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Comparison of the Test Results of Conventional Concrete with Sulphur-coated Aggregate Concrete

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Abstract Utilizing sulphur in concrete mixes stands out as an exemplary approach to mitigating environmental impacts. This method capitalizes on sulphur as a waste product from industrial operations, addressing waste disposal concerns and promoting environmental preservation. Sulphur concrete exhibits notable qualities, possessing heightened compressive strength, low hydraulic conductivity, and outstanding resistance to water permeation. It proves highly resilient to corrosion, particularly in acidic and saline conditions. Moreover, sulphur concrete boasts enhanced resistance to corrosion, augmenting its durability. When repeatedly loaded, its waterproofing properties prevent it from wearing out, accelerating the hardening process and enhancing its strength. This makes manufacturing more efficient and ensures durability in harsh environments. The objective of the study is to examine the effect of sulphur-coated aggregate concrete on compressive strength, sulphate resistance, and nitrate resistance. The study also aimed to compare the test results of conventional concrete with sulphur-coated aggregate concrete and to investigate the hardened properties of both normal concrete and sulphur-coated aggregate concrete across various cement percentages, including 5%, 7.5%, and 10%. Examining the compressive strength of concrete using different proportions of sulphur-coated aggregate consistently shows a decline in strength as the sulphur content rises to 5%, 7.5%, and 10%. However, the compressive strength fails to reach the target mean strength, unlike normal concrete. As the sulphur percentage increases, the concrete demonstrates improved performance against these ions. Following exposure to sulphate and nitrate attacks, concrete experiences a substantial reduction in strength, while sulphur-coated aggregate concrete maintains higher strength levels. Notably, the strength of concrete with a 10% sulphur content increases by up to 11.30%. Therefore, the findings indicate that sulphur concrete is suitable for applications in environments with high moisture levels and increased acid exposure. In terms of strength, sulphur concrete shows comparable performance to conventional concrete.

Keywords Comparative Study, Compressive Strength, Durability, Sulphur-coated Concrete, Conventional Concrete

1. Introduction

Portland cement concrete (PCC) has emerged as the predominant concrete type in the construction industry, extensively utilized in various structures such as sidewalks, bridges, buildings, tunnels, and dams [1]. The performance of concrete is intricately tied to its constituent ingredients, namely water, cement, and aggregates. Yanita [2] emphasizes the crucial role that Portland cement plays when mixed with water in binding and preventing aggregates from forming a solid mass. Concrete, being a versatile construction material, is integral to a wide range of infrastructure projects. However, the environmental impact of concrete, particularly the cement component, has prompted ongoing research to identify the most eco-friendly concrete mix. Cement is widely recognized for its significant carbon footprint, an issue that has garnered attention from researchers, like Djamil [3], who actively seek to address in their quest for more sustainable concrete technologies.

Concrete, a widely used building material, poses environmental challenges throughout its life cycle due to the generation of pollutants. To address this, efforts are underway to develop solutions for minimizing concrete's environmental impact and conduct life cycle assessments (LCAs) to evaluate its overall ecological footprint. On a global scale, research is actively exploring LCAs to understand and mitigate the greenhouse gas emissions associated with concrete, in response to the urgent need to combat climate change [4]. The increasing need for cement-based materials in sustainable construction and infrastructure is giving rise to concerns, primarily attributable to the significant greenhouse gas emissions and strain on resources linked with cement manufacturing [5]. Encouraging sustainability in the construction sector involves a growing focus on repurposing buildings and recycling debris from demolitions. Furthermore, the creation of new construction materials utilizing recycled construction and demolition waste contributes to environmentally conscious practices. Investigative efforts have been directed towards exploring the use of recycled aggregate as a viable alternative to traditional natural concrete, aiming for a more sustainable future [6].

The contemporary growth and progression in material technology, coupled with heightened ecological awareness, have led to significant advancements in the techniques for extracting sulphur from petroleum products [7]. Sulphur, with its diverse physical, chemical, and mechanical properties, has numerous applications in agriculture, the chemical industry, and the manufacturing of rubber, among others [8]. A notable application involves utilizing waste sulphur as a binding agent in various concrete compositions, leading to the development of sulphur concrete (SC). This innovative building material has the potential to surpass traditional concrete, which is typically made using Portland cement and water, in many construction applications [9]. Addressing the global concern of climate change, particularly the threat of global warming, is crucial for the sustainable future of human society. The introduction of sulphur concrete (SC) offers a promising solution by potentially reducing the environmental impact associated with traditional concrete production [10].

SC, a thermoplastic concrete mix, incorporates fillers such as coarse aggregate, fine aggregate, and fly ash, which are fused with molten sulphur at temperatures surpassing 120°C to attain a consistent blend [7-9]. Notably, SC does not utilize water or cement, resulting in enhanced durability properties compared to traditional concrete (NC). The high-temperature mixing of elemental sulphur and fillers induces the crystallization of liquid sulphur, forming monoclinic sulphur (S_β) at around 120°C and further transforming into stable orthorhombic sulphur (S_α) upon cooling below 115°C. Given its thermoplastic nature, careful consideration of SC's service temperature is essential [11]. Unlike Portland cement concrete (PCC), SC attains 90% of its mechanical properties within 24 hours of casting [11]. Additionally, SC proves beneficial in environments prone to acid attacks, exhibiting resistance to saline conditions and finding application in coastal, marine, and highly corrosive areas. These advantages position SC as a promising alternative where normal concrete (NC) falls short, prompting a comprehensive exploration of its distinct properties [12].

1.1. Background of the Study

Reinforced concrete has been widely used in construction areas. But there are some factors which are responsible for the deterioration of concrete. In this modern era, due to vigorous advancement in technology and industrialization, the environment has to face climate change and air pollution-like situations [13]. Due to this concrete gets affected, like reduction in strength, which leads to the collapse of structure [14, 15]. The area where sulphate attack on concrete can be seen is water containing sulphates, found in soils (in arid conditions), seawater, and wastewater treatment plants [16, 17]. Similarly, nitrate ions from fertilizers at agriculture sites affect the concrete. Ettringite is formed through the reaction of sulphate ions with C3A, calcium hydroxide, and various cement compounds found in concrete [18-20]. Ettringite, which is also called calcium sulfoaluminate ($Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$), is a mineral that grows very large when it forms large amounts. Due to the expansion of ettringite tensile stress develops in concrete by which concrete begins to crack. As the cracking increases, a large amount of sulfate ions breaks into concrete and expands it, by forming ettringite. Nitrate ions from fertilizers (ammonium nitrate) react with calcium hydroxide to decalcify the concrete [21, 22]. Calcium hydroxide is more soluble in ammonium nitrate than water, due to which corrosion of concrete occurs by decreasing its pH value [23, 24]. The first attempt to use sulfur as a construction material was around 1921 in the USA. Lee et al. [25] found that 40% sulfur and 60% sand give high strength and acid resistance. However, this mix has problems such as decreased flexural strength, cubic expansion, and micro-cracks rupture due to repeated changes in temperature. Then a new attempt was made to coat the aggregate with a material like pozzolanic which increased its slump value, compressive strength, and flexural strength [26, 27]. Nowadays, sulfur in petroleum products is prohibited in concern with its effect on the environment, sulfur as a byproduct from petroleum industries and coal industries can be used in the construction field [28, 29]. Extensive research is being conducted to investigate the potential application of sulphur in construction due to its hydrophobic properties, resistance to acids, and durability in challenging environments. During the 1920s and 1930s, sulphur found widespread application in various areas. In 1924, Kobbe conducted research on the acid-resistant characteristics of cement and concretes formulated from sulphur-coke compositions. In the 1930s, there were investigations into sulphur-aggregate compositions, exploring their viability for constructing and repairing acid tanks, flooring, and pipes resistant to corrosion.

1.2. Objectives of the Present Study

The objectives of the present study are:

- To examine the effect of sulfur-coated aggregate concrete on compressive strength, sulphate resistance, and nitrate resistance.
- Comparison of the test results of conventional concrete with sulphur-coated aggregate concrete.
- To investigate the hardened properties of both normal concrete and sulfur-coated aggregate concrete across various cement percentages: 5%, 7.5%, and 10%.

1.3. Properties of Sulphur and its Effect of Coating on Aggregate

Sulphur exists as a yellow solid and is known for its reactivity, readily forming compounds with all elements except noble gases, gold, and platinum. While insoluble in water, sulphur exhibits solubility in nonpolar solvents. It remains unreactive to dilute non-oxidizing acids but undergoes reactions with alkali hydroxides, leading to the formation of sulphides and thiosulfates.

Sulphur is known to exhibit approximately 30 distinct allotropic forms, each characterized by unique physical properties. While these allotropes may vary in molecular structure and chemical reactivity, they generally share similar chemical properties. Under specific temperature and pressure conditions, different allotropes can coexist in defined proportions, with their presence and concentrations influenced by the thermal history. Consequently, the solid sulphur's physical and chemical attributes are contingent upon its thermal treatment [30, 31]. Two important allotropic forms of sulphur exist: rhombic (a), which has orthorhombic crystals and stays stable below 95.5°C, with a melting point of 114°C; and monoclinic (b), which has needle-like crystals and stays stable between 95.5°C and its melting point of 119°C. Both forms consist of cyclo-S8 molecules. When in a liquid state above 159°C, sulphur transforms into a solution comprising linear chains resulting from the opening and polymerization of S8 rings, lacking a regular arrangement between them. Sulphur has been explored as a potential binding agent for various aggregates since the beginning of the century. Its suggested applications have spanned from pipes, industrial tanks, and roofing to pavement coatings, as well as compounds for jointing or grouting.

The effect of sulfur-coated aggregate concrete effectively increases acid resistance concerning normal concrete. Even 5% sulphur-coated aggregate concrete is very efficient following acid resistance compared to normal concrete [25], [32]. As we increase the amount of sulfur, we have to make compromises with strength as compared to normal concrete, but the resistance towards sulfate attack increases consequently. Sulphur somehow tends to decrease the strength of concrete as we increase the amount, so to minimize its effect some amount of superplasticizer is added, which effectively helps cement to set [33].

In our experimental work, we use the batch for different proportions of sulfur. For the M20 grade of the concrete amounts of sulphur 5%, 7.5%, and 10% are used and from the mix design, we conclude the various number of different materials which are used in the experiment.

2. Materials Used and its Properties

2.1. General

In this study, the mechanical behavior of sulfur-coated aggregate concrete of M20 grade prepared with different proportions of the same was studied. For each mix, six numbers of cubes (150×150×150) mm were investigated and a study was conducted on the mechanical behavior and microstructure of sulfur-coated aggregate concrete. The observational plan was held up in various steps to accomplish the following aims:

1. To prepare sulfur coating of both aggregates separately at different proportions.
2. To prepare sulfur-coated aggregate concrete of M20 grades and study their hardened properties.

2.1.1. Properties of Cement

Ordinary Portland cement of the Zuari brand available in the local market was used in the present studies. The physical properties of OPC 53 obtained from the experimental investigation were confirmed to IS: 269-2015 (**Refer to Tables 1 and 2.**).

Table 1. Properties of cement

Property	Value	Unit
Fineness	284	m^2/kg
Normal consistency	27	%
Specific gravity	3.15	-
Initial setting time	155	minute
Final setting time	210	minute
Compressive strength 3, 7, and 28 days	32, 43, and 53	N/mm^2

Table 2. Chemical properties of cement

Property	Value	Unit
Lime saturation factor	0.87 (> 0.6 and < 1.02)	%
Alumina iron ratio	1.07 (> 0.66)	%
Magnesia	1.12 (< 6)	%
Sulfuric anhydride	2.27 (3.35)	%
Insoluble Residue	2.08 (< 5)	%
Loss on ignition	1.32 (< 5)	%
Alkalis	0.42	%
Chlorides	0.01 (<0.10)	%

2.1.2. Properties of Coarse Aggregate

The coarse aggregate used were 20 mm and 10 mm down size and collected from Quarry near Jagdalpur conforming to IS:2386 (Part III)-1963.

2.1.3. Properties of Fine Aggregate

Natural river sand has been collected from Indravati River, Jagdalpur, Chhattisgarh, and conforming to Zone-II as per IS-383-1970 (See Table 3).

Table 3. Properties of coarse aggregate (CA) and fine aggregate (FA)

Properties of aggregates	CA	FA
Specific gravity	2.77	2.65
Fineness modulus	6.72	2.81

2.1.4. Water

The investigations utilized potable water adhering to the specifications outlined in IS 3025-1986 parts 22 and 23 and IS 456-2000. The water must be devoid of acids, oils, alkalis, vegetables, or any other organic impurities. The use of water can result in the production of less robust concrete. Water performs two crucial roles in a concrete mix: firstly, it reacts with cement to create a cement paste that holds the inert aggregate in suspension until the cement paste solidifies. Secondly, it acts as a medium or lubricant in the blending of fine aggregate and cement.

2.1.5. Properties of Admixture- Superplasticizer

Concerto chem brand of superplasticizer admixture used in this study is purchased from a local distributor. The admixture used is complying with IS9103. In this study, polycarboxylate ether is used. To achieve optimal workability in concrete with low water-to-cement ratios, plasticizers and superplasticizers are employed. These chemical additives effectively decrease the water requirements of concrete while maintaining the desired workability levels. Depending on their efficacy, they are categorized as water-reducing agents (plasticizers) and high-range water reducers (superplasticizers). Additionally, some of these additives possess amphiphilic properties, leading to the introduction of air into the concrete mix.

2.1.6. Properties of Sulphur

Fizmerk's sulfur resublimed powder is used in this study, purchased from the local chemical shop. To completely coat the aggregates, sulfur is heated to reach its melting point. Sulfur is hydrophobic and the coated aggregate cannot absorb the water when mixing. The sulfur properties are the following (**Refer to Table 4**):

Table 4. Properties of Sulphur

Properties	Test Value
Specific gravity	2.06
Melting point	115^0C
Colour	Lemon yellow

3. Methodology

3.1. General

The objective of this study is to assess and contrast the mechanical and durability characteristics of conventional concrete against sulphur-coated aggregate concrete. However, the main purpose of this study is to explore the potential advantages of integrating sulphur-coated aggregate into concrete production, particularly in terms of improved durability and mechanical resilience. Furthermore, the method involves making batches of both regular and sulphur-coated aggregate concrete. These are then put through a full set of standard tests that measure their durability, compressive strength, tensile strength, and ability to absorb water. We will meticulously analyze the gathered data to identify any discernible performance disparities between conventional and sulphur-coated aggregate concrete. Therefore, in this study, the conventional concrete of M20 grades is used with sulphur-coated aggregate specimens with varying percentages of 5%, 7.5%, and 10%. The general materials used in this project were tested to get their properties. Cube specimens were molded and allowed to cure for 28 days to assess mechanical properties such as compressive strength and acid resistance. Hence, the overall methodology adopted for the present study is illustrated in **Figure 1**.

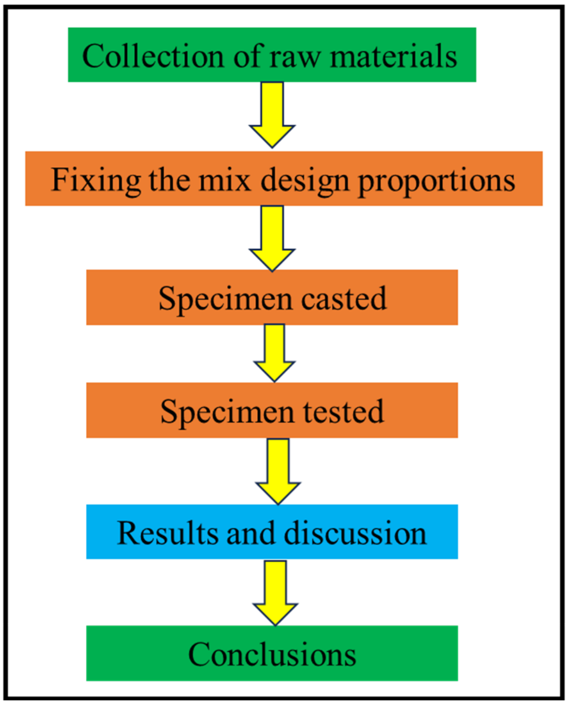

Figure 1. Methodology flowchart

3.2. Concrete Mix Proportioning

The concrete mix is formulated by IS 10292-2009. The coarse aggregate has a minimum size of 20 mm, and the water-to-cement ratio is determined to be 0.45, with a slump measurement of 150 mm.

3.3. Sulfur Coating of Aggregate

3.3.1. Coating of Coarse Aggregate

For coating sulfur on coarse aggregates following procedure is adopted in this study (**See Figure 2**).

Figure 2. Coating of aggregate with molten

- Coarse aggregate is weighted concerning mix design value obtained and kept in the oven for heating at 120^0C for two hours to remove the moisture present in it.
- Before removing the aggregate from the oven powdered sulfur of the quantity obtained in the mix design is melted with the help of a heater in a borosil beaker.
- The heated aggregate is removed from the oven and kept in a mixing plate, and the molten sulfur is poured on the aggregate at a slow rate and at the same time mixing is done to coat all the aggregate.

3.3.2. Coating of Fine Aggregate

For coating sulfur on fine aggregate, the weighted fine aggregate is preheated to remove its moisture, and sulfur powder is weighted according to the mix design and mixed with the help of a trowel. Then this mixture is kept in the oven for heating at 115°C for 2 hours (**Refer to Figure 3**).

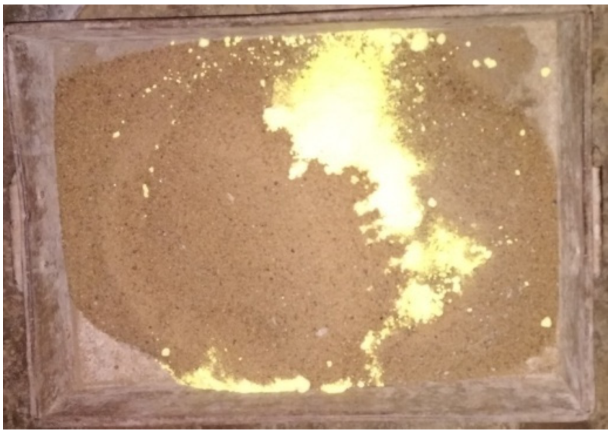

Figure 3. Mixing of preheated fine aggregate with sulphur powder

3.4. Mixing of Concrete

Utilizing specialized equipment, mechanical mixing of concrete entails the thorough integration of cement, aggregates, water, and additives. This method, which is typically used in concrete mixers, ensures even dispersion of components, thereby improving the uniformity and robustness of the resulting concrete. The rotating drum or blades of the mixer play a pivotal role in achieving consistent blending, thereby optimizing the hydration reaction between cement and water. Effective mixing is paramount in attaining the desired concrete characteristics, encompassing workability, strength, and durability.

Machinery such as drum mixers or pan mixers is used to mechanically mix concrete. The mixer first introduces dry components like cement, aggregates, and additives. The mixer rotates, subsequently adding water in stages to ensure comprehensive blending. The mixer continues to mix until it achieves a consistent uniformity, which is often identifiable by a homogeneous color and texture. Adequate mixing duration is critical to ensuring thorough hydration of cement particles and optimal concrete quality. Ultimately, the mixer releases the blended concrete for placement and curing, primed for construction purposes (**Refer to Figure 4**).

To address the hazards associated with sulphur in reinforced concrete and its detrimental effects on human health, several remedial measures are essential. Implementing strict safety protocols during sulphur handling, including adequate ventilation and personal protective equipment, can mitigate health risks for workers. Furthermore, research should focus on developing alternative materials or modifying sulphur-based formulations to enhance structural stability without compromising safety. Regulatory bodies must enforce stringent guidelines to ensure compliance with safety standards in construction practices. Additionally, public awareness campaigns highlighting the risks of sulphur exposure can promote safer handling practices and foster a culture of health and safety within the construction industry.

Figure 4. Mechanical mixing of concrete

3.8. Test Methods

The tests of concrete were conducted for slump test and compressive strength.

3.8.1. Compressive Strength Test

The most commonly conducted test on hardened concrete is the compressive strength test, due to its simplicity and its ability to reflect key properties of concrete. For this test, three cubes were prepared for each sulphur percentage, along with control concrete specimens for each mix. The specimens were cured for 28 days under moist conditions and subsequently tested in a compression testing machine (CTM) to assess their compressive strength. The size of the cube is 150x150x150 mm in side according to IS: 1881-1983 (Part 108) (**See Table 5**).

Table 5. 28 days cube strength after curing

S.No.	Type of Specimen	Load (KN)	Stress (N/mm^2)	Average (N/mm^2)
1	5% Sulfur Coated	536.2	23.83	23.58
		530.4	23.57	
		525.6	23.36	
2	7.5% Sulfur Coated	510.3	22.68	22.01
		499.3	22.19	
		490	21.17	
3	10% Sulfur Coated	485	21.5	21.5
		490.3	21.7	
		480	21.3	
4	Normal Concrete	582.2	25.87	26.09
		590.2	26.23	
		589.3	26.19	

3.8.2. Acid Test

This experiment is being conducted to assess the resilience of concrete in challenging environmental conditions. In this study, two types of acid tests are done with the help of sulfuric acid and nitric acid with 5% dilution. With the help of sulfuric acid sulfate attack is tested and from nitric acid, nitrate attack is checked (**Refer to Table 6**). The test is conducted in two manners, the first specimen of each percentage of sulfur-coated aggregate concrete is immersed in both acids for 7, 14, and 28 days (**Refer to Tables 7a, b, and c**), and the weight of each specimen is checked. Loss and gain of weight are calculated and presented in percent form. Second, after 28 days of immersion in acid, compressive strength is checked (**Refer to Tables 8 and 9**).

Table 6. Weight of various specimens before immersion in acids

quality-wise description of the concrete	weight of concrete after 28 days of curing for ice acid in (kg)	weight of concrete after 28 days of curing for nitric acid in (kg)
5% Sulphur	8.86	8.84
	8.42	8.50
	8.54	8.70
7.5% Sulphur	8.43	8.76
	8.57	8.68
	8.78	8.57
10% Sulphur	8.54	8.42
	8.83	8.70
	8.64	8.81
Normal Concrete	8.58	8.48
	8.56	8.68
	8.87	8.78

Table 7 (a). Weight after 7 days in acid solution.

Quality-wise descriptions of concrete	The average weight of concrete for sulfuric acid and its percentage increase and decrease weight (kg)	The average weight of concrete for nitric acid and its percentage increase and decrease of weight (kg)
5% sulphur	8.8 (-0.67%)	8.74 (-1.31%)
7.5% sulphur	8.39 (-0.35%)	8.42 (-0.94%)
10% sulphur	8.52 (-0.23%)	8.65 (-0.57%)
Normal concrete	8.5 (-2.07%)	8.72 (-1.58%)

Table 7 (b). Weight after 14 days in acid solution

Quality-wise description of concrete	The average weight of concrete for sulfuric acid and its percentage increase and decrease weight (kg)	The average weight of concrete for nitric acid and its percentage increase and decrease of weight (kg)
5% Sulfur	8.84 (+0.45%)	8.78 (+0.45%)
7.5% Sulfur	8.44 (+0.59%)	8.42 (0%)
10% Sulfur	8.58 (+0.70%)	8.74 (+1.04%)
Normal concrete	8.48 (-0.23%)	8.67 (-0.57%)

Table 7 (c). Weight after 28 days in acid solution.

Quality-wise description of concrete	Average Weight of concrete for sulfuric acid and its percentage increase and decrease weight (kg)	Average Weight of concrete for nitric acid and its percentage increase and decrease of weight (kg)
5% Sulphur	8.8 (-0.45%)	8.80 (+0.22%)
7.5% Sulphur	8.20 (-0.48%)	8.42 (0%)
10% Sulphur	8.64 (+0.69%)	8.74 (0%)
Normal concrete	8.24 (-2.83%)	8.43 (-2.76%)

Table 8. Strength after deepening in sulphuric acid for 28 days

S.No.	Type of Specimen	Load (KN)	Stress (N/mm^2)	Average (N/mm^2)	Percentage increase and decrease in strength
1	5% Sulphur Coated	520.2	23.43	23.29	-1.22%
		516.3	23.25		
		515.4	23.21		
2	7.5% Sulphur Coated	508.8	22.91	23.06	+4.77%
		510.2	22.98		
		517.3	23.3		
3	10% Sulphur Coated	530.2	23.88	23.93	+11.30%
		534.3	24.06		
		529.5	23.85		
4	Normal Concrete	430.2	19.6	19.6	-24.90%
		434.3	19.8		
		529.5	19.4		

Table 9. Strength after deepening in nitric acid for 28 days.

S.No.	Type of specimen	Load (kN)	Stress (N/mm^2)	Average (N/mm^2)	Percentage increase and decrease in strength
1	5% Sulphur Coated	523.2	23.25	23.08	-2.12%
		520.13	23.11		
		495	22		
2	7.5% Sulphur Coated	497.8	22.12	22.13	-0.54%
		501.3	22.28		
		489.3	21.74		
3	10% Sulphur Coated	486.4	21.61	21.57	0.33%
		481.2	21.38		
		584.7	25.9		
4	Normal Concrete	580.3	25.7	25.78	-1.18%
		579.2	25.74		

4. Results and Discussion

Fundamental analysis of the modelled structure focused on examining the performance of different batches of sulphur-coated aggregate concrete. The comparative study took into account several key factors to assess their behaviors.

4.1. Compressive Strength Test

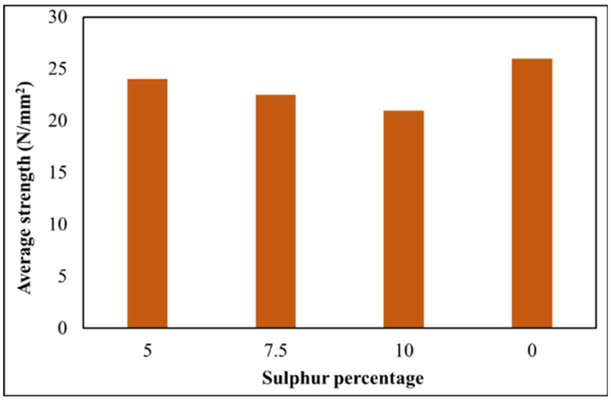

Figure 5. Graph of the average strength of each percentage of sulphur.

In the above **Figure 5**, sulphur content is increased from 5%, 7.5%, and 10%, concerning compressive strength calculated from cube strength. The first bar graph is of 5% sulphur-coated aggregate concrete which shows an average value of 23.58 N/mm^2, the second bar graph is of 7.5% sulphur which shows an average value of 22.01 N/mm^2, the Third bar graph is of 10% sulphur which shows an average value of 21.5 N/mm^2 and Fourth bar graph is of normal concrete which shows the average value of 26.09 N/mm^2. So, from the graph, we conclude that as we increase the sulfur content the compressive strength decreases but it is limited to what we designed for instead it couldn't reach the target mean strength, whereas the normal concrete reaches the target mean strength (**See Figure 5**).

4.2 Acid Test

From **Figures 6 and 7**, the graphs are shown concerning weight versus several days immersed in ice acid. The graphs drawn above show different variations in weight change in addition to sulphur-coated aggregate concrete. The purple colour in the two graphs is of normal concrete which shows a continuous decrease in weight for 28 days, and the loss of weight in 28 days has been observed in the study is about -5.06% in ice acid and -4.91% in nitric acid. The green line shows a continuous increase in weight in the first case and second case the weight doesn't change because sulphur is not reactive to dilute ice acid and nitric acid, the increase in weight in 28 days of immersing in ice acid and nitric acid is of +1.16% and +0.47% respectively. The other two colors red and blue are 7.5% and 5% -coated aggregate concrete, in which 7.5% coated the weight is decreased to -0.13% and -0.94% in ice acid and nitric acid respectively. In 5% sulphur coated the decrease in weight immersed in ice acid and nitric acid is -0.67% and -0.67% respectively. From the study, we see that the decrease in weight in the case of normal concrete is more than the different percentages of sulphur-coated aggregate concrete. Concerning strength, we can see the variation in the figure below.

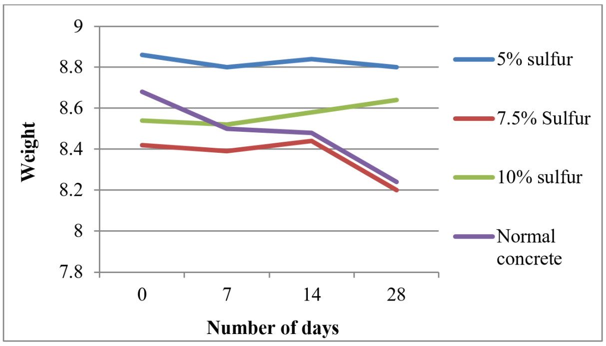

Figure 6. Graph of weight vs days in ice acid

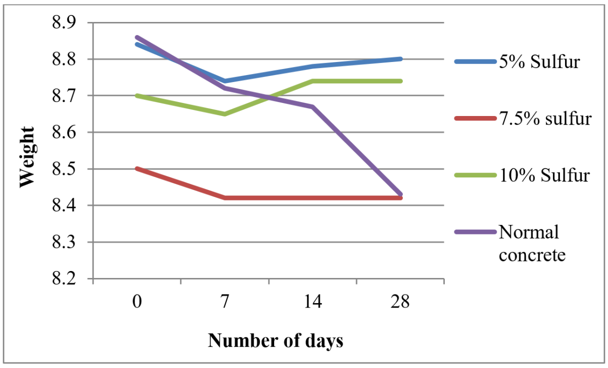

Figure 7. Graph of weight vs days in nitric acid

The above graph is of the strength of various sulphur percentages from 0%, 5%, 7.5%, and 10 % before and after immersion in acids (**Refer to Figure 8**). The blue line is of strength after 28 days of curing, and the line shows as we increase the percentage of sulphur the strength decreases. The red line is strength after sulphate attack with the use of acid so we can see that there is a slight decrease in strength in the case of normal concrete but in sulphur-coated aggregate concrete there is no change in strength although there is an increase in strength as the percentage is increased. In the case of nitric acid, the change in strength is not very varied, but there is corrosion which is seen on the concrete surface. However, the performance of normal concrete and sulphur-coated aggregate concrete the abrasion is quite high in normal concrete, and as we increase the coating the acid resistance is quite promising concerning appearance and strength. Furthermore, the performance of normal concrete and sulphur-coated aggregate concrete the corrosion which is quite high in normal concrete, and as we increase the acid resistance is quite promising concerning strength but we can see the corrosion that is visible to the naked eye.

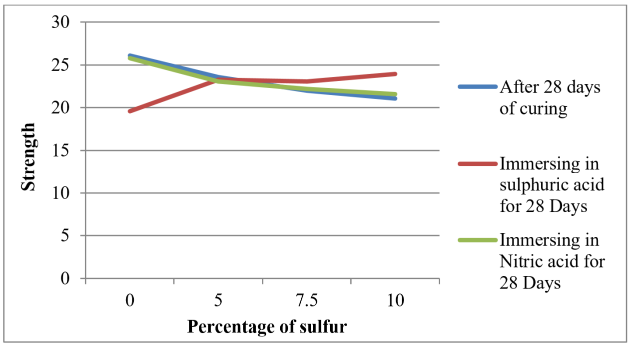

Figure 8. Graph of the average strength of 3 cubes before and after deepening in acids

5. Conclusions

a) For different percentages of sulphur-coated aggregate concrete, the strength is checked. As we increase the percentage of sulphur from 5%, 7.5%, and 10% the compressive strength of the cube tends to decrease and it doesn't reach its target mean strength whereas normal concrete does. We restrict the sulphur percentage to 10% to ensure the strength of concrete at 20 N/mm^2 (**Refer to Table 10**).

Table 10. Percentage decrease of strength concerning normal concrete

Percentage of used for coating	Strength (N/mm^2)	Percentage decrease in strength
5%	23.58	9.6%
7.5%	22.01	15.63%
10%	21.5	17.6%

b) The resistance against sulphate and nitrate attack on sulphur-coated aggregate concrete is promising in comparison with normal concrete. As we increase the percentage the concrete shows better performance against these ions. At the same time, the loss in weight after immersion in acid is quite high for normal concrete in comparison to sulphur-coated aggregate concrete.

c) After the sulphate and nitrate attack on concrete, the strength of normal concrete is reduced enormously compared to sulphur-coated aggregate concrete. The strength of 10% sulphur is increased up to 11.30%.

d) In this study, it is observed that, in the melting of sulphur, one compound SO_2 (sulphur dioxide) is formed which is not safe for reinforcement, so the application of sulphur-coated aggregate concrete is limited to prestressed and precast members of concrete.

Recommendation for Future Research

The prospects of sulphur-coated aggregate concrete show significant promise for advancing sustainable construction practices. This innovative material offers improved durability, a diminished environmental footprint, and enhanced performance in comparison to conventional concrete. Sulphur-coated aggregate concrete has the potential to transform the construction industry by effectively addressing issues such as corrosion, the alkali-silica reaction, and overall carbon emissions. Its distinctive properties contribute to prolonged service life, heightened resistance to harsh environments, and reduced maintenance expenses.

Future studies ought to explore the applicability of sulphur concrete in specialized areas such as marine infrastructure. Assessing its resistance to corrosive marine elements may reveal its viability as a resilient and eco-friendly building material for coastal structures, seawalls, and offshore platforms. Changing the ingredients in sulphur concrete to fit these environments' needs and carefully checking how well they work will give us useful information about their abilities for these specific uses, which will lead to more widespread use of these materials in different construction settings.

Limitations of the Present Study

Sulphur-coated aggregate concrete exhibits sensitivity to temperature fluctuations. Elevated temperatures can cause the binder to soften and deform, potentially leading to structural issues, while lower temperatures can render the material brittle, compromising its overall durability. This concrete variant is not universally suitable for construction purposes and finds its primary use in specialized projects like overlays and bridge decks. The restricted application stems from concerns related to temperature sensitivity and other performance factors. Coated aggregate concrete may lack the chemical resistance observed in some conventional concrete types. This limitation restricts its usage in environments where exposure to harsh chemicals is a significant consideration. Concerns about long-term durability surround sulphur-coated aggregate concrete, with potential susceptibility to aging and degradation over time, particularly when exposed to environmental elements such as ultraviolet radiation, moisture, and freeze-thaw cycles. The handling and installation of sulphur-coated aggregate concrete pose challenges, necessitating specialized equipment and procedures. Maintaining precise temperature control during mixing and laying processes is imperative for successful application. In addition, a byproduct of the petroleum industry raises environmental apprehensions in the context of sulphur-coated aggregate concrete.

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Data Availability Statement

The author declares no data has been analyzed/generated during the present study.

Conflict of Interest

The authors declare there is no conflict of interest.

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