

# Collation the durability of modified and non-modified sulfur concrete in erosive environments

Abdulsame Fazli, Sajad Fathi, Maryam Fazli, behrooz fathi

**Abstract**— One of applications of sulfur in building industry is producing sulfur concrete (SC). High resistance, in acid environments, gaining high and rapid resistance, not using water during preparation, the possibility of recycling and low permeability can be pointed out as the most significant specifications of sulfur concrete .The present study investigates the role of acid on mechanical resistances including compressive and tensile strength on modified and none-modified sulfur concrete .The implications indicate that sulfur concretes are much more resistant against acids as compared with regular concretes .economically, It can be referred that if preparation of SC becomes more easier, it can replace regular concrete in a number of regular hydraulic projects.

**Keywords**—sulfur concrete, Mechanical resistance, durability, erosive environment

## I. Introduction

Progress and advancement in technology, has made possible for the man to achieve new means of producing products or offering special services in a wider aspects. Since all producing and servicing processes leave damages, a need to use these wastes is deeply conceived. On the other hand, as the laws for environment protection do become more and more strict, using these wastes seem even more significant. One of the most important realizations of the wastes is in the sulfur producing processes. When separating sulfur from natural gas and also in the process of refining raw oil, a great amount of sulfur is produced which causes huge accumulation of sulfur. One of the best methods of utilizing sulfur in the field of civil engineering is to use it in sulfur concrete. We can say that United States, Canada and Russia are among the first countries that took benefit from sulfur concrete as a new material. Producing sulfur concrete needs small investment.

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Abdulsame Fazli  
Civil Engineering Department/ Ferdowsi university of Mashhad  
Iran

Sajjad Fathi  
Civil Engineering Department/ Ferdowsi university of Mashhad  
Iran

Maryam Fazli  
Civil Engineering Departmen/ Eqbal Collage of Mashhad  
Iran

Behrooz Fathi  
Industrial Department/ Sajjad Collage of Mashhad

Global markets analysis has shown that the most part of sulfur consumption in the future will be in producing sulfur concrete. In many cases, it is a suitable or even a better replacement for Portland cement.[1-3]

Appropriate physical and chemical properties of sulfur have caused it to be widely used as sticking material. These properties include: low chemical reactivity, excellent resistance against corrosive materials (mainly acids and solvable salts) and hydrophobicity. We should not ignore the fact that the cost of producing sulfur concrete is much less than regular concrete. Sulfur concrete can be used in many projects. There are places with severe acidic invasions or climatic conditions impose frequent cycles of freezing and melting on concrete. There we cannot expect an appropriate application from Portland cement. In these conditions sulfur concrete is the best replacement is sulfur concrete. [1-3]

There are 30 different **allotropes** of sulfur can be found in the nature. Basically, allotropes have different physical properties but their chemical properties are rather the same .depending on temperature and pressure, it is possible that a few allotropes do exist in a certain amount of sulfur with different ratios .As a result, the existence and proportion of the allotropes of sulfur depends on the heat applied on it. By changing the type and proportion of the allotropes, the physical and chemical properties of sulfur changes as well. Thus it can be understood that sulfur properties depends on the heat exerted on it. Main allotropes of sulfur include rombic, monoclinic and polymeric. Rumbic sulfur forms arthorombic crystals that are stable up to 95.5 °C .Monoclinic sulfur forms monoclinic needle-shaped crystals that are stable up to 95.5 °C.[4]

Unmodified sulfur can be used as sticky material in concrete. However, experiments show that even though unmodified sulfur has very good mechanical properties after being prepared, its stability is low. That is the sulfur concrete is sheeted and dismantles finally.[5] n other words, if the concrete made from unmodified sulfur is exposed to a moist environment or inside water, or is exposed to frequent cycles of freezing and melting, it is rapidly eroded and destroyed. The reason for this undesirable event is that while preparing sulfur concrete, the nature of sulfur modifies .The description is that in the process of cooling sulfur concrete, firstly the monoclinic crystals are formed in temperature of 114 °C with concentration percentage of 7% then by reducing the temperature to below 95.5 °C, within 20 hours, these crystals are changed to rumbic crystals. Since rumbic crystal is denser than monoclinic, waste tensions and consequently lots of microscopic cracks are formed inside the substance. This event causes the moisture to penetrate into concrete and it causes it to dismantle more rapidly[4] in order to solve the problem, the stick material of modified sulfur was formed.

This substance has a much higher stability as compared to unmodified sulfur. Perhaps we can say that the most application of modified sulfur concrete as a newly-emerged substance in road construction and building restoration.[6-8] One of the properties of sulfur is that it tends to polymer formation. By adding some correcting chemical materials such as polymercaptans and polysulphids, the tendency to form polymer can be multiplied. While some other chemical materials make the process of polymer formation longer. The result of using these correcting materials is to prevent the change in sulfur crystals from monoclinic to orthorhombic and increase in tendency to form more and longer polymers[5] Amended sulfur has a considerably lower thermal coefficient compared to unmodified type. Therefore, contraction and tensions of the wastes are much less.[9] Long durability of modified sulfur concrete depends on the stability of its crystals in microscopic dimensions.[10] This means that unlike Portland cement concrete that after 28 days gets to its approximate 80% of its final mechanical resistance, sulfur concrete gets to its approximate 80% of its final mechanical resistance only after 24 hours[1]

Sulfur concrete is a thermoplastic composite consisting of mineral grains, filler and sulfur as stickers (instead of cement and water). Sulfur must be in a temperature higher than its point of rigidity that is 120 °C.[1]

Considering the form and size of the fillers, they can be used in different applications. By adding a suitable amount of fillers, the maximum density can be gained and some other properties of concrete can be improved. Among other applications of fillers, is saving in the amount of cement in a way that it does not decrease the strength of cement. Fillers are mainly very tiny and thus can be placed among the holes existing in the concrete and eventually cause increase in the density of concrete.[11]

Sulfur concrete has the following advantages to Portland cement concrete[1-3]:

- sulfur concrete and Portland cement concrete have rather identical volume of holes, but their difference is that unlike Portland cement concrete, the holes of sulfur concrete are not bound to each other and as a result, sulfur concrete has a less permeability.
- Sulfur concrete has a very high resistance against the invasion of acids and solvable salts even if their concentration is very high. Thus sulfur concrete can easily be used in highly corrosive environments.
- Sulfur concrete hardens rapidly and acquires its desired properties within about 24 hours.
- Sulfur concrete holds a desired compressive, tensile and bending strength. It is also highly resistant against the phenomenon of fatigue.
- The nature of sulfur concrete is in a way that it can be produced and performed in most undesirable climatic conditions even in zero degree centigrade.
- Sulfur concrete can easily be recycled.

In the present paper, the advantages of sulfur concrete to Portland concrete cement is studied and finally the findings of both parts are compared with modified sulfur concrete made by [12].

## II. Methods and materials

### A. Materials

#### Sulfur:

primarily unmodified sulfur was used as a sticky material in making concrete. The results of modified sulfur concrete compressive strength have been taken from [12]

#### Aggregate:

Aggregate with maximum size of 2mm gained by sand – Aggregate mixed screening existing in the place. In order to compare sulfur concrete with Portland cement concrete, in making all samples including sulfur or Portland, the same Aggregate was used.

#### Filler and Portland cement:

No special filler has been used in the present study. Portland cement type 1 has been used to make regular cement.

### B. Samples preparation

#### 1) Preparing modified sulfur concrete samples

According to the researches made by [12] sulfur concrete preparation was based on manufacturing method. That is, primarily, the Aggregates and fillers are heated. (Higher than 160° C) and then they are poured into a mixer and are mixed for 15 minutes. Then the modified sulfur is melted. The temperature of melting sulfur is between 132-141° C. Now melted sulfur is added to homogenous and dry filler mixture and Aggregates. It should be noted that the reason for heating filler and Aggregates is that the sulfur does not harden in contact with them and at the same time the time for mixing sulfur with Aggregates and fillers are reduced. The heated Aggregates and fillers are well mixed with melted modified sulfur in order to have homogenous slimy mixture. After the homogenization and mixing continues for 2 minutes, sulfur concrete mixture is poured into a mold that has previously been heated up to 120 °C and is vibrated for 10 seconds. The surface of any of the samples is abraded and they are put aside in order to be hardened in room temperature. One of the most significant specifications of sulfur concrete is that it hardens rapidly ranging from 15 minutes to a few hours depending on its size and form. This property lets us early remove the concrete from the mold and in this way we can process the concrete in a rather short time. That will be only 24 hours in room temperature. In this way after 3 hours, hardened concrete

is removed from the mold and is kept in room temperature for 24 hours.

## 2) Preparing unmodified sulfur concrete samples

Since the purpose in this study is to compare the effect of modified sulfur with unmodified sulfur, it has been tried to the conditions of preparing unmodified sulfur concrete (like Aggregates) to be completely the same with modified sulfur concrete.

## 3) Preparing Portland cement samples preparation

Portland cement mixture is made by identical Aggregates with sulfur concrete. Since Portland cement properties

depends on the ratio of water to cement, the logical and practical water to cement ratio of 5 to 0 has been used. Of course it should be noted that by such a hypothesis, the generality of the findings of the experiment will be affected. Thus it seems that there should be more investigations with a variety of water to cement ratios. First the Aggregates are poured into mixer and are mixed with water. Then cement and the rest of water is added and the homogenization continues. The total time for mixture was about 6 minutes. Concrete mixture is poured into molds and are concentrated by shaking table .after 24 hours, testing samples are taken out from the molds and are processed by moisture. Processing was done in a chamber with  $20 \pm 2$  C temperature in the form of dipping for 28 days.

**Table 1: The plan for mixing laboratorial samples**

Sample	Cementing Material	Water	W/C Ratio	Aggregate $\phi$	Filler
	Percent	Percent		Percent	Percent
Portland Concrete	30	15	0.5	55	-
Sulfur Concrete	35	15	-	55	10

**Table 2: aggregate distribution**

Size of screen	Remained amount	Remained percent	Remained collective percent	Remained collective amount	Passing amount	Remained percent	Passing collective percent
1"	39	0.79	0.79	39	4909.00	99.2118	99.21
3/4"	167	3.38	4.16	206	4742.00	95.84	195.05
1/2"	377	7.62	11.78	583	4365.00	88.22	283.27
#4	3483	70.39	82.17	4066	882.00	17.83	301.09
#8	348	7.03	89.21	4414	534.00	10.79	311.88
#16	241	4.87	94.08	4655	293.00	5.92	317.81
#30	123	2.49	96.56	4778	170.00	3.44	321.24
#50	108	2.18	98.75	4886	62.00	1.25	322.49
#100	51	1.03	99.78	4937	11.00	0.22	322.72
#200	11	0.22	100.00	4948	0.00	0.00	322.72
Total	4948						

The selected Aggregate distribution is based on ACI Standard range.

### C. Method

The samples of Portland cement concrete are cured for 28 days. The curing period for sulfur concrete takes only 24 hours. These samples are placed into solutions of 20%, 40% and 60% acid sulfuric for 28 days. the compressive strength and weight reduction was observed in days of 7, 14 and 28.

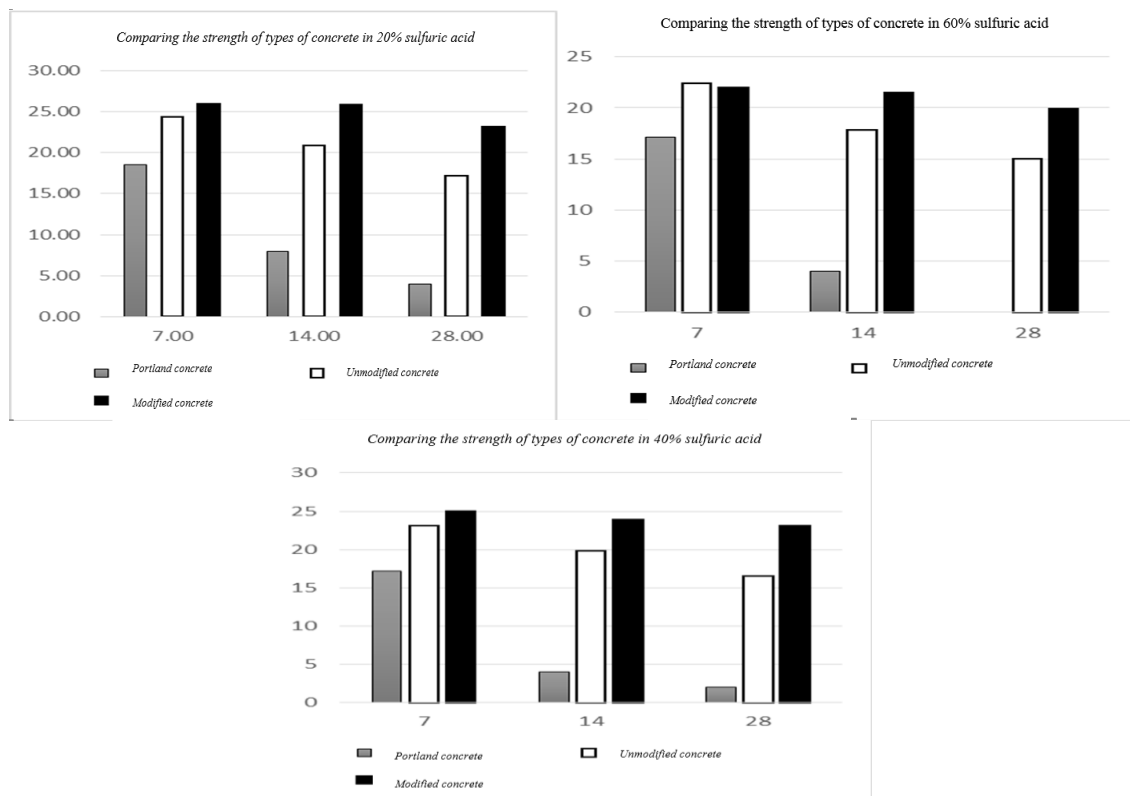
In order to find the changes in the weight of samples, the samples are primarily washed so that the corrosive solutions are taken away from them. Then the samples are placed into the furnace to be dried in temperature ranging from 145 to 155 degree centigrade. The samples are heated until they get to a fixed weight. The percent of change in the mass of the samples

as compared with the condition before being placed in corrosive solution is gained. The samples were then placed on press machine in order to gain their compressive strength. In order to obtain more certainty of the results of the test, any of the reported amounts are the average of three readings gained from three separate samples.

## III. Results and discussion

### 1) Reduction of mechanical strength in a solution as a result of time

Studying the samples showed that as the time passes, mechanical strength of the samples do change after being placed in 20%,40 % and 60 % corrosive solution of sulfuric acid.



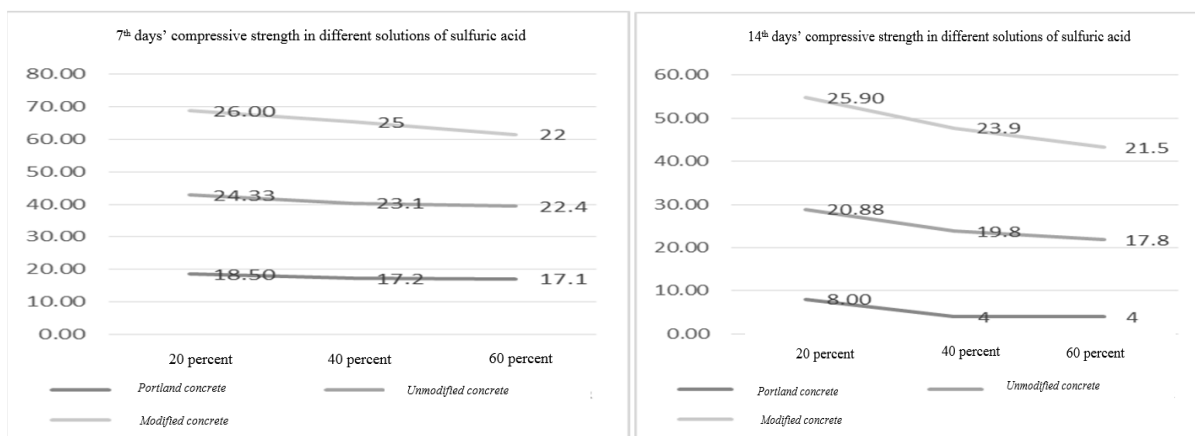
**Fig.1 The ratio of mechanical strength of the samples to acid percentage**

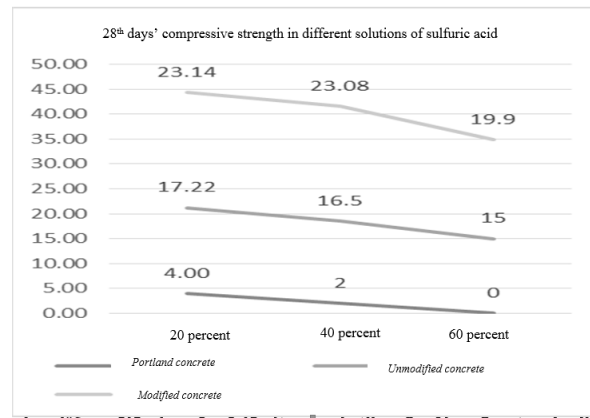
compressive strength of unmodified sulfur concrete is higher than Portland cement concrete.

## 2) Drop in mechanical strength of the samples in acidic solution with different concentrations

As it can be seen in the diagrams in figure 2, throughout all days, the compressive strength of modified sulfur concrete is higher than other samples of the other types. After that, the

By increase in the concentration in a definite time, the compressive strength in all samples experience a drop. This drop is much more in Portland cement concrete than modified and unmodified sulfur cement. The whole findings so far indicate the advantage of modified sulfur concrete on unmodified sulfur concrete and Portland cement.

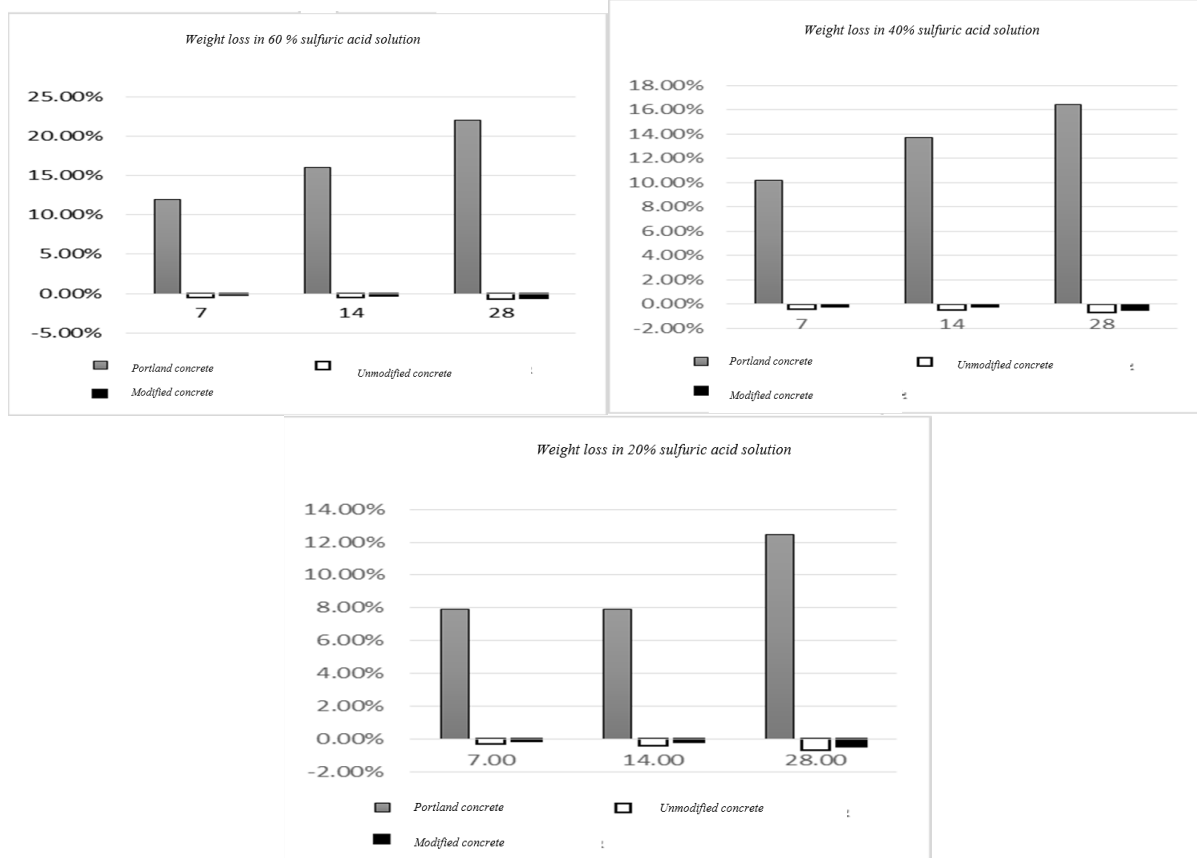




**Fig.2: The ratio of mechanical strength of the samples in different percentages of acid**

**3) The percentage of weight reduction in a solution through the time**

As it can be seen in the diagrams of figure 3, the samples of Portland cement experience severe drop in weight in different concentrations. Weight reduction is in fact an indicator to understand the degree of durability of the samples. Hence, as the time passes, the durability of the concrete samples reduces severely in a way that there is not even possible to determine the compressive strength the Portland cement samples after 28 days in 60% concentration.



**Fig.3 : Weight reduction Percentage in Different percentages of Acid**

As it can be seen the samples of Portland cement lost their weight in the worst condition after is being placed in sulfuric acid 60% within 28 days to more than 20 % of their weight.

Meanwhile, unmodified sulfur concrete not only face no weight reduction, but also had a weight increase to about 0.5% which shows a significant difference with Portland cement



samples. As a conclusion, we can say that in a definite time, the more the density of sulfuric acid increases, and the change in weight in all samples increases. No matter the weight change is positive or negative, change in density has a high influence on the samples of Portland cement samples.

#### iv. Conclusion

Three samples were made from modified sulfur concrete, unmodified sulfur and Portland cement. These samples were placed in 20%, 40% and 60% solutions and the changes in weight and reduction in compressive strength of the samples in the days of 7, 14 and 28 were gained and the following findings were gained.

The samples of Portland cement concrete showed high weakness against erosion in a way that after 28 days being dipped into sulfuric acid 60%, they lost about 20 % of their weight.

The sulfur concrete samples showed a desired resistance against erosion in a way that after 28 days being placed in sulfuric acid 60%, they had 0.5% change in weight.

- The samples of modified and unmodified sulfur concrete experienced increase in weight which is probably because of the chemical composition of the type of filler. The samples of Portland cement concrete experienced severe reduction in weight.

-The more the solution is concentrated, the higher will be the strength reduction and weight change.

-As the time passes, the modified and unmodified sulfur concrete faced very low strength reduction but the degree of strength reduction was higher in the samples of Portland samples.

The findings of the present study confirmed the favorability and advantage of applying sulfur concrete specially modified sulfur concrete in corrosive environments.

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About Author (s):



Abdulsame Fazli is civil engineering Senior Student  
Trend:  
Sulfur Concrete  
Self compact concrete  
Building Information Modeling