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# Study on the Properties of Alumina Based Sulfur Concrete Made with Waste Granite Aggregates

Varsha Shaji[1], Chinku Alphons Tom[2]
[1, 2]Department of Civil Engineering, Toc H Institute of Science and Technology, Arakkunnam, Kerala, India-682313

***Abstract—*** *Growing interests in sulfur usefulness as a bond in the sulfur concrete is because of the large availability of this raw material and advantages of the created composite. A huge amount of sulfur is obtained as a by product from the fuel desulphurisation process or crude oil refining process or as a natural raw material. As an innovative solution for the waste disposal problem, this waste sulfur can be efficiently utilized in many ways like preparing sulfur concrete, sulfur asphalt, and aggregate coatings. Mainly waste sulfur used for the role of binder in concrete has been rapidly pursued to replace entire water required for concrete mixing. As this eliminates the use of water for mixing, the concrete prepared is also called waterless concrete. This study tries to investigate the variation in mechanical and durability properties of sulfur concrete based on alumina as filler material and industrial waste granite as partial replacement for coarse aggregates. The properties are then compared with ordinary sulfur concrete without filler material and made with natural coarse aggregates. Most suitable mix proportion for the sulfurcrete is taken by reviewing different literatures of the available journals. The selected mix proportion includes 34% Sulfur, 30% fine aggregates and 36% coarse aggregates. An unsaturated cyclic hydrocarbon Dicyclopentadiene is used for the modification of sulfur. Filler alumina is added in different combinations into the selected mix. The optimum percentage combination of sulfur and alumina is found out. The coarse aggregates are then replaced with 10%, 20%, 30%, 40%, and 50% percentages of waste granite aggregates and the optimum percentage replacement is worked out. Various mechanical and durability tests including compressive strength, split tensile strength, water absorption and acid resistance are conducted for the normal and replaced sulfur concrete. The variations in mechanical and durability properties of replaced sulfurcrete are then to be compared with sulfur concrete without filler material.*

***Keywords—*** *Sulfur concrete, Alumina, Filler, Waste sulfur, Waterless concrete, Dicyclopentadiene*

## I. INTRODUCTION

Fossil fuel consumption is rapidly increasing all over the world, and so is the amount of elemental sulfur which is a by product of petroleum refining process, natural gas processing and coking plants. The principle source of this recovered elemental sulfur is hydrogen sulphide in sour natural gas and organic sulfur compounds in crude oil. Hydrogen sulphide is converted into elemental sulfur by Clau's process. In 2013, the global production of sulfur was approximately 69 million tons. Since 2009, 1.2 million tons of sulfur has been generated annually in India, and about 90% of the total amount originated from the desulfurization of petroleum and crude oil refining processes [7]. While some of the waste sulfur is consumed as a component in industrial chemicals and agriculture industry, most sulfur waste generated is left unused. As an innovative solution, using sulfur as a component in composite construction materials such as sulfur asphalt and sulfur concrete has been pursued interest. In particular, it has been attended that sulfur may be used to replace entire cement and water in concrete for the role of a binder, thermoplastic sulfur melted by heat bonds aggregates and fillers together, and forms stable hardened concrete.

Sulfur concrete is generally a thermoplastic mixture of modified or unmodified sulfur and aggregates mixed at a high temperature. In order to prepare modified sulfur concrete, it must be heated above the melting point of sulfur at around $115^0$C. At this temperature, sulfur liquefies and lubricates the aggregate and converts it into a plastic mixture. When unmodified sulfur and aggregate are mixed in high temperature, the sulfur binder crystallized from the liquid state as monoclinic sulfur (Sβ) at 120˚C. On cooling to below 115 ˚C, Sβ starts to transform to orthorhombic sulfur (Sα), which is stable form of sulfur at ambient temperatures. By reacting sulfur with an unsaturated hydrocarbon, dicyclopentadiene (DCPD), stable sulfur cements were developed by the formation of long-chain polymeric polysulfides [7]. The maximum operating temperature without much losing the strength and stiffness of sulfur concrete is known to be around 120˚C. However, sulfur concrete made with elemental sulfur has limitations for practical use, because it has inferior properties such as poorer resistance to water and higher brittleness than conventional concrete. In order to overcome these drawbacks, several types of modified sulfur have been developed [10]. By reacting elemental sulfur with an unsaturated hydrocarbons (e.g., dicyclopentadiene, Olefin hydrocarbons), stable modified sulfur may be developed through the formation of long-chain polymeric polysulfide's.. Sulfur concrete achieves 70 to 80% of the maximum compressive strength within 24 hours and its complete strength within the third day after casting [7]. This in turn will make such material a good candidate for its use in construction. Also, sulfur concrete may be useful in sewage and waste treatment plants, drainage pipelines, marine structures, and retaining walls to look into how this largely unwanted material could be used. It can also used for pavements and other surface coatings also [2]. This study investigated the mechanical and durability properties of sulfur concrete made with modified sulfur binder and alumina as filler material instead of Portland cement.

## II. MATERIALS USED

The different important materials used in this particular work are described below.



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*A. Sulfur*

Sulfur, which is the basic component for modified sulfur concrete originates from Claus's procedure in the Oil and petroleum refinery and its purity is 99%. The sulfur used in this work is collected from BPCL Kochi Refineries, Ambalamugal, Kochi and is used in powder form.

*B. Alumina*

Aluminium oxide commonly called alumina is a chemical compound of aluminium and oxygen with the chemical formula $Al_2O_3$. It is the most commonly occurring of several aluminium oxides, and is mainly a waste product obtained from aluminium ores. It is commonly called alumina, and may also be called aloxide or alundum depending on particular forms or applications. It is finer than sulfur powder. The alumina used in this study was collected from Regional exporters Pvt Ltd., Kochi.

*C. Dicyclopentadiene*

Di-cyclopentadiene is an unsaturated hydrocarbon with light yellow colour and having an acrid odour. Polymerization occurs if subjected to heat for short periods or if got contaminated. In this project work di-cyclopentadiene, is used to provide modification for elemental sulfur through the formation of long chain polymeric cyclic poly-sulfides. Dicyclopentadiene used in this work is collected from Lab Agencies, Kacheryppady, Kochi.

*D. Waste Granite Aggregates*

Granite is a light-coloured igneous rock with grains large enough to be visible with the unaided eye. Granite is composed mainly of quartz and feldspar with minor amounts of mica, amphiboles, and other minerals. Large amount of granite is left unused as waste materials in different granite production and exporting firms. Granite waste used in this study was collected from Cochin granites and marbles, Mundamvelli and crushed in to smaller sizes. The nominal maximum size of granite aggregate used in the project was 20mm.

## III. MANUFACTURING OF SULFUR CONCRETE

Sulfur concrete specimens were fabricated using the proposed method by ACI 548.2R-93 "Guide for Mixing and Placing Sulfur Concrete in Construction" [1]. At first, the coarse and fine aggregates are preheated in an oven at 130˚C for 6-8 hours. The preheated aggregates were then added to the container that was preheated up to 130˚C. The sulfur powder is then heated in another container at about 120˚C and thus the sulfur is melted when it is heated above the melting point of sulfur which is 115˚C. Modification for the sulfur is provided by adding 5% of an unsaturated hydrocarbon called Dicyclopentadiene ($C_{10}H_{12}$) into the half melted sulfur and is heated again to initiate polymerisation. After 1 minute of dry mixing of aggregates, the modified sulfur binder was also poured into the container and is mixed well. Mixing is continued until the sulfur binder gets completely liquefied, and also for an additional 10 min after the liquefaction. Then, sulfur concrete were casted and compacted. Before casting of the sulfur concrete, the cube moulds used for concrete casting are also preheated in an oven to around $120^0$C for 2 - 4 hrs. The casted sulfur concrete specimens were de-moulded after 24 hours and kept in room temperature (20-25˚C) and humidity. The de-moulded specimens can be tested for its strength even after the first day. Strength testing for the specimens are done at the 1 day, 3 day and 28 days after de moulding.

## IV. TEST VARIABLES AND MIX PROPORTION

To determine the mix proportions of sulfur concrete, the test results of ACI 548.2R-93 "Guide for mixing and placing sulfur concrete" [1], Kyu-hun "Mechanical Properties of Sulfur Concrete" [10], Youngsu et al. "Durability of sustainable sulfur concrete with fly ash and recycled aggregate against chemical and weathering environments" [7] were used. There is no particular IS codes or other standards available for proportioning the mix ratio of sulfur concrete. The research in all literatures showed the most stable compressive and flexural strengths when the ratio of Sulfur and aggregate is 1:1.9 by volume. Therefore, coarse and fine aggregates selected take 36% and 30% respectively by volume if the total volume of sulfur concrete is considered as 100%. Then the sulfur takes 34% by volume of sulfur concrete respectively. The maximum size of the coarse aggregate used is 19 mm to ensure workability and strength. Amount of the alumina was increased considering price of the sulfur concrete by minimizing the amount of sulfur with preserving workability. the study is conducted by preparing different combinations of alumina and sulfur by volume and finding out the optimum mix percentage combination of sulfur and alumina. The weight amount of each component was calculated by multiplying specific gravity of each material. The table I shows the different replacements provided.

TABLE I. Different volume combination of sulfur and alumina (For 1m$^3$).

| Sl no | % combination | Wt of sulfur (kg) | Wt of alumina (kg) |
|---|---|---|---|
| 1 | 34 % Sulfur + 0 % Alumina ($S_0$) | 714 | 0 |
| 2 | 32 % Sulfur + 2 % Alumina ($S_0$) | 672 | 52.8 |
| 3 | 30 % Sulfur +40 % Alumina ($S_0$) | 630 | 105.6 |
| 4 | 28 % Sulfur + 6 % Alumina ($S_0$) | 588 | 158.4 |
| 5 | 26 % Sulfur + 8 % Alumina ($S_0$) | 546 | 211.2 |
| 6 | 24 % Sulfur + 10 % Alumina ($S_0$) | 5.4 | 264 |
| 7 | 22 % Sulfur + 12 % Alumina ($S_0$) | 462 | 316.8 |
| 8 | 20 % Sulfur + 14 % Alumina ($S_0$) | 420 | 369.6 |

## V. EXPERIMENTAL PROGRAMME

Different tests conducted on sulfur concrete includes compressive strength test, split tensile strength test and acid resistance test.



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*A. Compressive Strength*

Compressive strength test is the most common test conducted on hardened concrete in order to determine the compressive strength of the concrete. The compressive strength is assessed by crushing to destruction of the test cubes by means of compression testing machine. For that 150mm x 150mm x 150mm concrete cube is casted. These specimens are then tested by compression testing machine after different days of curing. Load should be applied gradually till the specimen fails. Load at the failure divided by area of the specimen gives the compressive strength. The compressive strength test was conducted as per IS 516-1959 (reaffirmed 1999. Table II shows the compressive strength results.

TABLE III. Compressive strength values for different concrete mixes.

| % combination | 1 Day compressive strength (N/mm$^2$) | 3 Day compressive strength (N/mm$^2$) | 28 Day compressive strength (N/mm$^2$) |
|---|---|---|---|
| 34 % Sulfur + 0 % Alumina ($S_0$) | 22.28 | 26.26 | 26.81 |
| 32 % Sulfur + 2 % Alumina ($S_1$) | 23.28 | 27.04 | 27.65 |
| 30 % Sulfur +40 % Alumina ($S_2$) | 24.04 | 28.01 | 28.14 |
| 28 % Sulfur + 6 % Alumina ($S_3$) | 25.92 | 31.87 | 31.42 |
| 26 % Sulfur + 8 % Alumina ($S_4$) | 27.16 | 33.26 | 33.21 |
| 24 % Sulfur + 10 % Alumina ($S_5$) | 34.29 | 37.40 | 37.84 |
| 22 % Sulfur + 12 % Alumina ($S_6$) | 37.17 | 43.04 | 44.21 |
| 20 % Sulfur + 14 % Alumina ($S_7$) | 34.18 | 40.97 | 41.31 |

Fig 1 shows the variation of compressive strength with different percentage combinations.

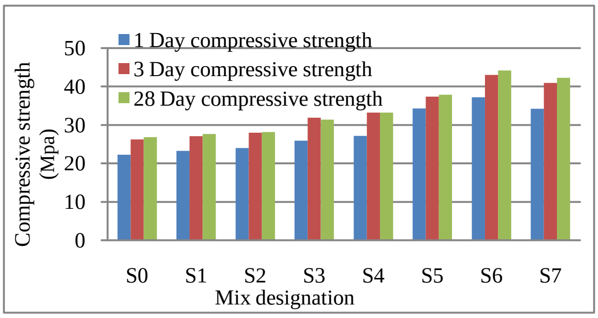


Fig. 1. Compressive strength results.

From the above results it can be seen that the addition of alumina as filler material increases the strength of the normal sulfurcrete. This is likely attributed to the better particle size distribution and packing of the concrete components that resulted from the addition of alumina. It is seemed that alumina increased the density of sulfur concrete by filling the pores and better packing the particles, which led to the strength improvements. The strength development may also be attributed due to the development of alumino silicates formed by the reaction of alumina and silicon oxide present in the sulfur powder. This alumino silicate gel is formed and it hardens to provide the strength for concrete. The combination of (12% alumina + 22 % Sulfur) shows the highest strength of 43.04 N/ mm$^2$ even at the third day and is having only a slight increase of up to 44.21 N/mm$^2$ at the 28th day which shows 65% increase in strength when compared to normal sulfurcrete without filler alumina. But further addition of alumina in excess of 12% results in decrease of the strength and density gradually because, excess amount of filler and lesser amount of filler leads to extreme dry mixture and increased amount of pore spaces in the concrete. This suggests that alumina can be used as filler to produce high strength sulfur concrete but only up to 12% when the total amount of sulfur taken is 34%.

In order to utilize waste materials effectively in the sulfur concrete the natural coarse aggregates are replaced by industrial waste products waste granite aggregates with maximum size of 19 mm and the optimum replacement level is to be found out. The sulfur concrete with 12% alumina and 32% sulfur is taken as the control specimen for further replacements. The aggregates are then replaced with 10%, 20%, 30%, 40% and 50% of waste granite aggregates and the datas are given in table III.

TABLE IIII. Compressive strength values for different granite replacements.

| % replacements | 1 Day compressive strength (N/mm$^2$) | 3 Day compressive strength (N/mm$^2$) | 28 Day compressive strength (N/mm$^2$) |
|---|---|---|---|
| 0 | 37.17 | 43.04 | 44.21 |
| 10 | 38.10 | 43.48 | 44.92 |
| 20 | 39.91 | 44.53 | 45.25 |
| 30 | 42.31 | 46.03 | 47.13 |
| 40 | 43.68 | 47.82 | 48.96 |
| 50 | 36.10 | 41.12 | 43.12 |

Fig 2 shows the variation of compressive strength with different granite replacements.

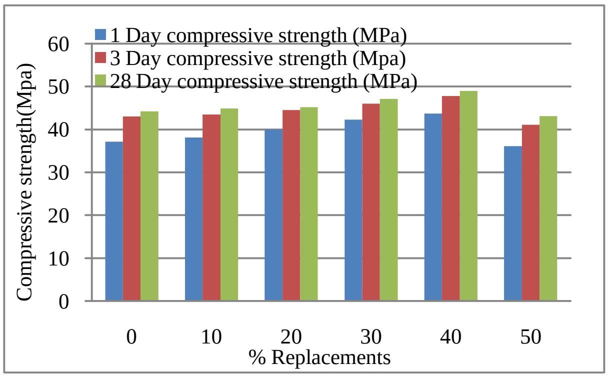


Fig. 2. Compressive strength results.

From the results obtained it is observed that the granite aggregates can be used as replacement for natural coarse aggregates but only up to 40%. Replacement with 40% of granite aggregates shows an increase of around 10% strength for the alumina based sulfur concrete. The 3 day compressive strength increased from 43.04 N/mm$^2$ for alumina based



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sulfurcrete without replacement to 47.82 N/mm$^2$ for alumina based sulfurcrete with 40% replacement of CA with granite aggregates. The 28 day compressive strength increased from 44.21 N/mm$^2$ to 48.96 N/mm$^2$. Furthermore replacement with granite aggregates reduced the compressive strength gradually.

### B. *Split Tensile Strength*

The split tensile strength test is indirect tension strength which is carried out by placing a cylindrical specimen horizontally between the loading surface of the compression testing machine and the load is applied until the cylinder failure along the vertical diameter. The specimen of sulfur concrete having dimensions 300 mm diameter and 150 mm length is used. The split tensile strength test was conducted as per IS 5816-1999 (reaffirmed 2004). Table IV shows the variation in tensile strength with variations filler content.

TABLE IV. Tensile strength values for different concrete mixes

| % combination | 1 Day Tensile strength (N/mm$^2$) | 3 Day Tensile strength (N/mm$^2$) |
|---|---|---|
| 34 % Sulfur + 0 % Alumina ($S_0$) | 2.65 | 2.69 |
| 32 % Sulfur + 2 % Alumina ($S_1$) | 2.82 | 2.91 |
| 30 % Sulfur +40 % Alumina ($S_2$) | 3.08 | 3.12 |
| 28 % Sulfur + 6 % Alumina ($S_3$) | 3.19 | 3.25 |
| 26 % Sulfur + 8 % Alumina ($S_4$) | 3.39 | 3.48 |
| 24 % Sulfur + 10 % Alumina ($S_5$) | 3.58 | 3.62 |
| 22 % Sulfur + 12 % Alumina ($S_6$) | 3.67 | 3.71 |
| 20 % Sulfur + 14 % Alumina ($S_7$) | 3.42 | 3.48 |

Fig 3 shows the variation in tensile strength with different filler content.

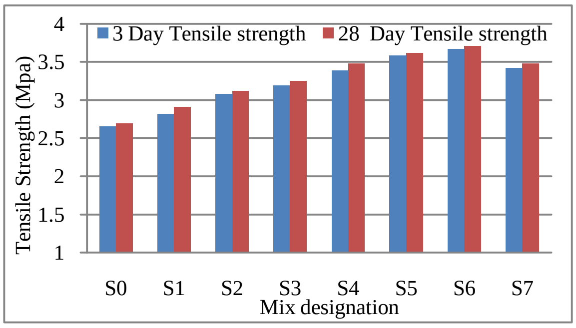


Fig. 3. Split tensile strength results.

The 3 day and 28 day split tensile strength of normal sulfurcrete is found to be 2.65 Mpa and 2.69 Mpa respectively. The split tensile strength also increases with increase in filler content but only to a limited range. The 3day and 28day split tensile strength of sulfurcrete with $S_6$ combination is found to be increased to 3.67 mpa and 3.71 mpa respectively. Further increment in percentage of alumina leads to the decrease in tensile strength. Therefore, it can then be inferred that as compressive strength, the tensile strength can also be increased with the addition of fillers but only to a limited range of combinations. Table V shows the variation in tensile strength when the coarse aggregates are replaced with waste granite aggregates in $S_6$ combination of alumina based sulfurcrete.

TABLE V. Tensile strength values for different granite replacements.

| % replacements | 1 Day Tensile strength (N/mm$^2$) | 3 Day Tensile strength (N/mm$^2$) |
|---|---|---|
| 0 | 3.67 | 3.71 |
| 10 | 3.74 | 3.82 |
| 20 | 3.82 | 3.89 |
| 30 | 3.88 | 3.91 |
| 40 | 3.97 | 4.02 |
| 50 | 3.58 | 3.60 |

Fig 4 shows the variation in tensile strength with different granite replacements.

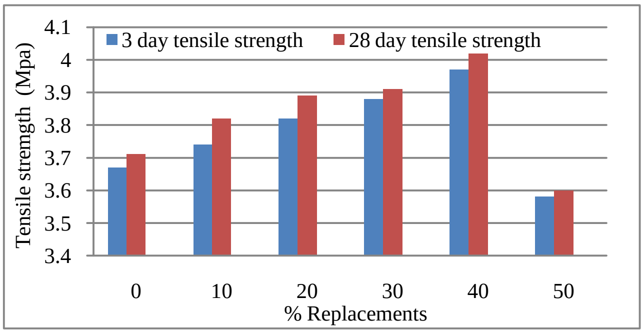


Fig. 4. Split tensile strength results.

The third day and 28day split tensile strength of $S_6$ combination of alumina based sulfurcrete, is found to be 3.67 MPa and 3.71 MPa respectively. As compressive strength, the split tensile strength also increases with increase in percentage replacements for coarse aggregates. The split tensile strength was increased to 3.97 MPa and 4.02 MPa at the 3 day and 28 day up to 40% replacement with waste granite aggregates. Any further replacement above 40% causes decrease in tensile strength dramatically. This decrease may be attributed due to the non tensile behaviour of granite aggregates.

### C. *Acid Resistance*

In order to evaluate the chemical resistance or acid resistance of sulfur concrete, 100mm x 100mm x 100mm specimens are casted and these specimens were immersed in aggressive chemical environments of 10% HCl solution after normal temperature curing. The resulting destruction of sulfur concrete during 90 days immersion in acidic solution were observed by measuring the mass periodically on digital laboratory scale and compared with initial mass before immersion. Also, the compressive strength loss after 60 days and 90 days immersion was measured. Before determining the mass change and compressive strength, the specimens were removed from the chemical solution, washed and dried in an oven at 105°C. The chemical resistance test was performed according to the procedure adopted from different relevant



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journals. The test results of weight loss after 90 days immersion are presented in table VI.

TABLE VI. Wt loss at 60 and 90 days after immersion in 10% HCl.

| Mix designation | Wt before immersion (kg) | Wt after immersion (kg) | | % weight loss | |
|---|---|---|---|---|---|
| | | 60 days | 90 days | 60 days | 90 days |
| $S_0$ | 2.61 | 2.608 | 2.606 | 0.076 | 0.153 |
| $S_1$ | 2.61 | 2.60 | 2.593 | 0.383 | 0.651 |
| $S_2$ | 2.62 | 2.605 | 2.597 | 0.572 | 0.991 |
| $S_3$ | 2.64 | 2.621 | 2.606 | 0.719 | 1.24 |
| $S_4$ | 2.67 | 2.642 | 2.629 | 0.898 | 1.53 |
| $S_5$ | 2.71 | 2.679 | 2.658 | 1.14 | 1.91 |
| $S_6$ | 2.74 | 2.662 | 2.676 | 1.38 | 2.33 |
| $S_7$ | 2.77 | 2.714 | 2.698 | 2.02 | 2.59 |

Fig 5 shows the variation of weight loss with different combinations.

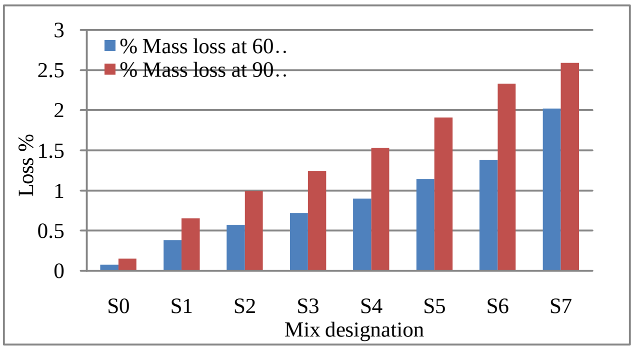


Fig. 5. Variation of mass loss after immersion in 10% HCl.

Dilute hydrochloric, or any other acids do not affect sulfur alone. Therefore normal sulfur concrete made of sulfur and aggregates exhibits a very negligible reduction in mass at 60 days and 90 days of 0.076% and 0.153% respectively. The percentage loss increases with increase in alumina content due to the formation of aluminium chlorides and other metal chlorides by the reaction of filler alumina and HCl. Aggregates and fillers used in sulfurcrete contain mineral oxides, which are mainly basic. The attack of alumina based sulfur concrete by hydrochloric acid solution is based on the reaction of basic oxides with acids, resulting in metal chlorides formation.

TABLE VII. Compresive strength loss at 60 and 90 days after immersion in 10% HCl

| Mix designation | CS before immersion (kg) | CS after immersion (kg) | | % CS loss | |
|---|---|---|---|---|---|
| | | 60 days | 90 days | 60 days | 90 days |
| $S_0$ | 25.46 | 25.43 | 25.35 | 0.095 | 0.421 |
| $S_1$ | 26.32 | 26.29 | 26.14 | 0.106 | 0.664 |
| $S_2$ | 27.01 | 26.98 | 26.78 | 0.120 | 0.841 |
| $S_3$ | 31.87 | 31.80 | 31.50 | 0.219 | 1.14 |
| $S_4$ | 33.26 | 33.18 | 32.84 | 0.240 | 1.26 |
| $S_5$ | 37.40 | 37.29 | 36.78 | 0.294 | 1.64 |
| $S_6$ | 43.04 | 42.90 | 42.26 | 0.342 | 1.81 |
| $S_7$ | 40.97 | 38.01 | 39.96 | 1.40 | 2.42 |

The mass loss increases with increase in the sulfur and alumina combination. The mass loss increased from 0.153% to 2.59% from S0 to S7 combinations. With each combination with increased content of alumina, the percentage weight loss increases. Table VII shows the loss of compressive strength of alumina based sulfurcrete with different granite replacements

Fig 6 shows the variation of compressive strength loss with different sulfur and alumina combinations.

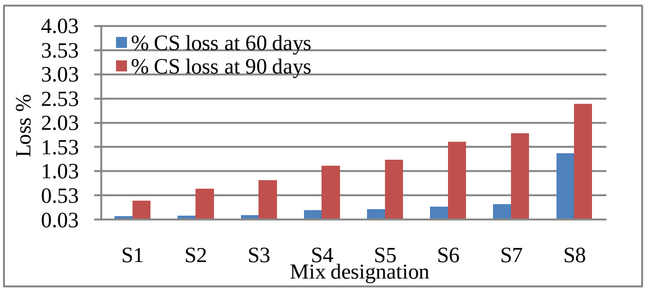


Fig. 6. Variation of compressive strength loss after immersion in 10% HCl.

It is clear from the results that similar to the mass loss, the compressive strength loss also increases with increase in the filler content. The 60 day compressive strength loss was found to increase from 0.095% - 1.40% for different combinations from $S_0$ – $S_7$ and similarly, the 90 day compressive strength loss was also increased from 0.421 – 2.42 for different combinations. The natural aggregate used in the manufacture of sulfur concrete are constituted by mineral oxides, which are mainly basic. The attack of sulfur concrete by hydrochloric or sulfuric acid solution is based on the reactions of basic and amphoteric oxides with acids and resulted in the formation of metal chlorides. But the compressive strength loss in HCl solution was found to be less than 5% in all the concrete specimens with and without filler combinations. Noting that the same specimen units were used for measuring both strength and mass, no consistent relationship is found between the strength reduction and mass change of sulfur concrete. The degradation of sulfur concrete in these acid solutions is attributed to the reactions of acids with basic and amphoteric mineral oxides existing in aggregate and alumina and formation of metal chlorides. Therefore, it can be inferred that the sulfur concrete specimens without filler addition is much more resistant to acidic environments than that with filler addition. But sulfur concrete developed in this study can be recognized as much more resistant to acidic and saline environments as compared to any grade of ordinary Portland cement concrete.

TABLE VIII. Tensile strength values for different concrete mixes

| % Replacement | % Wt loss | | % CS loss | |
|---|---|---|---|---|
| | 60 days | 90 days | 60 days | 90 days |
| 0 | 0.875 | 2.40 | 0.342 | 1.81 |
| 10 | 0.912 | 2.84 | 0.354 | 1.89 |
| 20 | 1.124 | 3.02 | 0.381 | 1.96 |
| 30 | 1.257 | 3.42 | 0.425 | 2.14 |
| 40 | 1.462 | 3.67 | 0.451 | 2.24 |
| 50 | 1.890 | 3.88 | 0.512 | 2.45 |

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Table VIII shows the results of variation of mass loss and compressive strength loss of alumina based sulfur concrete of $S_6$ combination when coarse aggregates are replaced with different percentages of waste granite aggregates after immersion in 10% HCl.

Fig 7 and 8 shows the variation of mass loss and compressive strength loss of $S_6$ combination with different granite replacements.

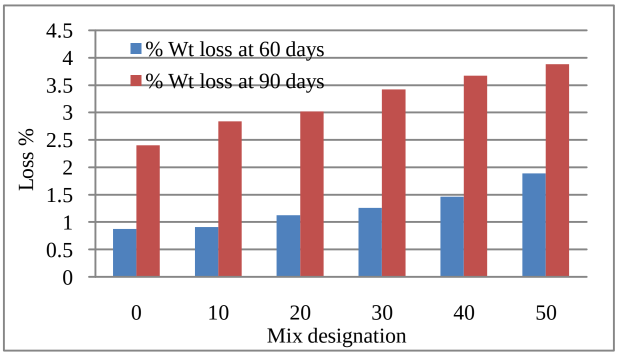


Fig. 7. Variation of mass loss after immersion in 10% HCl.

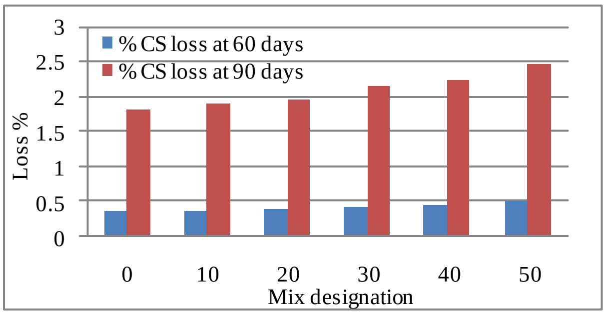


Fig. 8. Variation of compressive strength loss after immersion in 10% HCl.

The attack of replaced sulfur concrete made with granite aggregates are based on the reactions of the formation of metal chlorides and sulphates by the reaction of mineral oxides present in the granite aggregates with HCl. The mass and compressive strength loss of sulfurcrete made with waste granite aggregates are higher than that of normal sulfurcrete because of the higher calcium content in granite aggregates and thus the formation of higher amount of Calcium chloride, aluminium chloride and other metal chlorides which leads to degradation in mass and compressive strength. The 90 day mass loss and compressive strength loss was found to increase from 2.40% - 3.88% and 1.88 – 245% respectively for different combinations from $S_0$ – $S_7$. It is seen that all specimens made of alumina replacement and waste granite aggregate replacement showed small or negligible amount of mass loss and compressive strength loss of less than about 5% even after 90 days in the HCl solution. The alumina based sulfurcrete with aggregates replacement are less durable than that made with natural coarse aggregates. But as the mass change and compressive strength change is much lesser as compared to ordinary cement concrete, Sulfur concrete proves to be a durable product in the construction industries.

## VI. CONCLUSION

In this study, an experimental investigation on the strength and durability parameters of normal and alumina based sulfurcrete made with industrial waste granite aggregates as partial replacement for coarse aggregates were conducted. All values of mechanical properties obtained from the current investigation are compared with the sulfur concrete control specimen without filler alumina only. The following conclusions were drawn from this investigation:

- Sulfur concrete is an excellent alternative to OPC concrete
- The normal temperature cured sulfur concrete attained its maximum strength within 3 days and the compressive strength even at the 28 day is almost similar to the 3 day strength.
- The compressive strength and split tensile strength obtained for sulfur concrete control specimen are 26.81Mpa and 2.69MPa respectively.
- The $S_6$ combination of 12% alumina + 22% sulfur gives 64% increase in the compressive strength as compared to normal sulfur concrete without filler material. The addition of filler alumina contributes to better packing of particles and filling of pores by alumina which contributes to strength increase. The increase in strength is also attributed due to the formation of alumino silicates by the reaction of alumina and silica present in the elementary sulfur. Further addition of alumina in excess of 12% results in decrease of the strength and density gradually.
- Replacement of 40% of coarse aggregates with waste granite aggregates shows 13% increase in the compressive strength of alumina based sulfurcrete having 12% alumina and 22% sulfur. The strength increase is attributed due to the formation of calcium alumino silicates by the reaction of alumina with silica and calcium present in the waste granite aggregates. Further replacement beyond 40% resulted in the reduction of compressive strength.
- The $S_6$ combination of 12% alumina + 22% sulfur gives 30% increase in split tensile strength as compared to normal sulfurcrete. Decrease in split tensile strength is observed for any further increase in percentage of alumina. Also the replacement of 40% of coarse aggregate by waste granite aggregate shows 10% increase in the tensile strength of the alumina based sulfur concrete having $S_6$ combination.
- All specimens showed slight reduction in mass and compressive strength of about less than 5% even after 90 days in the 10% HCl solution which proves that the sulfur concrete exhibits satisfactory durability performance. Therefore the work can be concluded as that the sulfur concrete made with a combination of 12% alumina + 22% Sulfur and 40% replacement of coarse aggregates with waste granite aggregates shows higher strength characteristics as compared to ordinary sulfur concrete without filler alumina, but it shows a slight reduction in acid resistance as compared to the sulfurcrete without filler material.



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