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PROSPECTS FOR UTILIZING TECHNOLOGICAL WASTE PRODUCED FROM THE PURIFICATION OF SULFUR-CONTAINING GASES AT GAS FIELDS IN THE REPUBLIC OF UZBEKISTAN AND THEIR TARGETED APPLICATION IN VARIOUS SECTORS

Abstract

Today, there is a growing demand for environmentally safe, recyclable, and highly durable materials for modernizing railway infrastructure using industrial waste generated from the purification of sulfur gases in gas fields. The high CO_2 emissions and hydrophilic properties of traditional cement-based concretes are limiting their use in long-term and aggressive environments. In light of this, the present study explored the prospects of using sulfur-based concretes with hydrophobic, chemically stable, and thermoplastic properties in railway sleepers. Samples obtained from compositions consisting of molten sulfur, modified stabilizers, basalt fiber, and nano-additives were analyzed using TGA/DTA and IR spectroscopy methods. Important physicochemical properties such as compressive strength, water absorption coefficient, thermal conductivity, and resistance to mechanical wear were evaluated through laboratory and industrial tests. The research results demonstrated that sulfur concrete could be implemented not only as an alternative cement-free solution but also as a sustainable, long-lasting, and recyclable structural material for future railway sleepers.

Keywords: sulfur concrete, railway sleepers, recyclable material, hydrophobicity, CO_2 emissions, TGA/DTA analysis, modifying stabilizer, nano SiO2, eco-friendly concrete, mechanical durability.

Introduction

Today, as a result of the rapid construction of infrastructure and buildings, the demand for concrete products is increasing sharply. However, in the traditional concrete production process, the main binding agent used is Portland cement, the large-scale production of which leads to significant CO_2 emissions into the atmosphere. Cement production accounts for approximately 7–8% of global greenhouse gas emissions. To mitigate this environmental threat, many researchers have begun searching for alternative binding agents. One such promising solution being considered is sulfur-based concrete [1–2].

Materials and Methods

In this study, sulfur-based concrete compositions intended for railway sleeper production were selected as the research object. The main components of these compositions include: Molten sulfur (S_8) as the primary binding agent; Modified chlorosulfonated polyethylene as a stabilizer controlling sulfur crystallization; Basalt fiber as a reinforcing component to increase load-bearing capacity; Microsilica and nano-silicon oxide (SiO_2) to enhance microstructure density and reduce cracking; Antioxidants and UV stabilizers as additives ensuring resistance to external factors (sun, oxygen, temperature). Additionally, based on Belgian experience, sulfur-concrete sleepers manufactured under the THIOTRACK® brand were examined in terms of technical specifications and subjected to comparative analysis.

Thermogravimetric analysis (TGA/DTA) is used to determine the thermal stability of sulfur and the temperature resistance limit of compositions. A gradual decrease in mass and sublimation were observed at 200–300°C.

IR Spectroscopy (FTIR) is used to identify functional groups (S-S, C-C-H) in sulfur concrete and confirm the presence of modification. The spectra were analyzed in the range of 470–920 cm^{-1}.

Mechanical tests: Compressive strength was measured over periods of 3 hours and 30 days, with recorded values of 60–65 MPa.

Water absorption tests: To determine water resistance, the material was immersed in water for 24 hours, resulting in an absorption rate of <0.5%.

The process of re-melting and recasting into molds was performed up to 10 times, with the degree of mechanical property retention observed after each cycle.

Results and Discussions

The problem of global sulfur production and waste recycling. One of the largest components of high-tonnage waste generated by the expansion of the oil and gas industry is sulfur, which is often produced as a by-product. According to the US Geological Survey (USGS), global sulfur production in 2018 amounted to 80 million tons. This figure clearly indicates the necessity for sulfur processing and utilization [3].

The largest producers are:

- China – 17 million tons (main contributor),
- USA – 9.7 million tons,
- Russia – 7.1 million tons,
- Saudi Arabia – 6 million tons,
- Canada – 5.5 million tons,
- Japan and Kazakhstan – 3.5 million tons each.

Advantages of sulfur concrete. Sulfur-based concrete has several advantages over traditional Portland cement concrete:

- Rapid hardening (compressive strength up to 55–65 MPa in 3 hours),
- Low thermal and electrical conductivity,
- High chemical and acid resistance,
- Low water absorption and water resistance,
- Freeze-thaw resistant (up to 300%),
- Quick setting, radiation-resistant, highly abrasion-resistant,
- Concrete can be poured even in cold conditions.

This type of concrete is recommended as an alternative material for underground structures, hydraulic structures, and marine infrastructure.

Allotropic forms and physical states of sulfur. Sulfur can exist in various allotropic forms - these can be in the form of chemically bonded chains (catena, polycatena) or ring-shaped molecules (cyclo-S_n). The most stable forms are based on the S_8 ring:

- Rhombic form (stable up to 95.5 °C),
- Monoclinic form (stable in the range of 95.5–119.3 °C),
- Plastic sulfur (above 159°C — chain structure).

Due to these properties, sulfur can be melted, molded, and solidified again for use - this allows for 100% recycling.

Sulfur-based concrete plays an important role in transforming industrial waste into an environmentally and economically beneficial resource. Its high strength, corrosion resistance, recyclability, and quick setting properties create advantages for modern construction sectors. Furthermore, at a time when global sulfur production is increasing, actively using it in construction rather than storing it is the most optimal environmental solution [4].

Belgian railway infrastructure tested a sulfur concrete sleeper under the THIOTRACK® brand in 2021. By 2025, it is planned to install 200,000 such sleepers across the country. The manufacturer of these sleepers is De Bonte Group, which has developed 100% recyclable, cement-free concrete that requires no water consumption. This concrete can be melted at 135°C for reuse [5].

Sulfur concrete sleepers are a reliable solution for railways, fully meeting all functional and technical requirements established by European standards and technical specifications. Moreover, sulfur concrete is considered a material with very low environmental and climate impact.

When recycling sleepers manufactured under the THIOTRACK® brand, it is possible to easily separate sulfur concrete from components such as steel inside. Therefore, the concrete and all integrated parts can be reused indefinitely, like new concrete, without loss of quality.

Because sulfur-based sleepers do not absorb water (due to their hydrophobic properties), the physical, mechanical, and chemical properties of the product are preserved 100%. This ensures a long service life.

The production process of THIOCRETE® has very low CO_2 emissions compared to traditional cement concrete or other widely used materials (steel, ceramics, plastics). This leads to a 50–80% reduction in emissions due to the non-use of cement and the low energy consumption of the process [6].

Below, a method for preparing sulfur-based concrete using a special chemical composition for railway sleepers and its physicochemical properties have been investigated. This analysis aligns with modern approaches to producing environmentally friendly, sustainable, and recyclable concrete materials.

Application of sulfur-based concrete in railway sleepers: composition and physicochemical properties. Railway sleepers require long-term performance under heavy static and dynamic loads. Traditional cement-based concretes, due to their hydrophilic properties, tendency to crack, and susceptibility to carbonation, often cannot withstand aggressive environments. Therefore, hydrophobic, corrosion-resistant, rapidly-strengthening sulfur concretes can be recommended as an alternative solution.

For the application of sulfur-based concrete in railway sleepers, several chemical compositions are mixed at a temperature of 130–140 °C, with molding carried out at 135 °C. The cooling stage is completed within 10–20 minutes. The compositions presented in this table are considered relatively effective, and their total mass fractions were studied.

Table 1 – Composition and mass fraction of sulfur-based concrete

Component	Mass fraction (%)	Explanation
Solude sulfur (S8)	40–45%	Binding, hydrophobic, and re-meltable
Modified chlorosulfonated polyethylene	5–7%	Sulfur polymerization stabilizer
Basalt fiber	45–50%	For high density and mechanical strength
Microsilicate	2–3%	Increases temperature stability, reduces cracks
Antioxidant/UV Stabilizer	0.5–1%	Reduces degradation due to sunlight
Nano-silicon oxide (SiO8)	0.2–0.5%	Increases interface adhesion, increases durability

When studying the thermal decomposition of sulfur-based concrete compositions presented in Table 1 using TGA/DTA, it was found that sulfur sublimation occurs at 200–300°C, demonstrating high thermal stability. Additionally, IR spectroscopy analysis of sulfur-based concretes revealed the presence of S-S stretching at 470–550 cm^{-1}, crystalline sulfur at 720 cm^{-1}, and C-C-H deformation signals in the range of 880–920 cm^{-1} for modified samples.

The physicochemical properties of sulfur-based concrete compositions make them promising materials for infrastructure elements subjected to heavy dynamic loads, particularly railway sleepers. The results presented in Table 2 below were obtained through laboratory and industrial tests, with each finding scientifically substantiated in terms of its technical significance.

It was observed that the compressive strength of sulfur concrete samples reaches 60–65 MPa within 3 hours. This value is significantly higher than the approximately 25 MPa achieved by traditional Portland cement-based concrete after 28 days of curing. This property is attributed to the rapid formation of an amorphous structure as sulfur cools and the influence of modifying compounds added as stabilizers. In the railway sector, this characteristic allows for increased construction speed and savings in time and energy resources.

Table 2 – Physical and mechanical properties of sulfur-based concretes

Indicator	Sulfur concrete sleeper	Explanation
Strength (M60 level)	60–65 MPa (3 hours)	Fast strengthening, 2-3 times faster than cement
Water absorption coefficient	< 0.5%	Poorly water-absorbing due to hydrophobicity
mechanical friction (DIN 52108)	< 1.5 mm/1000 cycle	Highly abrasion-resistant
Corrosion resistance (H_2SO_4, NaCl)	Very high	Stable even in aggressive environments
Thermal conductivity	0.27–0.35 W/m·K	Good thermal insulation properties
Heat deformation temperature (HDT)	110–120 °C	Suitable for summer railway friction conditions
Melting point (sulfur)	115–120 °C	Recyclability available
Processing cycle	≥ 10 times	Properties are retained

The changes in strength of sulfur concrete over time, its comparison with Portland cement-based concrete, and the impact of modifying additives that ensure its stability are significant. Sulfur concrete initially provides very high strength; however, if appropriate stabilizers and modifiers that slow down degradation caused by sunlight exposure and improve adhesion are not used, a decrease in mechanical stability of up to 5–10% may be observed over time.

Table 3 – Time-based dynamics of sulfur concrete strength (comparison after 3–30 days)

Indicator	3-hour sulfur concrete	30-Day Sulfur Concrete	30-day Portland cement
Pressure resistance (MPa)	60–65	55–60 (may decrease slightly)	30–40 (increasing)
Flexural strength (MPa)	10–15	9–13	6–8
Crack resistance	High	Decreases slightly	Medium
Chemical stability	High (almost unchanged)	High	Medium

The water absorption coefficient of sulfur concrete is < 0.5%, which makes it practically waterproof. This hydrophobic property is due to the crystalline structure of sulfur and its non-reactivity with water. When used as a sleeper, this property prevents structural cracking under the influence of soil moisture and precipitation, and in cold climates increases resistance to freeze-thaw cycles.

According to tests conducted in accordance with the DIN 52108 standard, the mechanical abrasion of sulfur concrete is less than 1.5 mm/1000 cycles. This confirms its ability to withstand intensive friction between rails, sleepers, and connecting elements under railway conditions. It reduces the frequency of sleeper replacement during long-term operation.

Sulfur concrete has high inertness to H_2SO_4, NaCl, and other aggressive environments, and it undergoes almost no chemical destruction. This ensures the long-term operation of railway infrastructure even when in contact with acid rain, chemical dust, and salts in industrial zones.

The thermal conductivity of sulfur concrete is around 0.27–0.35 W/m·K, making it a good thermal insulator. This feature is of great importance in railway lines subjected to sharp temperature fluctuations. Also, due to its high resistance to thermal deformation (110–120 °C), softening or deformation of the material in summer heat is not observed.

Sulfur concrete has a meltable thermoplastic character and can be recycled up to ≥10 times. This allows for melting the material and reusing it in a new mold, instead of replacing the entire structure. Unlike cement concretes, no quality is lost during reprocessing.

Advantages and strategic benefits of sulfur concrete application. 100% recyclable: Sulfur concrete sleepers can be melted and molded into a new shape, no cement is used: CO2 emissions are reduced by 60–80%, not water-absorbent: Sleepers do not react with water in the soil, cracks do not appear, strong anti-corrosion protection: Extends the service life of steel rails and connectors, earthquake-resistant: Suitable for use in smooth deformation zones (transition to plastic phase).

Conclusion

Sulfur-based concrete is an environmentally sustainable, recyclable, and innovative material worthy of consideration for the production of high-quality railway sleepers. Due to its hydrophobic nature, high mechanical durability, and recyclability properties, it can not only serve as an alternative to cement but also potentially become the foundation of future railway infrastructure.

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ӨЗБЕКСТАН РЕСПУБЛИКАСЫНЫҢ ГАЗ КЕН ОРЫНДАРЫНДА КҮКІРТ ҚҰРАМДЫ ГАЗДАРДЫ ТАЗАРТУ КЕЗІНДЕ ТҮЗІЛЕТІН ТЕХНОГЕНДІК ҚАЛДЫҚТАРДЫ ПАЙДАЛАНУ ЖӘНЕ ОЛАРДЫ ӘРТҮРЛІ САЛАЛАРДА МАҚСАТТЫ ҚОЛДАНУ

Аңдатпа

Қазіргі уақытта газ кен орындарында күкіртті газдарды тазарту нәтижесінде түзілетін өнеркәсіптік қалдықтарды пайдалана отырып, теміржол инфрақұрылымын жаңғырту үшін экологиялық қауіпсіз, қайта өңделетін және жоғары берік материалдарға деген сұраныс артып келеді. Дәстүрлі цемент негізіндегі бетондардың жоғары CO_2 шығарындылары мен гидрофильді қасиеттері олардың ұзақ мерзімді және агрессивті ортада қолданылуын шектейді. Осыған байланысты бұл зерттеуде теміржол шпалдарында қолдануға арналған гидрофобты, химиялық тұрақты және термопластикалық қасиеттерге ие күкіртбетондардың қолдану перспективалары қарастырылды. Балқытылған күкірт, модификацияланған тұрақтандырғыштар, базальт талшығы және наноқоспалардан тұратын композициялар негізінде алынған үлгілер термогравиметриялық (ТГА/ДТА) және инфрақызыл спектроскопия (ИҚ) әдістерімен зерттелді. Сығылуға беріктік, су сіңіру коэффициенті, жылуөткізгіштік және механикалық тозуға төзімділік сияқты маңызды физика-химиялық қасиеттер зертханалық және өнеркәсіптік жағдайларда сыналды. Зерттеу нәтижелері күкіртбетонның тек цементсіз балама ретінде ғана емес, сонымен қатар болашақ теміржол шпалдары үшін ұзақ мерзімді, тұрақты және қайта өңделетін құрылымдық материал ретінде қолдануға болатынын көрсетті.

Тірек сөздер: күкіртбетон, теміржол шпалдары, қайта өңделетін материал, гидрофобтылық, CO_2 шығарындылары, ТГА/ДТА талдауы, модификацияланған тұрақтандырғыш, нано-SiO_2, экологиялық таза бетон, механикалық беріктік.

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ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ ТЕХНОГЕННЫХ ОТХОДОВ, ОБРАЗУЮЩИХСЯ ПРИ ОЧИСТКЕ СЕРОСОДЕРЖАЩИХ ГАЗОВ НА ГАЗОВЫХ МЕСТОРОЖДЕНИЯХ РЕСПУБЛИКИ УЗБЕКИСТАН, И ИХ ЦЕЛЕВОЕ ПРИМЕНЕНИЕ В РАЗЛИЧНЫХ ОТРАСЛЯХ

Аннотация

В настоящее время возрастает потребность в экологически безопасных, перерабатываемых и высокопрочных материалах для модернизации железнодорожной инфраструктуры с использованием промышленных отходов, образующихся при очистке сернистых газов на газовых месторождениях. Высокие выбросы CO_2 и гидрофильные свойства традиционных бетонов на основе цемента ограничивают их применение в условиях длительной эксплуатации и агрессивных сред. В связи с этим в настоящем исследовании изучены перспективы применения серобетонов, обладающих гидрофобными, химически стойкими и термопластичными свойствами, в железнодорожных шпалах. Образцы, полученные из композиций, состоящих из расплавленной серы, модифицированных стабилизаторов, базальтового волокна и нанодобавок, были проанализированы методами ТГА/ДТА и ИК-спектроскопии. Важные физико-химические свойства, такие как прочность на сжатие, коэффициент водопоглощения, теплопроводность и стойкость к механическому износу, оценивались в ходе лабораторных и промышленных испытаний. Результаты исследования показали, что серобетон может быть внедрен не только как альтернативное бесцементное решение, но и как устойчивый, долговечный и перерабатываемый конструкционный материал для будущих железнодорожных шпал.

Ключевые слова: серобетон, железнодорожные шпалы, перерабатываемый материал, гидрофобность, выбросы CO_2, ТГА/ДТА анализ, модифицирующий стабилизатор, нано SiO_2, экологически чистый бетон, механическая прочность.

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