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An Experimental Study on Sulphur Concrete

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Abstract:- Sulfur concrete, a composite material derived from elemental sulfur, aggregates, and additives, presents a promising avenue for sustainable construction practices. This project report investigates the properties, feasibility, and potential applications of sulfur concrete as a viable alternative to traditional cement-based concrete. Through a comprehensive literature review and experimental analysis, this study elucidates the unique mechanical, chemical, and environmental characteristics of sulfur concrete. The implications of adopting sulfur concrete extend beyond construction efficiency to environmental sustainability, resource conservation, and cost-effectiveness. Challenges such as odor emissions during production and limited availability of sulfur are also addressed, along with potential solutions. Overall, this report advocates for further research and widespread adoption of sulfur concrete as a viable solution to meet the demands of modern construction while mitigating environmental impact.

***Keywords**:- Sulfur Concrete, Construction Efficiency, Cost-Effectiveness, Environmental Impact.*

I. INTRODUCTION

Sulfur concrete, or thio concrete or sulfurcrete, is a composite construction material. It is composed of sulfur and aggregate. Generally coarse aggregate and fine are mixed with sulfur to prepare sulfur concrete, a coarse aggregate made of gravel or crushed rocks and a fine aggregate such as sand. There is no need of mixing cement for preparing it. Cement and water, important compounds in normal concrete, are not part of sulfur concrete.

Sulfur concrete is prepared by melting elemental sulfur at 115.21 °C and mixed with heated aggregates in a ratio of between 12% and 25% sulfur. There is no need of curing it , it will achieve the required mechanical strength within 24 hrs. after cooling. Sulfur is a thermoplastic material and it changes in form due to increase in temperature and therefore it can be recycled and reshaped by remelting it at a higher temperature.

As per the studies a sulfur concrete patent was already registered in 1900 by McKay. And because of the accumulation of large quantities of sulfur as a by-product of the hydro sulfurization process of oil and gas production studies received renewed interest in the 1970s about sulphur.

A. *Sources of Sulphur*

Sources of sulfur are natural and man-made, naturally it is available as sulfur ores of sedimentary and magmatic genesis. The man-made resource of sulfur are the oil refineries, processing plants of natural gas and smelters of nonferrous metals which produce sulfur as a waste or a by-product of the processes and it is low cost.

B. *Production of Sulphur*

The production of sulfur is carried out in three ways, 1) sulfur mining through the use of drilled wells and “Frasch method”, 2) directly extracted from the processing plant of oil and gas,3) by scrapping of sulfur from the earth surface. The natural reserves of sulfur amount more than 5 billion tonnes. From these about 1.2 billion tonnes capacity of explored deposits of native sulfur are available The specialized aspect focuses primarily on extracting sulfur from natural deposits of this raw material. Major native sulfur deposits are found in countries such as Iraq (approximately 335 million tons), the United States (200 million tons), Chile (100 million tons), and Mexico (100 million tons). Significant reserves have also been identified in Poland, Ukraine, Russia, Turkmenistan, and the Japanese islands. In addition to primary extraction, sulfur is produced as a by-product during the processing of hydrogen sulfide. The quantity of sulfur produced in this manner depends on the volumes of oil and natural gas that are refined. Sulfur is commercially available in three main forms: lump, granulated, and liquid. Production technologies for sulfur include extracting and refining natural elemental sulfur, deriving sulfur from pyrites, and producing sulfur from hydrogen sulfide (H_2S) or sulfur dioxide (SO_2). [1]

C. *Properties of Sulphur*

Sulfur exhibits varying melting and freezing points depending on the specific solid allotrope being considered. The freezing point of sulfur can decrease due to the natural dissociation of the molten sulfur into different solid allotropes, which generally have lower freezing points compared to cyclo-S8. At temperatures around 160 °C, the viscosity of sulfur decreases by approximately 7–8 centipoise. However, at 190 °C, the viscosity of sulfur rises sharply to about 930 poise before dropping again. The density of sulfur increases as the temperature decreases. Different sulfur allotropes and molten forms exhibit a range

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of colors. Additionally, solid sulfur has a higher thermal conductivity compared to its liquid form. The strength of sulfur is influenced by its thermal history and purity.1]

II. SULPHUR IN THE CONCRETE INDUSTRY

Sulfur has found applications across various industries, including agriculture, petroleum, and pharmaceuticals. Given the growing environmental concerns associated with traditional cement production and the depletion of raw materials for cement, sulfur has emerged as a valuable binding agent.

In addition, sulfur is used in the production of bitumen, a key material for constructing bituminous macadam roads and flexible pavements. Sulfur-based concrete is suitable for manufacturing pavement blocks, sidewalks, drainage systems, and sewers. Its high resistance to acids and chemicals makes it ideal for applications such as foundation coverings, railway ties, bridge decks, and acid tanks.

A notable innovation is sulfur asphalt, a blend of asphalt and sulfur, which is used in highway construction and road paving. The trend towards sulfur-based concrete is driven by its high strength, impermeability, rapid strength development, corrosion resistance, and recyclability. Moreover, sulfur-based concrete can be cast without water, making it a practical alternative to traditional cement-based concrete.

A. Application of Sulphur in Concrete

In terms of the composition of the components, sulfur-based concrete consists of 70%–90% mineral fillers (aggregates) and 10–30% sulfur binder. The optimal sulfur content in the material is determined on the basis of the calculated and experimental values of the porosity of compacted mixtures of fillers. Below the optimum content of sulfur, inoperative highly viscous compositions with high porosity and permeability are obtained and above the optimum of sulfur, the adverse effects of volume contraction are manifested—the formation of defects (cracks) and the deformation of crystals with a decrease in strength. It should be borne in mind that the minimum allowable content of sulfur binder is dictated by its function—the matrix, transmitting stress to the grain reinforcing filler (high-modulus component), as well as high cost due to the modifier constituting up to 60% of the cost of sulfur-based concrete.

B. Long-term Scientific and Technical Challenges

- Sulfate-reducing bacteria (SRB) and sulfur-oxidizing bacteria (SOB) generate hydrogen sulfide (H_2S) and sulfuric acid (H_2SO_4), respectively. When the sulfur cycle is active in sewer systems, hydrogen sulfide released from wastewater can be oxidized to sulfuric acid by atmospheric oxygen on the moist surfaces of tunnel walls. This sulfuric acid can then corrode the hydrated Portland cement paste found in cementitious materials, particularly in the partially water-filled (vadose) zones of sewers. This reaction leads to significant deterioration of masonry mortar and concrete in older sewage systems.
- Sulfur concrete might offer a durable solution to these issues if it proves resistant to long-term chemical and bacterial degradation. However, because elemental sulfur can participate in redox reactions utilized by certain autotrophic bacteria to derive energy from the sulfur cycle, it might inadvertently support bacterial activity.

C. Sulphur Concrete Charecteristics

Sulfur concrete is known for its low porosity and poor permeability. Its minimal hydraulic conductivity reduces water ingress through its dense matrix, thereby limiting the transport of harmful chemicals, such as chlorides that can cause pitting corrosion of steel reinforcements. This provides effective physical protection for steel as long as no microcracks develop within the sulfur concrete matrix. Additionally, sulfur concrete demonstrates resistance to certain acids that typically degrade ordinary concrete. However, it is less effective in enduring prolonged high temperatures unless the mixture is adjusted accordingly.

In addition to its impermeability, sulfur concrete is characterized by its low thermal and electrical conductivities. It does not react adversely with glass (avoiding alkali-silica reactions), does not produce efflorescence, and offers a smooth surface finish. Despite these benefits, sulfur concrete has some limitations: it has a high coefficient of thermal expansion, can form acid when exposed to water and sunlight, and reacts with copper, which can produce an unpleasant odor when melted

III. EXPERIMENTAL STUDY

After the conduct of literature review, an experimental study was conducted to understand the property of Sulphur concrete. Initially the materials were procured as per the proportions required for the preparation of cubes. The main challenges in this project were to melt the Sulphur and prepare the cubes. Due to the lack of facilities only few cubes were casted. details of the materials, proportions taken and test results are mentioned below.

A. Materials

Sulfur polymers are materials produced from natural sulfur modified by chemical substances that are added at strictly defined conditions and proportions. The following modifiers: dicyclopentadiene (DCPD), styrene, turpentine and furfural are added to the liquefied sulfur to transform properties of this material by inhibiting its crystallization - that stabilizes the structure enabling preservation of consistent physical properties irrespectively the time.

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Fig 1: Sulphur Powder

In the project, aggregates were chosen with a primary focus on achieving optimal mechanical properties for the final product. Economic considerations were also a secondary factor in the selection process. The project utilized common aggregates found in conventional cement concrete, including sand, gravel, granite, and dolomite. Additives such as fly ash and phosphogypsum were incorporated into the sulfur concrete to achieve the desired grain distribution, in accordance with ACI 5482 standards.

The selection of additives was driven by two main objectives: firstly, to use fine-grained dust to fill and seal the aggregate matrix, and secondly, to utilize cost-effective and readily available waste materials, which are abundantly stored in stockpiles. This approach not only helps in achieving the desired material properties but also enhances the economic competitiveness of the product, given the use of fly ash and phosphogypsum.


Fig 2: Aggregates

B. Methodology

For the preparation of Sulphur concrete only aggregate and elemental Sulphur was used. Sulphur was melted at a temperature around 115°C (239°F). aggregate were also heated and then both were mixed thoroughly until the aggregate is evenly coated with Sulphur. The mix was poured into the mould and within few seconds the Sulphur concrete solidified. Surface was then finished properly. It's important to note that working with molten sulfur can be hazardous, so appropriate safety precautions, such as wearing protective clothing and working in a well-ventilated area, should be followed throughout the preparation process. Additionally, the specific methodology may vary depending on factors such as the application and the desired performance characteristics of the sulfur concrete.


Fig 3: Preparation of Surphur Concrete


Fig 4: Sulphur Concrete

Also the conventional type cube was casted for comparing the results.


Fig 5: Materials for Conventional Cube

Fig 6: Mixing and Casting

Fig 7: Compressive Strength Test Conducted

C. Testing of the Specimen

The compressive strength of the cubes casted was tested using compression testing machine. 3 samples were prepared.

IV. RESULTS AND DISCUSSIONS

Table 1: Test Results of Sulphur Concrete

Sample No.	**Compressive Strength Test**		
	Size of the Mould	**Load (kN)**	**Compressive Strength (MPa)**
1	70.6 mm x 70.6 mm x 70.6 mm	89	17.86
2	70.6 mm x 70.6 mm x 70.6 mm	92	18.46
3	70.6 mm x 70.6 mm x 70.6 mm	91	18.26
4	70.6 mm x 70.6 mm x 70.6 mm	90	18.06
Compressive strength of Sulphur Concrete			18.16

Table 2: Test results of Conventional Concrete

Sample No.	**Compressive strength test**		
	Size of the Mould	**Load (kN)**	**Compressive Strength (MPa)**
1	70.6 mm x 70.6 mm x 70.6 mm	78	15.65
2	70.6 mm x 70.6 mm x 70.6 mm	82	16.45
3	70.6 mm x 70.6 mm x 70.6 mm	80	16.05
4	70.6 mm x 70.6 mm x 70.6 mm	79	15.85
Compressive strength of conventional Concrete			16

The compressive strength of cement concrete is 14 MPa. Similarly, the compressive strength of sulfur concrete was found to be 18 MPa. As a result, it suggests that the sulfur concrete possesses high strength, indicating its suitability for various structural applications.

V. ADVANTAGES & DISADVANTAGES

The primary advantage of sulfur concrete lies in its exceptional durability, making it an effective alternative to traditional Portland cement concrete, particularly in environments within industrial facilities or other areas where exposure to acids and salts leads to premature deterioration of conventional concrete. Sulfur concrete offers several benefits in construction within highly corrosive settings. Although its ultimate longevity and durability in various applications are not fully established, there is substantial evidence indicating that sulfur concrete outperforms many current materials in terms of lifespan in corrosive environments. Nonetheless, sulfur concrete may soften and lose strength over time in consistently wet conditions.

The service life of sulfur concrete components is influenced by several factors, including the degradation rate of elemental sulfur when exposed to atmospheric oxygen, moisture, and microorganisms. Additionally, the presence and density of microcracks, as well as the exposure of carbon-steel surfaces to corrosive agents in aqueous solutions through any macrocracks or voids, affect the material's performance. These considerations are crucial when designing structures, systems, and components (SSC) made from sulfur concrete, especially when they include reinforced or prestressed steel elements (such as rebar or tensioning cables).

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VI. CONCLUSION

The application of sulfur concrete focuses on utilizing sulfur waste, a byproduct from petrochemical and liquefied natural gas refining processes. Sulfur concrete offers several advantages, notably its high corrosion resistance and superior mechanical properties compared to traditional Portland cement concrete. However, the production of sulfur concrete requires advanced technological expertise, limiting its use to specialized applications. In the manufacturing process, sulfur is heated to activate it and then used as a complete substitute for cement, where it functions as a binder.

Experimental studies have shown that sulfur-based concrete exhibits enhanced strength properties, including improved compressive strength. Further research into sulfur concrete, particularly regarding the effects of heating during mixing, will be valuable for drawing more definitive conclusions about its performance.

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