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Experimental investigation on the use of alumina as filler material in ordinary sulfur concrete

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Abstract—The demand for Ordinary Portland Cement (OPC) increases exponentially with the worldwide development of infrastructure. Increased cement production is one of the major causes of CO_2 emission in to the atmosphere which leads to global warming and environmental pollution. In order to reduce the environmental effects associated with these, an alternative binder to make concrete needs to be developed. Concrete made with sulfur as binder material is a major alternative for this situation. The amount of sulfur yielded as a byproduct of petroleum refining process is increasing day by day. As an innovative solution, using sulfur as a binder in concrete has been recently pursued to replace entire cement and water. This study tries to investigate the mechanical properties of sulfur concrete made with alumina as filler material. Different mix proportions are designed for further investigation. In all the concrete mixtures, neither cement nor water is included. Essential mechanical properties such as compressive and tensile strengths are examined.

Index Terms —Alumina powder, compressive strength, filler, sulfur, sulfur concrete, tensile strength

1 Introduction

Concrete is the one of the most widely used construction material in the world. Concrete is a blend of coarse aggregate, fine aggregate, cement and water. The production of Portland cement which is an essential part of concrete leads to the emission of significant amount of CO2 to the atmosphere [2]. Cement industry produces 5 to 8% of atmospheric CO2 in the world. This CO2 is largely responsible for the increases in the green house gas effect which leads to global warming [3]. One of the best alternatives to this is to produce cement free sulfur binder for the production of concrete.

Fossil fuel consumption is rapidly increasing all over the world, and so is the amount of sulfur that is yielded as a byproduct of petroleum refining processes [1]. In 2014, the global production of sulfur was approximately 89 million tons. While some sulfur is consumed as a component in industrial chemicals, most of the material is left unused or is exported at low rates. Also, the amount of sulfur being produced worldwide greatly exceeds the demand for sulfur, although huge quantities are consumed in many industries [8]. The production is expected to grow in the future, and the waste disposal will be the major threat if no counter plan is prepared for it.

As an innovative solution for the increasing sulfur emissions, using sulfur as a component in composite construction materials such as asphalt and concrete is of high interest [3]. In particular sulfur may be used to replace entire cement and water in concrete to act as the role of a binder in concrete: sulfur melted by heat bonds the aggregates and fillers together, and forms stable hardened concrete.

Sulfur concretes or sulfurcretes are high performance thermoplastic composite materials made of mineral aggregate, filler, and sulfur as a binder, instead of cement and water as in Portland cement concrete (PCC), at temperature above the hardening point of sulfur (120^{0}C) .

Characterizations and properties of sulfur concrete and Portland cement concrete are quite similar because their possible applications are mostly the same. Therefore, comparison of their characteristics is important when making choice between the two concretes [5].

When unmodified sulfur and aggregate are mixed at a high temperature, sulfur in the liquid state crystallizes as monoclinic sulfur (Sb) at approximately 120^{0}C. Upon cooling to below 115^{0}C, it starts to transform from monoclinic to orthorhombic sulfur (Sa), which is a stable form of sulfur at ambient temperatures. The temperature is an important factor because sulfur binder melts at a temperature above about 120^{0}C due to the thermoplastic characteristics of sulfur itself [8]. The maximum operating temperature without much lose in the strength and stiffness of sulfur concrete is known to be 93-100 ^{0}C, depending on the mix proportions [8].

However, sulfur concrete made with unmodified sulfur has limitations for practical use, because it has inferior properties such as poorer water resistance and higher brittleness than conventional concrete [5]. In order to overcome these limitations elemental sulfur is made to react with an unsaturated hydrocarbon (e.g., dicyclopentadiene, DCPD), in order to develop stable modified sulfur through the formation of long-chain polymeric reactions.

Some studies [8, 19] reported that sulfur concrete using modified sulfur has excellent resistance in aggressive environments such as high acid or salt concentrations. Moreover, sulfur concrete may achieve a high compressive strength inherent from sulfur itself, and it acquires 70–80% of the compressive strength within 24 hours [6]. The advantages of sulfur concrete over Portland cement concrete are quick hardening, setting time less than 24 hours, attaining its complete strength even within 3 days, high strength and fatigue resistance; very low water permeability, high resistance to acid and salt agents, which allows its use in extremely aggressive environments and it can be recycled. This material allows utilization of large amounts of sulfur

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from worldwide oil refineries and metallurgical industries.

This study investigates the mechanical and durability properties of sulfur concrete with alumina as filler material and the increase in properties by adding filler to the normal modified sulfurcrete. Essential mechanical properties such as compressive and tensile strengths are examined. Neither cement nor water is included in the mixing process of sulfur concrete specimens. No particular Indian Standard (IS) codes are available for selection of the mix design for sulfur concrete. The existing Portland cement standards are not adopted for mix design of sulfur concrete, presently the findings based on different experimental investigations on sulfur concrete have been considered as reference. To produce sulfur concrete of desired strength, various mix proportioning by trial and error methods are being used on the basis of type of work, availability and properties of materials, field conditions and durability requirements.

2 EXPERIMENTAL PROGRAM

2.1 Material

A sulfur concrete is a mixture of sulfur binder and aggregate. Several waste material and other industrial byproducts such as fly ash, silica fume etc can be used as a filler material for sulfur concrete. Sulfur, which is the basic component for a modified sulfur binder originates from oil refining process by Claus's procedure in the Oil and petroleum refinery and its purity is 99.9%. The sulfur used for this project is collected from BPCL Kochi Refineries, Kochi and is used in powder form. The specific gravity of sulfur is 2.2.

In order to produce modified sulfur concrete, an unsaturated hydrocarbon, Dicyclopentadiene (DCPD) and sulfur is melted in the temperature range from 120^{0}C to 140^{0}C for 30 min, and then rapid cooling and solidification of the obtained sulfur polymer.

Here in this study Aluminium oxide commonly known as alumina powder (Al_2O_3), which is a chemical compound of aluminium and oxygen is used as filler material. The alumina used is obtained from local sources. The specific gravity of alumina is 2.85.

Manufactured sand with specific gravity of 2.73 and water absorption of 2.08% was used as fine aggregate. Natural crushed stone of specific gravity 2.85 and water absorption of 0.50% was used as coarse aggregate.

2.2 Mixture design

There is no Standard Specification or Indian standard was not available for mixing of the sulfur concrete. The mix ratio was taken on the basis of trial and error method. The mixes are taken by studying various literatures and the results given in the literatures. Here, the percentage of sulfur was calculated in powder form and not in molten stage. The selected mix ratio includes 34% of sulfur, 36% of coarse aggregates and 32% of fine aggregates. All the ratios are expressed in percentages of volume. The sulfur percentage is varied from 10 – 20% and accordingly the percentage of filler material alumina is varied.

2.3 Manufacturing process

Sulfur concrete specimens were fabricated using the procedures recommended by ACI 548.2R-93 [6], ''Guide for Mixing and Placing Sulfur Concrete in Construction.''. First, the coarse and fine aggregates are preheated in an oven at 180^{0}C for 4-6 hours. It is then transferred to a container that was also preheated. It is then mixed dry. After 1 min of dry mixing, modified sulfur and alumina were added into the container. Then, mixing was continued until the sulfur melts, and also for an additional 10 min after the liquefaction [1]. Finally, sulfur concrete specimens were cast and compacted. The specimens were de-molded after 24 hours of curing, and kept in room temperature and humidity.

2.4 Experimental details

The experimental investigation of this work extended as the sulfur in sulfur concrete was replaced by alumina powder at percentage ranging from 20% to 30% with an increment of 10%. Then sulfur concrete specimens were casted. Then all the specimens were de molded after 6 hours. After 6 hours they were stored at ambient condition. It can be tested at the 3rd day as they obtain 100% strength within three days. It also obtains 90% of its strength within 1 day.

2.5 Testing

A series of tests were conducted on the normal modified sulfur concrete and alumina based sulfur concrete. To assess the mechanical properties of modified alumina based sulfur concrete compressive strength test and split tensile strength test were conducted. Then all the test results were compared with normal sulfur concrete specimens.

3 RESULTS AND DISCUSSIONS

Different concrete specimens of alumina based sulfur concrete were designed to study the effect of filler material on the compressive strength, and split tensile strength. The test results are following.

3.1 Compressive strength test

The compressive strength development of the sulfur concrete with different percentage of alumina powder is shown in the figure 1. From the figure it was clear that the filler material has a significant influence on compressive strength. Normal sulfur concrete is made with 34% sulfur, 30% fine aggregate and 36% coarse aggregates. The sulfur percentage is varied from 20 to 30 % and accordingly the alumina content is varied. Alumina percentage is varied from 6 – 14 % from the total of 34% sulfur. The addition of alumina as filler material increases the strength of the normal sulfur concrete. 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 seen that alumina increased the density of sulfur concrete by filling the pores and better packing the particles, which led to the strength improvements. The addition of 12% of alumina increased the strength of sulfur concrete from 25.01 Mpa for normal sulfurcrete to 39.43 Mpa for alumina based sulfurcrete. .But further addition of alumina in excess of 12% results in decrease of the strength and density gradually because excess 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%.The improvement in the compressive strength was mainly due to the alumina powder has more tendency to fill the micro pores inside the sulfur concrete to form more compacted structure. Also the high pozzolanic characteristics lead to increased strength.

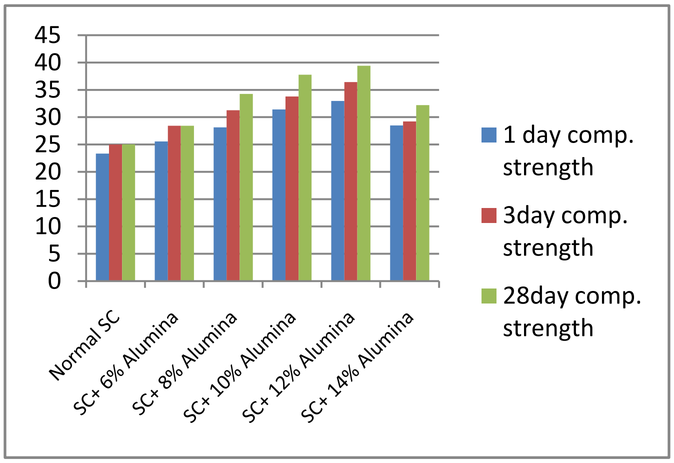

Fig 1: Graph showing variation of compressive strength with different replacement level

3.2 Split tensile strength test

The effect of alumina powder on tensile strength of sulfur concrete is presented in the figure 2. From the test results it can be found that the tensile strength of the sulfur concrete was also influenced by adding alumina powder. Unlike compressive strength, the sulfur concrete tensile strength was only slightly increased with alumina powder up to 12% replacement. The 3 day tensile strength obtained for normal sulfur concrete was 3.21 MPa and for 12% alumina powder replacement the strength was 3.32 MPa. The percentage increment in the strength compared to normal sulfur concrete was 0.04%. The increment in tensile strength was mainly due to the pozzolanic characteristics and slight silica content in the alumina powder.

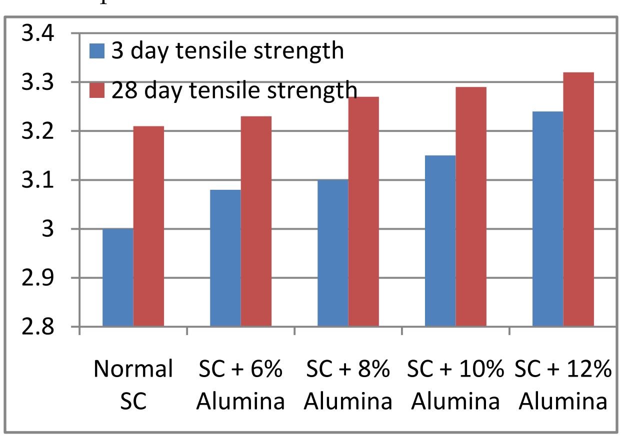

Fig 2: Graph showing variation of tensile strength with different replacement level

3.3 Water absorption

The percentage of water absorption of normal sulfur concrete and alumina based sulfur concrete with different percentage of alumina powder is shown in the figure 1.3. From the figure it was clear that the filler material has a significant influence on the water absorption. Already the rate of water absorption of normal sulfur concrete was very low of about 4.6% when compared with ordinary Portland concrete. With the addition of filler material the water absorption rate again decreases to about 2.0% for 12% of alumina. This decrease in water absorption is likely to be because of the increased the density of sulfur concrete by sulfur filling all the pores and better packing of the particles, which led to the decrease in pore spaces and thus decrease in water absorption

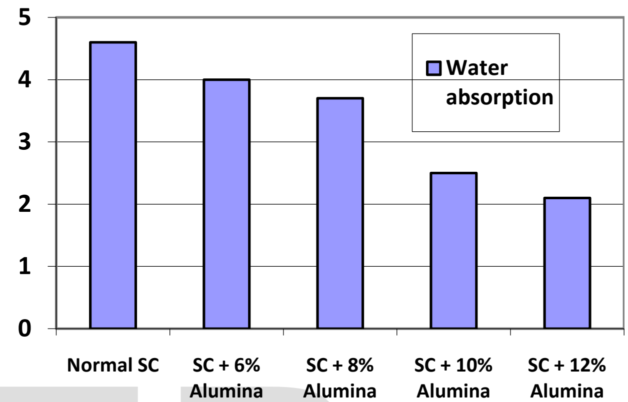

Fig 3 : Graph showing variation of water absorption with different replacement level

4 CONCLUSION

This paper presents the possibility of using alumina powder as filler material or replacement for sulfur in sulfur concrete. Based on a the different experimental works the following conclusions are drawn;

- The compressive strength of sulfur concrete increased with the increase in the amount of alumina powder up to 12% replacement. Beyond 12 % replacement the compressive strength was decreased.
- Unlike compressive strength the tensile strength of sulfur concrete is also increased but only with a slight increment with the increase in the amount of alumina powder up to 12% replacement.
- The water absorption of sulfur concrete reduced from 4.4% to 2.1% with the replacement of sulfur with alumina powder from 6% to 12%.

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