitted for equipment, processes and chemicals for the modification of sulfur and products made from it №2023 128440/04, №2023 128436/04, №2023 128434/04 and No.2023 128438/04.

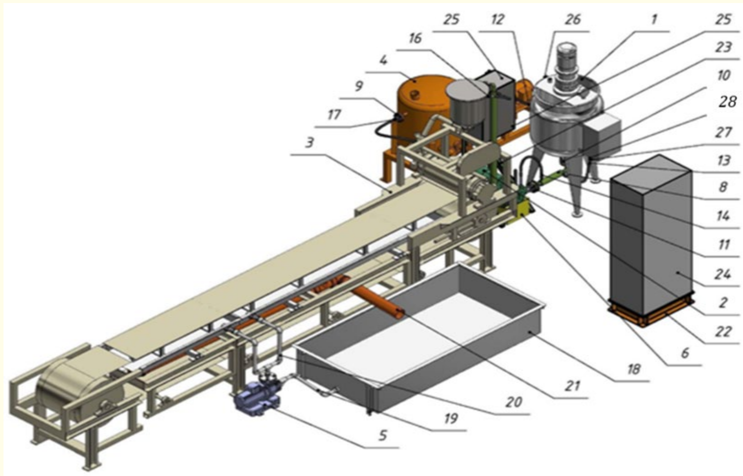

Figure 4: MADI installation scheme for sulfur modification.
Designations: 1 - Melter; 2- Pump; 3- Granulator; 4 - Oil supercharger; 5 - Pump; 6 - Subframe; 7 - Pipeline; 7, 8 - Pipelines; 9 - 11 - adapters, 12-17 - Hoses; 18 - Reservoir; 19 - 21 - Pipelines; 22 Subframe; 23 - Frame assembly; 24-25 - Electric cabinets; 26 - Boss; 27 - Fitting; 28 - Adapter.

A patent for the invention RU 2 212 487C2 “Method for repairing concrete and reinforced concrete coatings and structures” has already been obtained for the composition and technology of repairing coatings and structures with sulfur-concrete mixtures, and in August 2021, the national standard of the Russian Federation GOST R 59613-2021 “Concrete sulfur mixtures and sulfur concrete” was put into effect. Specifications” developed by the small innovative enterprise MADI “Sulfotex MADI”.

As can be seen from the photo (Fig.5), the course of pilot tests of the production of road slabs made of sulfur concrete with a modified sulfur binder “Sulfoteks-SB” confirmed the safety for human health and allowed the production of samples of sulfur concrete (Fig.6) and road slabs (Fig.7) made of it of proper quality.

Figure 5: The section of forming of sulfur concrete road slabs in MADI.

Figure 6: Samples of sulfur concrete for testing.

Figure 7: Samples of sulfur concrete for testing.

Results and discussion

Tests of the modified binder Sulfotex-SB according to the system of technical requirements of the national standard GOST R 59613-2021 “Concrete sulfur mixtures and sulfur concrete” allowed to demonstrate the following advantages of sulfur concrete:

- Fast set of high strength without cracking (2-3 hours before compressive strength of more than 40 MPa, and bending strength of more than 6.5 MPa);
- High resistance in acidic (90%- 95%) and alkaline (86% - 93%) environments;
- High water resistance (W 20) and water resistance (1.0);
- High frost resistance (F21000);
- Curing at low ambient temperatures (tested to minus 100C);
- Low abrasion resistance (0.2-0.3 g/cm2).

In addition, the following improved technological properties were demonstrated:

- Good adhesion to old concrete;
- Good dielectric properties;
- The possibility of using man-made aggregates and the waste-free production process.

One of the most significant results of sulfur modification was the achievement of 100% in terms of the resistance of sulfur concrete samples to prolonged exposure to acids and alkalis (Fig.9), which opens up the prospect of neutralizing one of the most frequently mentioned risks of using sulfur concrete - severe corrosion of reinforced structural elements from it, described in [6].

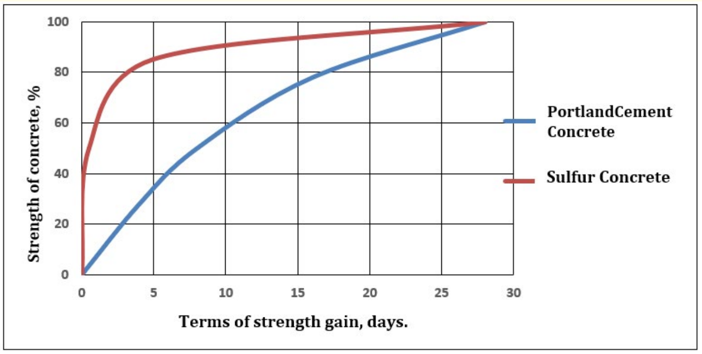

Figure 8: Kinetics of concrete strength gain.

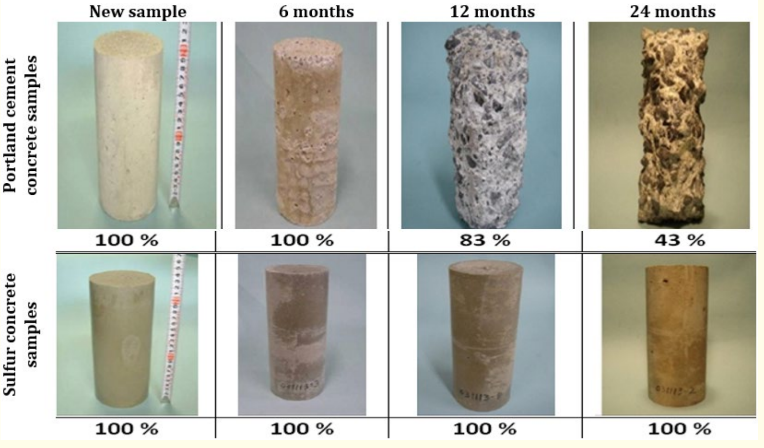

Figure 9: Photos of samples of Portland cement concrete and sulfur concrete exposed to aggressive acid-base effects during various periods.

At the same time, in addition to the achieved rather high chemical resistance of sulfur concrete samples, it should be noted that it is well compatible with composite reinforcement (Fig. 10-11).

Figure 10: Composite reinforcement for grey concrete road slabs.

Figure 11: Reinforcement with composite reinforcement during the manufacture of road slabs.

Conclusion

An analysis of the results obtained from the pilot production of sulfur concrete modified with sulfur binder using the Sulfoteks-SB technology shows the prospects of developing a technology for its application for paving not only from road slabs reinforced with composite reinforcement, but also from mixtures heated (to sulfur melt) and laid directly at the road construction site. One of the most energy-efficient options for implementing such a heating technology may be microwave induction installations similar to those specified in Article [3], which can subsequently be used for the repair of sulfur-concrete coatings (if necessary).

In this variant, a dry and “cold” mixture of sulfur concrete can be laid directly on the road surface with withstanding slopes, after which it is heated to a sulfur melt using a self-propelled microwave induction unit and (if necessary) compacted with rollers (Fig.11). Analogues of similar mounted installations transported by tractors have already been developed and tested by the company “Center-Novatsiya”, Moscow [3].

Another option for the technology and installation may be microwave heating of the sulfur-concrete mixture in the hopper of a self-propelled installation, followed by unloading and laying the mixture on the surface and sealing.

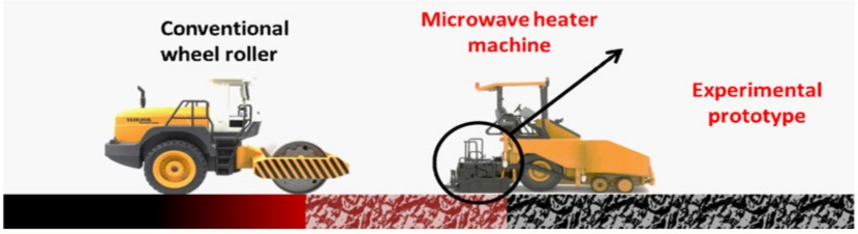

Figure 12: Technology of microwave-induced heating and compacting of the road pavement [3].

Figure 13: Suspended microwave installation, created by LLC "Center-Novatsiya", Moscow [3].

At the same time, it is possible that for these two options, additional modification of the sulfur binder will be required to increase its heating efficiency by increasing susceptibility to microwave induction. It is also obvious that specialized work will be required to find the optimal compositions of mixtures for such variants of sulfur-concrete coatings. The totality of these tasks becomes the content of the next stage of a fairly large-scale program of innovative developments in the manufacture and application of gray concrete road surfaces. In this regard, in order to ensure a sufficient level of productivity and representativeness of industrial production processes, the installation of a pilot industrial plant for the production of sulfur concrete mixtures has already begun in MADI (Fig.13).

Figure 14: Commissioning works at the installation for the production of foam concrete mixtures in MADI.

All of the above inspires confidence in accelerating research and development to ensure the efficiency of construction and maintenance of infrastructure facilities in the Arctic zone at all stages of the life cycle, which are so important for the sustainable development of Russia and the entire Eurasian continent in modern conditions [7].

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