Influence of Internal Sulfate Attack on Some Properties of High Strength Concrete

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ABSTRACT

One of the most important problems that faces the concrete industry in Iraq is the deterioration due to internal sulfate attack , since it reduces the compressive strength and increases the expansion of concrete. Consequently, the concrete structure may be damage .The effects of total and total effective sulfate contents on high strength concrete (HSC) have been studied in the present study.

The research studied the effect of sulfate content in cement , sand and gravel , as well as comparing the total sulfate content with the total effective SO_3 content. Materials used were divided into two groups of SO_3 in cement ,three groups of SO_3 in sand ,and two groups of SO_3 in gravel.

The results show that considering the total effective sulfate content is better than the total content of sulfates since the effect of sulfate in each constituent of concrete, depends on it's granular size .The smaller the particle size of the material the more effective is the sulfate in it. Therefore, it is recommended to follow the Iraqi specification for total effective sulfate content, because it gives more flexibility to the use of sand and gravel with higher sulfate content.

The results of compressive strength at 90-days show that the effect of total effective SO_3 content of (2.647% , 2.992% , 3.424%) that correspond to total sulfate of (3.778%, 3.294%, 4.528%) decrease the compressive strength by (7.53%, 11.44%, 14.59%) respectively.

Key words: internal sulfate attack, total effective sulfate content, high strength concrete, total sulfate content, particle size.

تأثير هجوم الاملاح الكبريتية الداخلية على بعض خواص الخرسانة عالية المقاومة

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الخلاصة

واحدة من أهم المشاكل التي تواجه صناعة الخرسانة في العراق هي التدهور بسبب هجوم الكبريتات الداخلية، نظرا لانه يقلل من مقاومة الانضغاط ويسبب حدوث تمدد في الخرسانة. وبالتالي،قد يسبب الضرر للمنشاء الخرساني.

في الدراسة الحالية تم دراسة تأثيركل من الاملاح الكبريتية الكلية والاملاح الكبريتية الكلية الفعالة على الخرسانة عالية المقاومة.

يدرس البحث تأثير محتوى الكبريتات في السمنت والرمل والحصى، وكذلك مقارنة المحتوى الكلي للكبريتات مع المحتوى الكلي للكبريتات الفعالة. وقد تم تقسيم المواد المستخدمة في البحث الى مجموعتين من محتوى (SO_3) في السمنت، وثلاث مجموعات من (SO_3) في الرمل، ومجموعتين من (SO_3) في الحصى.

بينت النتائج أنه يمكن اعتبار المحتوى الكلي للاملاح الكبريتية الفعالة أفضل من المحتوى الكلي من الكبريتات نظرا لانه يعتمد على حجم الحبيبية للمادة المستخدمة.ان المادة ذات أصغر حجم حبيبي تكون من المواد أكثر فعالية في تأثير الكبريتات .وبالتالي، فمن المستحسن أن تتبع المواصفات العراقية لمجموع محتوى الاملاح الكبريتية الكلية الفعالة لأنه يعطي مزيدا من المرونة لاستخدام الرمل والحصى مع المحتوى العالي من الكبريتات.

أظهرت النتائج خلال عمر سبعة ايام أن تأثير المحتوى الكلي الفعال للSO_3 (2.647٪، 2.992٪، 3.424٪) التي تتقابل مع الكبريتات الكلية (3.778٪، 3.294٪، 4.528٪) يقلل من المقاومة بنسب (5.26٪، 7.44٪، 12.45 ٪) على التوالي.

الكلمات الرئيسية: هجوم الاملاح الكبريتية الداخلي , محتوى الاملاح الكلية الفعالة ,الخرسانة عالية المقاومة , محتوى الاملاح الكلي ,الحجم الحبيبي.

1. INTRODUCTION

High strength concrete is a type of high performance concrete generally with a specified compressive strength of (40MPa) or higher, the production of high strength concrete requires a comprehensive research and more attention to quality control than the conventional concrete **ACI 363.2R, 1998**. High strength concrete is needed to implement the structural elements into service at much earlier age, such as maximize the spaces , construction of long span structures such as bridges and enhance the durability of bridge decks **ACI 363.2R, 1998**. New vanguard producers of ready mixed concrete are directing their promotion efforts toward commercialization of high strength concrete (60MPa and more).Some of the basic concepts that need to be understood for high strength concrete are ; The aggregate should be strong and durable, the aggregate need not necessarily be hard and of high strength but need to be compatible, in terms of stiffness and strength, with the cement paste, high strength concrete mixtures , generally , need to have a low water-cementitious material ratios (w/cm). W/cm ratios can be in the range of(0.23 to 0.35) and the use of air entrainment in high strength concrete will greatly reduce the strength potential **James, 1989, and Ron Burg, 1993**. Internal sulfate attack results from the reaction between sulfate in concrete constituents (water , cement , sand and gravel) .The reaction between these constituents, which have calcium aluminates, and water forms calcium sulphoaluminate . The hazard is illustrated in the materials which cause high tensile stresses leading to expansion and disruption of concrete **Skalny, and Odler, 2002**.

Raof, 1970 considered Calcium sulfate (gypsum) more dangerous for this type of attack , because of the addition of gypsum to the cement at the grinding stage to control the hydration speed and setting of cement paste .

The deleterious action of internal sulfate attack is brought about by an excessive SO_3 content in the finer material or, less often, in the aggregate used. Under these conditions , the whole volume of the material is affected more-or-less uniformly. The extent of damage depends on the composition of the mixture, the curing conditions, and the environment to which the object of concern is exposed **Skalny, and Odler, 2002**.

The optimum SO_3 content, at which higher mechanical properties and little tendency to expanding are obtained, is at SO_3 equal to 5 (% by weight of cement).Further increase in sulfates content in concrete after this optimum value shows a considerable reduction in mechanical properties; compressive strength, flexural strength , U.P.V and rebound number. Nonetheless, there is some recovering with advance in age at which the affected mixtures retrieve some of their lost strength **Al-Ameeri, and Issa, 2013**.

The cement made with clinker containing somewhat high percentages of SO_3 and low alkali had relatively slower strength development and higher resistance to sulfate attack than classical cement with similar chemical composition **Sayed Horkoss, et al., 2011**.

Al-Rawi, et al., 2002 found that the allowable sulfate content in sand could be increased without a significant loss in strength provided that sulfate content in cement is reduced . They presented the theory of effective sulfate content in concrete constituents and developed the following Eq.(1) which is based on this theory :

$$SO_3(\text{effective}) = 0.9 - 0.25\sqrt{F.M} \qquad ....(1)$$

This theory implies that sulfates in cement are more effective than sulfate in sand and sulfates in sand are more effective than that in coarse aggregates. Sulfates in cement could be more than double as effective as sulfates in sand, the same is applicable with the case of sulfate in sand compared with sulfate in coarse aggregate .It will also be used to calculate the effective SO_3 content in the present work **Al-Rawi, et al., 2002**.The different between al-Rawi work and the present work is the method of sulfate content in constituents of concrete which is used naturally contaminated in the present work.

Sulfate problem in fine aggregate increases with time in Iraq and the construction companies face several difficulties to find fine aggregate within the specification with regard to sulfate content. The possibility of adjusting fine aggregate content in concrete mixes is studied to facilitate using fine aggregate with sulfate content higher than that studied by the Iraqi Specification limit to (0.5%), but the total sulfate content of the mix is to be within the **IQS, No.45, 1984**.

In coarse aggregate, the presence of gypsum coatings is the major source of contamination **Saco, and Rassam, 1989**. Work done by **Sharif, et al., 1993** indicates that no gypsum exists in the interior mineral composition of coarse aggregate .By using X-ray Microscopic atomic absorption , and Auto analyzer they found that the gypsum exists only at the external surface of coarse aggregate.

The quality of mixing water plays an important role in the strength of the resulting concrete . Impurities in water may interfere with the setting of cement and adversely affect the strength and may lead to corrosion of reinforcement . Drinking water satisfies specification of quality assurance for mixing and curing of concrete, most specification **BS 3148, 1980** put an upper limit for sulfate not exceed (1000 ppm), The **ASTM C94, 2003** gives the use of the wash water (SO_3 not exceed 3000 ppm)and the **I.Q.S 1703, 1992** limited (SO_3 not exceed 100 ppm) in water as SO_3% (by weight) as reported by **Al-Salihi, 1994**.

1.1 Objectives

The objectives of this research can be summarized as follows:

1. The research is conducted to produce high strength concrete according to ACI 211.4R(2008) .
2. It also demonstrates the correlation between the total and total effective SO_3% content with (HSC) at different ages.

2. MATERIALS CHARACTERISTICS

2.1 Cement

Ordinary Portland cement (OPC) (Type I) as (cement 1 and cement 2) under commercial name of (Al-Kufa) was used for HSC mixes throughout work. The chemical analysis and physical properties of the cement used are given in **Tables 1** and **2.** The results conform to, **IQS, No.5, 1984**.

2.2 Fine Aggregate

Al-Obeidi (sand 1) , Al-Ekhaider (sand 2) and sand 3 which mixed from (sand 1 and sand 2) natural sands of 4.75 mm maximum size was used as fine aggregate in HSC mixes. Some properties of the three natural fine aggregates are illustrated in **Table 3** according to **IQS, No.45, 1984**.The grading of fine aggregates is shown in **Fig 1**.

2.3 Coarse Aggregate

Aggregate predominately retained on the No.4 (4.75mm) sieve, in this work crushed coarse aggregate with a nominal size of (19 mm) was used and it was obtained from Al-Nibaai region as (gravel 1 and gravel 2). Some properties of coarse aggregate are illustrated in **Table 4** according to **IQS, No.45, 1984** ,**Fig. 2** illustrate the gradation used throughout the investigation.

2.4 High Range Water Reducing Admixture (HRWRA)

A super plasticizer which is known commercially as Flowcrete PC-200 was used as a high range water-reducing agent . It is a highly effective superplasticizer with a slight set retarding effect which produces free-flowing concrete in hot climates . Also a substantial water reducing agent promotes high , early and ultimate strength .

The dosage of this superplasticizer that was recommended by the manufacturer was (0.7-2.5) % by weight of cement . Exact dosage rates depend on type of the effect required, quality of cement , aggregate , water cement ratio and ambient temperature therefore , in many cases, it is advisable to carry out trial mixes . This admixture conforms to the **ASTM**

C494, 2006 type G .Table 5 shows some physical and chemical analysis of the superplasticizer (PC-200).

2.5 Water

The water used in HSC mixes was potable water for both casting and curing of specimens.

3. PREPARATION OF CUBE SAMPLES

3.1 Mix Design

The design of concrete mixes to achieve characteristic compressive strength of (60) MPa at 28 days is made according to the American Method **ACI 211.4R, 2008**. Cement content is (512.5 kg/m³) and W/C ratio is 0.32. The slump required for all mixes is (75-100 mm). According to the mix design procedure, the mix proportion is (1: 1.44: 1.87). Mixes of HSC have been investigated by using two percentages of SO_3 in cement (type I with SO_3 content =2%) and (type I with SO_3 content=2.75%) ,These mixes have been studied by using different percentages of sulfate in fine aggregate of (0.3, 3.1, 5.3)%, and in coarse aggregate of (0.06,0.72)% and then its effect on the compressive strength, flexural strength, ultrasonic pulse velocity, density, and absorption at the age of 7, 28 , and 90 day.

3.2 Measurement of Workability of the HSC

Workability is one of the most important features defining the fresh properties of concrete and can be defined as a measure of the ability of concrete to be mixed, handled, transported and most important its ability to be placed without loss in homogeneity and with less air voids. A slump test is a suitable test to determine the workability for all types of concrete mixes ; This test is performed according to **ASTM C143, 2006**.

Several slump tests have been carried out to choose the appropriate dosage of HRWRA to give workability of (75 -100 mm) slump for all mixes.

3.3 Cube Mould and Curing

Mixing process was performed by manually operated mixer according to **ASTM C192, 2006**. Firstly, sand was well mixed with the cement to attain a uniform mix. then, gravel was added to the mix and the whole dry materials were well mixed for about (2) minutes. The required amount of tap water and HRWRA were then added gradually and the whole constituents were mixed for further (2) minutes to get a homogenous mix.

After mixing, the concrete mix was placed in the standard cubic steel moulds Specimens (100*100*100) mm which used for compressive strength , ultrasonic , absorption , and density test. The specimens were compacted using a vibrating table for sufficient period about (20 sec), in addition to the use of a metal rod to remove any entrapped air as much as possible. Then , the concrete surface was leveled and smoothed by means of trowel, and the specimens were covered with nylon sheet for 24 hrs at laboratory temperature to prevent evaporation of moisture from the fresh concrete. After, moulds were opened and cured permanent (continuous) water curing until testing date.

4. DETERMINATION OF THE TEST RESULTS

4.1 Compressive strength

Compressive strength test was measured on 100 mm cube for the determination of average compressive strength according to, **B.S. 1881: part 116, 1983** using a compression testing machine with a capacity of (2000 KN).

Specimens were kept under curing method conditions until testing. The loading rate used in the test was 0.3 N/mm^2 per second. The test was conducted at ages of 7, 28 and 90 days.

4.2 Flexural strength (Modulus of rupture)

The (100*100*400) mm concrete prisms were used for flexural strength. Test was carried out according to **ASTM C293, 2006** .The flexural strength (modulus of rupture) is calculated using the formula:

$$Fr = 3PL/2BD^2 \qquad \text{............... (2)}$$

4.3 Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (U.P.V.) is one of the non-destructive tests of concrete. Samples of (100*100*100) mm were used in the test according to **ASTM C597, 2006** using a device commercially known as (PUNDIT). The ultrasonic pulses have a wide range frequencies between (24-200) kHz, although the (55 kHz) and the (82 kHz) versions will normally be used for site or laboratory testing of concrete **Bungey, and millard, 2010**.

4.4 Density

Density test was performed on a (100*100*100) mm concrete cubes according to **ASTM C642, 2006**. The density of concrete cubes is determined in dry air by measuring the dimensions and weight of specimens using the measurement device (vernier) and the electrical scale.

4.5 Water Absorption

This test was carried out on (100*100*100) mm samples according to British Standard **B.S. 1881-part 122, 1983**. Three specimens are placed in a drying oven. So that each one was not less than 25 mm from any heating surface or from each other.

5. DISCUSSIONS of TEST RESULTS

Table 6 shows the mix designation and sulfate content for all HSC mixes. **Table7** shows the compressive strength and flexural strength results for all HSC mixes at different ages . **Fig.3** and **Fig.4** shows the relation between the reduction in compressive strength with the total effective SO_3% and total SO_3% at different ages. **Fig.5** , **Fig.6** and **Fig.7** shows the relationships between the compressive strength and age of the HSC specimens for different percentages of sulfate content in cement, sand and gravel at 7 , 28 and 90 days . **Fig.8** and **Fig.9** shows the relation between the reduction in flexural strength with the total effective SO_3% and total SO_3% at different ages. **Fig.10** , **Fig.11** and **Fig.12** shows the relationships between the flexural strength and age of the HSC specimens for different percentages of sulfate content in cement, sand and gravel at 7 ,28 and 90 days .The HSC specimens having low sulfate content such as reference mix exhibit an increase in compressive strength with increasing of curing age, while concrete specimens having the higher percentages of sulfate content such as (MCSHG) mix exhibit slight increase in compressive strength with increasing of curing age .This complies with studies carried out by, **Al-Rawi, et al., 2002,** and **Al-Salihi, 1994.**

In general, the results show that concrete mixes with the lower sulfate content gives a good results for compressive strength due to fill voids by hydration products and increase the density and decrease permeability of concrete .This complies with studies carried out by **Samaa ali, 2010**.

The highest percentages of sulfate content decreasing the compressive strength values at different ages from (5-40)% at 7 days, (6-41)% at 28 days , and (7-42)% at 90 day and decreasing the flexural strength values at different ages from (3-28)% at 7 days, (4-29)% at 28 days , and (6-32)% at 90 day with the increase in the values of total SO_3% and total effective SO_3%,but total effective SO_3% show a good correlation with the decreasing in compressive strength and flexural strength than the total SO_3% content. The trend of (Ultrasonic pulse velocity and density) is compatible with the compressive strength . The trend of absorption results is adverse with the compressive strength results because of sulfate action which absorb more water when the concentration of it increase **Fig.13** shows the effect of total effective SO_3% sulfate content on U.P.V ,density & absorption at 7 ,28 and 90 days .This fact according to the particle size of concrete constituent, the cement which has the higher fineness than sand and coarse make high surface area causing high reaction and high solubility with the sulfate **Al-Rawi, et al., 2002**.

There exist several factors that affect the strength development of concrete having different mixes. These factors are: fineness of the particles of the concrete constituent which are related to the effective SO_3% in materials, The percentages of SO_3% content in cement , in coarse and in fine aggregate, the size and shape of aggregate, concrete porosity, and chemical attack.

Concerning the above factors, the reference mix whose sulfate contents SO_3 (2%) in cement showed higher values of compressive strength , flexural strength , U.P.V and density when the (OPC) is of a low SO_3 in cement ,Thus, the quantity of expansive ettringite becomes less in the cement paste of concrete **Neville, 2010**.

In the fine aggregate when (SO_3%) content increases, the compressive strength of concrete decreases as compared to the reference HSC with SO_3 (0.3%), this is complies with the results of **Al-Salihi, 1994**.The (SO_3) ions which react with C_3A in cement to produce calcium sulphoaluminate causes expansion of concrete which therefore , may reduce the strength.

6. CONCLUSION

Depending on the results of the experimental work which has been done to investigate the effect of internal sulfate attack on HSC, the following conclusions can be drawn from analysis of these results:

1. The increase in total effective sulfate content in concrete causes an decrease in density of concrete about (0.38 - 4.8) at 90 days, but total effective sulfate content is more related linearly with this decrease than the total sulfate content.
2. The reduction in the SO_3 content in cement would allow using higher percentages of sulfate in aggregates used in concrete.
3. The total effective SO_3 shows a good correlation with the conducted result of all tests as compared with the total SO_3, so that the total effective SO_3 gives a good indication of the possibility of using material in concrete.

4. The reduction in the compressive strength ranged about (7-40%) at 7-days for mixes with total effective SO_3 content of (2.6-6.9%) and with total SO_3 content of (3.77-11.72%) (by weight), and the reduction is about (11-42%) in the compressive strength at 90-days of test, these result show a good resistance in HSC to the sulfate action at different ages.
5. Increasing the SO_3 content in cement has a more significant effect than increasing the SO_3 content in fine aggregate, fine aggregate has a more significant effect than increasing the SO_3 content in the coarse aggregate on the properties of concrete .This reduction is due to the surface area and fineness of cement .The total effective SO_3 which depends on the particle size of the materials shows a good trend with the increment in sulfate content in concrete constituent.HSC mixes suffer significant deterioration in all its properties.
6. The compressive strength, flexural strength ,U.P.V, and density results decrease at early ages about (5-40)% ,(3-28)% ,(1-10)% ,(0.38-4.8)% respectively with the increase in total effective SO_3 content of (2.6-6.9%) .
7. The absorption results increase about (-7 to -68)% with the increase in total effective SO_3 content of (2.6-6.9%) .

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NOMENCLATURE

F.M = fineness modulus of aggregate.
Fr = flexural strength, (MPa).
P = maximum applied load indicated by tested machine, (N).
L = average length of specimen, (mm).
B = average width of specimen, (mm).
D = average depth of specimen, (mm).

Table 1. Chemical composition and main compounds of cement 1& cement 2*

Oxide composition	cement 1 % by weight	cement 2 % by weight	*IQS (No.5:1984) limits*
Lime (CaO)	62.14	61.55	----
Silica (SiO_2)	20.70	20.24	----
Alumina (Al_2O_3)	5.96	6.25	----
Iron oxide (Fe_2O_3)	3.34	3.39	----
Sulfate (SO_3)	2	2.75	≤ 2.8%
Magnesia (MgO)	3.94	3.96	≤ 5%
Loss on Ignition (L.O.I.)	1.07	0.95	≤ 4%
Lime saturation Factor (L.S.F.)	0.90	0.90	0.66-1.02
Insoluble residue (I.R.)	0.60	0.40	≤ 1.5%
Main compounds (Bogue's equations) **			
C_3S	38.49	41.71	----
C_2S	28.99	27.88	----
C_3A	10.83	10.64	----
C_4AF	10.32	10.16	----

* The tests were carried out in the Laboratory of the Kufa Cement Plant ..
** According to, ***ASTM C 150, 2006***.

Table 2. Physical properties of cement 1& cement 2

Properties Physical	**Test Result cement 1****	**Test Result cement 2****	***IQS (No.5:1984) limits***
Specific surface area, Blaine method, m^2/kg *	313.1	321.5	≥ 230
Setting time , Vicat's Method Initial setting , hr : min Final setting , hr : min	90 2:30	90 2:30	≥ 45 minutes ≤ 10 hours
Compressive strength MPa 3-days 7-days	27.2 35	28.4 35.2	≥15 ≥23

* The tests were carried out in the Laboratory of the Kufa Cement Plant .
** cement 1= SO_3 %(2) , cement 2 =SO_3 %(2.75).

Table 3. Properties of fine aggregate*

Sieve size (mm)	Passing% of sand 1**	Passing% of sand 2**	Passing% of sand 3**	Limits of Iraqi spec. No.45/1984/Zone 2
10	100	100	100	100
4.75	95	92	91	90-100
2.36	79.29	83.7	85.1	75-100
1.18	65	73.8	70.7	55-90
0.6	45.43	49.2	48.6	35-59
0.3	13.71	19.3	21.6	8-30
0.15	2.71	4	3	0-10
Physical properties	Physical properties of sand 1	Physical properties of sand 2	Physical properties of sand 3	Limits of Iraqi spec. No.45/1984
Fineness modulus	2.98	2.78	2.8	-
Specific gravity	2.76	2.53	2.6	-
Absorption%	1.2	1.21	1	-
SO_3%	0.3	5.3	3.1	≤ 0.5%
Dry rodded density kg/m^3	1680	1675	1672	-

* Performed in laboratory of Building Materials-University of Baghdad.
** sand 1 = SO_3 %(0.3) , sand 2 = SO_3 %(5.3) , sand 3 (mix sand 1 & sand 2) = SO_3 %(3.1).

Table 4. Properties of coarse aggregate*

Sieve size (mm)	Passing % of gravel 1**	Passing % of gravel 2**	Limits of Iraqi spec. No.45/1984 (5-20)mm
37.5	100	100	100
20	95.35	96.13	95-100
10	31.38	33.9	30-60
4.75	2.48	3.4	0-10
Physical properties	Physical properties of gravel 1	Physical properties of gravel 2	Limits of Iraqi spec. No.45/1984
Specific gravity	2.56	2.57	-
Absorption %	0.56	1.14	-
SO_3 %	0.06	0.72	$\leq$ 0.1%
Dry rodded density kg/m³	1600	1550	-

* Performed in laboratory of Building Materials-University of Baghdad.
** gravel 1 = SO_3 %(0.06) , gravel 2 = SO_3 %(0.72)

Table 5. Technical description of superplasticizer (PC-200) *

Properties	Technical description
Type	Synthetic dispersion
Colour	Light yellow liquid
Specific gravity	1.05 kg/l @ 25°C
Freezing point	- 1°C approximately
Air entrainment	Less than 2% at normal dosage

* Technical description according to Don Gonstruction Products Ltd www.donconstruction.eo. uk.

Table 6. Mix designation and sulfate content for all HSC mixes

Set No.	Sulfate content % in Mix			Slump of Mixes (75-100) mm	Total SO_3% of Mixes	Total effective SO_3% of Mixes
	SO_3% in cement	SO_3% in sand	SO_3% in gravel			
MRef	2	0.3	0.06	100	2.544	2.238
MG	2	0.3	0.72	99	3.778	2.669
MC	2.75	0.3	0.06	95	3.294	2.988
MCG	2.75	0.3	0.72	90	4.528	3.419
MSm	2	3.1	0.06	90	6.576	4.181
MSmG	2	3.1	0.72	87	7.810	4.614
MCSm	2.75	3.1	0.06	87	7.326	4.932
MCSmG	2.75	3.1	0.72	85	8.560	5.364
MSh	2	5.3	0.06	83	9.744	5.779
MShG	2	5.3	0.72	82	10.978	6.211
MCSh	2.75	5.3	0.06	80	10.494	6.529
MCShG	2.75	5.3	0.72	78	11.728	6.961

Table 7. Compressive strength and flexural strength results for all HSC mixes at different ages.

Set No.	Total SO_3% of Mixes	Compressive strength (MPa)			Flexural strength (MPa)		
		7 days.	28 days.	90 days.	7 days.	28 days.	90 days.
MRef	2.544	51.72	61.7	71.7	7.47	8.47	10.26
MG	3.778	49.0	57.98	66.3	7.23	8.13	9.68
MC	3.294	47.87	55.2	63.5	7.13	7.85	9.44
MCG	4.528	45.28	52.09	61.24	7.02	7.78	9.32
MSm	6.576	43.79	51.55	59.3	6.89	7.68	9.02
MSmG	7.810	42.2	49.68	57.08	6.73	7.26	8.67
MCSm	7.326	39.8	47.3	54.35	6.5	7.02	8.47
MCSmG	8.560	38.3	45.2	51.82	6.32	6.78	8.11
MSh	9.744	36.33	42.1	48.3	6.05	6.62	7.78
MShG	10.978	34.77	40.8	45.56	5.85	6.29	7.53
MCSh	10.494	33.03	38.22	43.41	5.7	6.18	7.26
MCShG	11.728	31.0	36.2	41.45	5.35	5.95	7.02

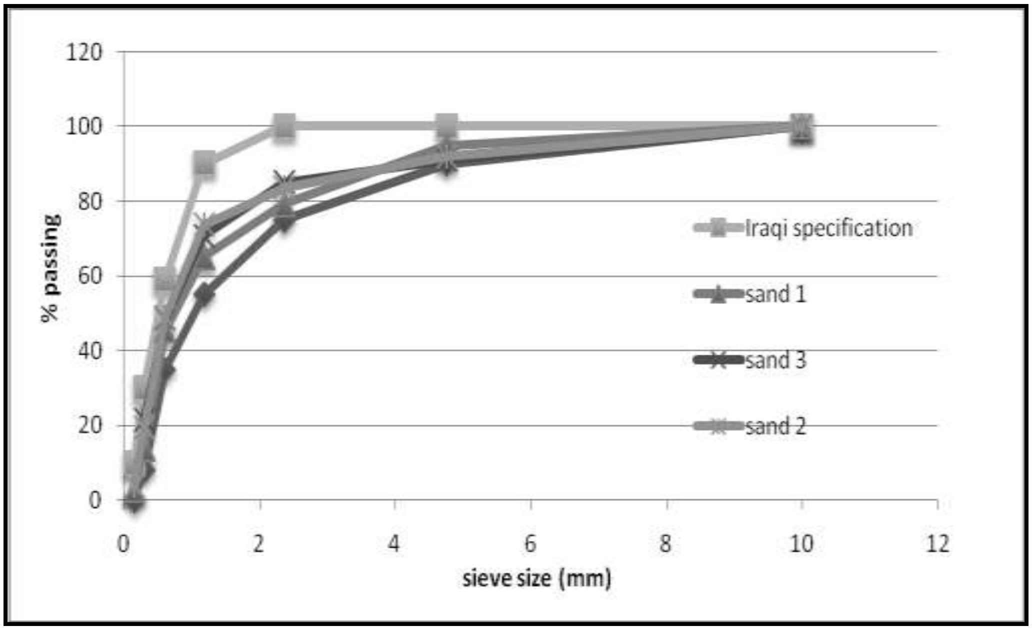


Figure 1. Grading curve for used fine aggregate with (sand 1),(sand 2) and (sand 3).

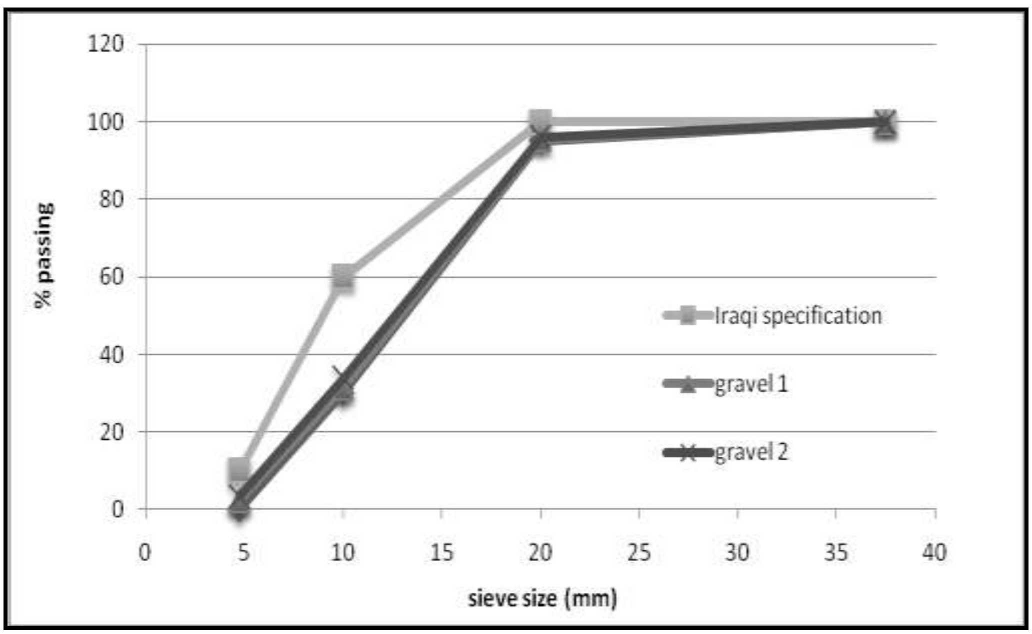


Figure 2. Grading curve for used coarse aggregate with (gravel 1) and (gravel 2).

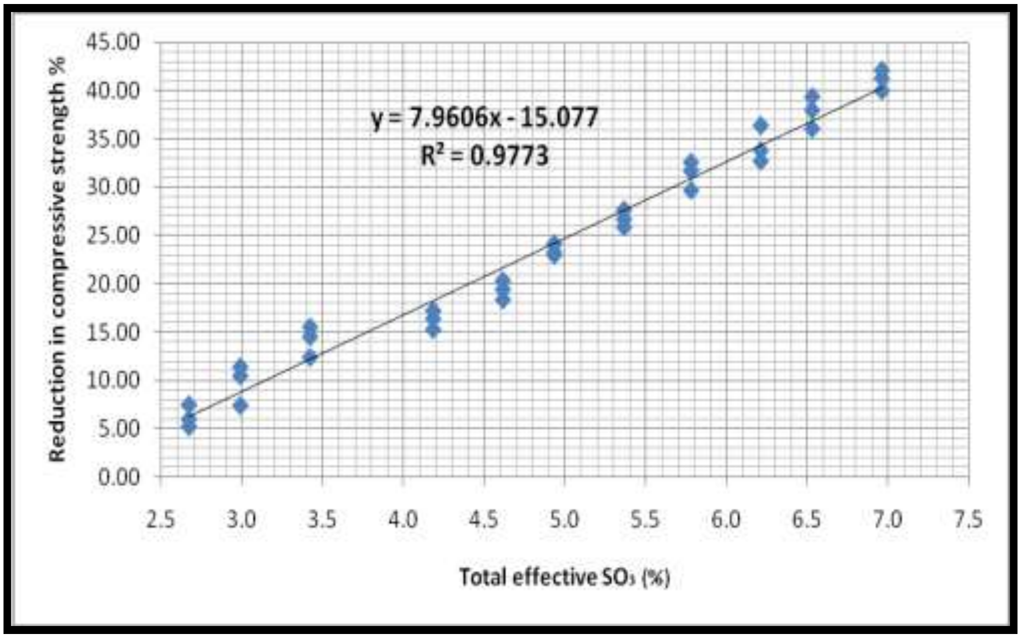


Figure 3. Relation between total effective SO_3% and reduction in compressive strength at different ages.

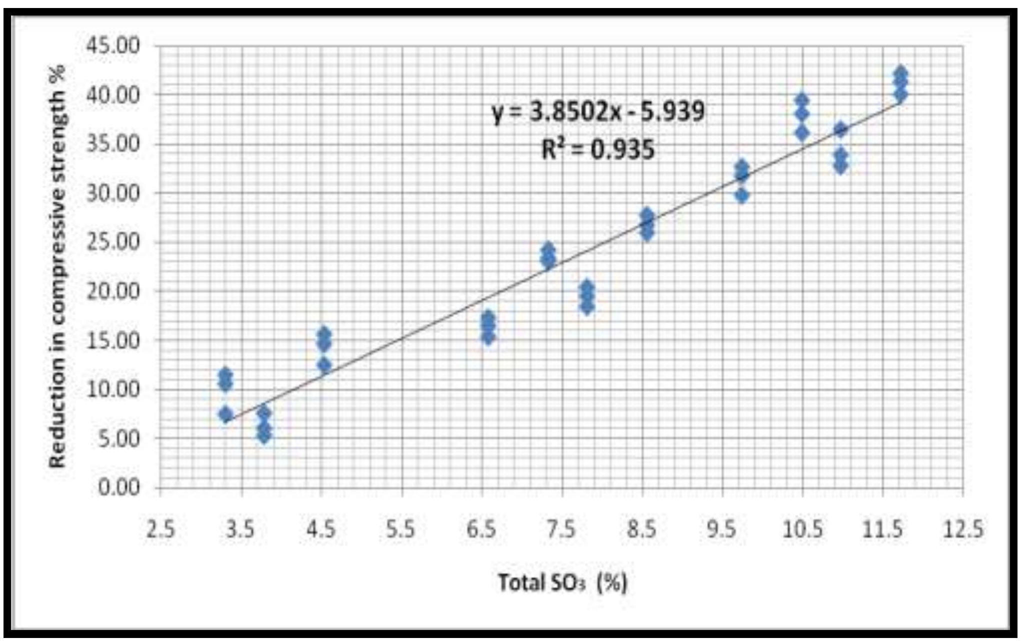
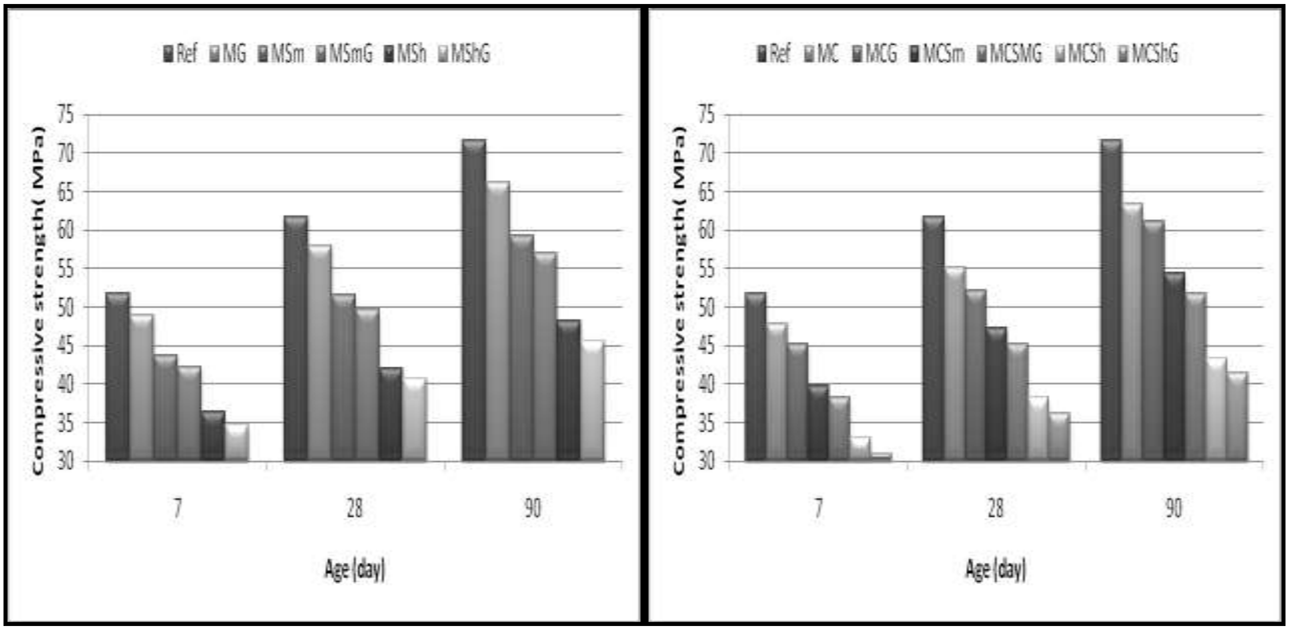
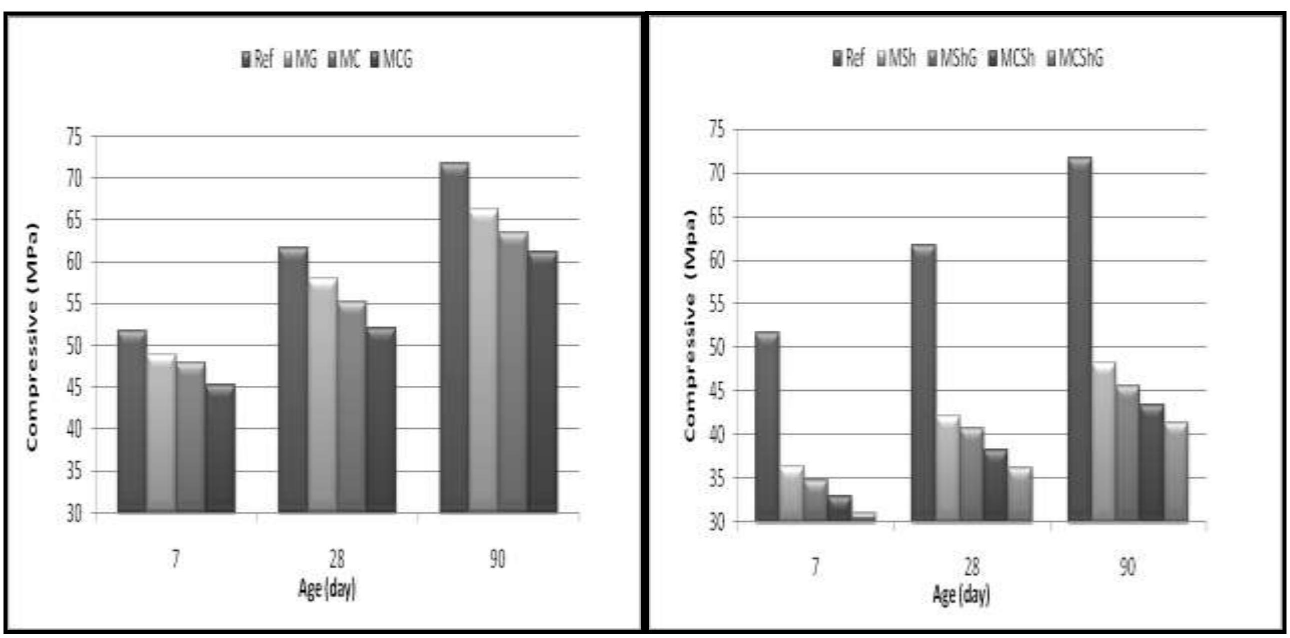


Figure 4. Relation between total SO_3% and reduction in compressive strength at different ages.

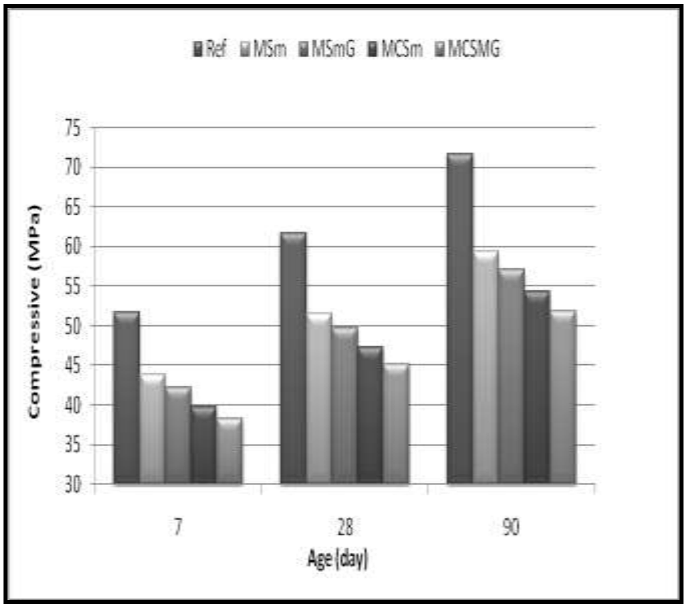


5.a. Cement 1 **5.b. Cement 2**

Figure 5. Effect of different sulfate content in cement on compressive strength at different ages.

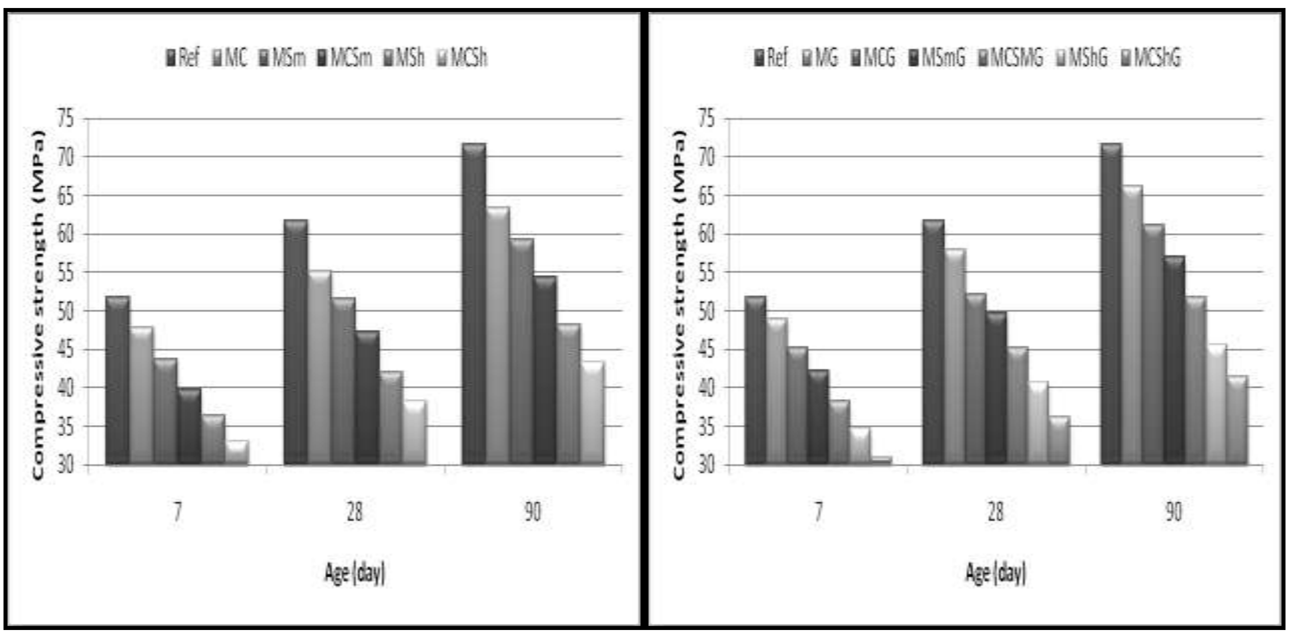


6.a. Sand 1 **6.b. Sand 2**



6.c. Sand 3 (mix sand 1 & sand 2)

Figure 6. Effect of different sulfate content in fine aggregate on compressive strength at different ages.



7.a. Gravel 1 **7.b. Gravel 2**

Figure 7. Effect of different sulfate content in coarse aggregate on compressive strength at different ages.

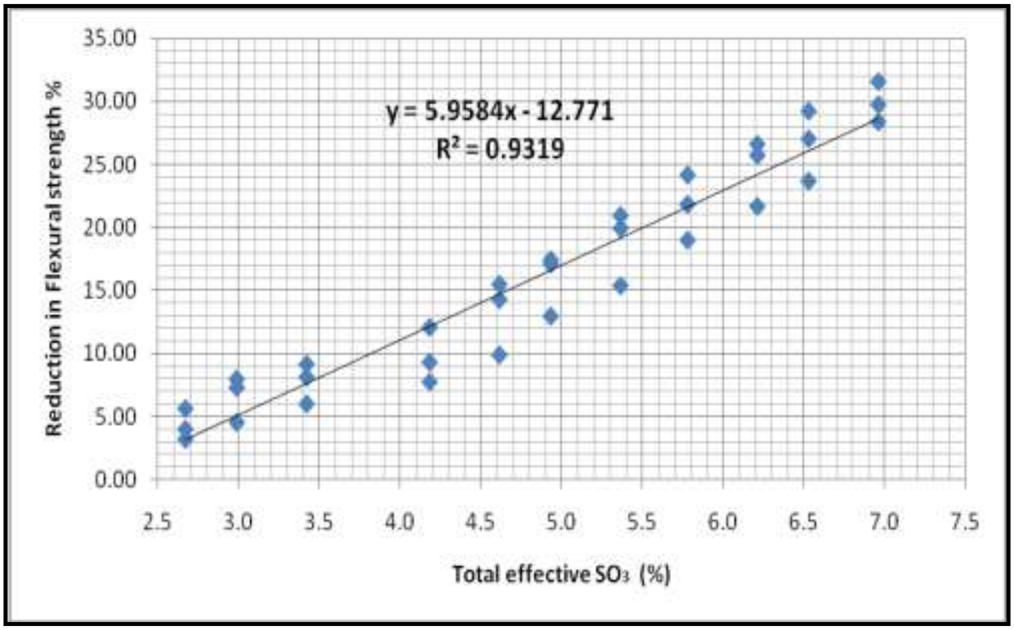


Figure 8. Relation between total effective SO_3% and reduction in flexural strength at different ages.

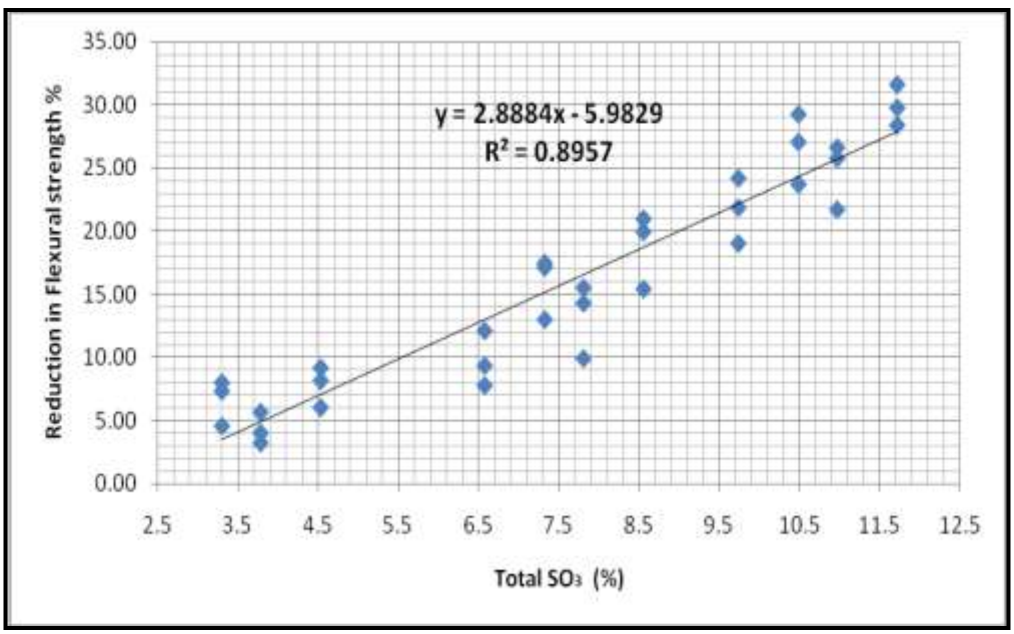
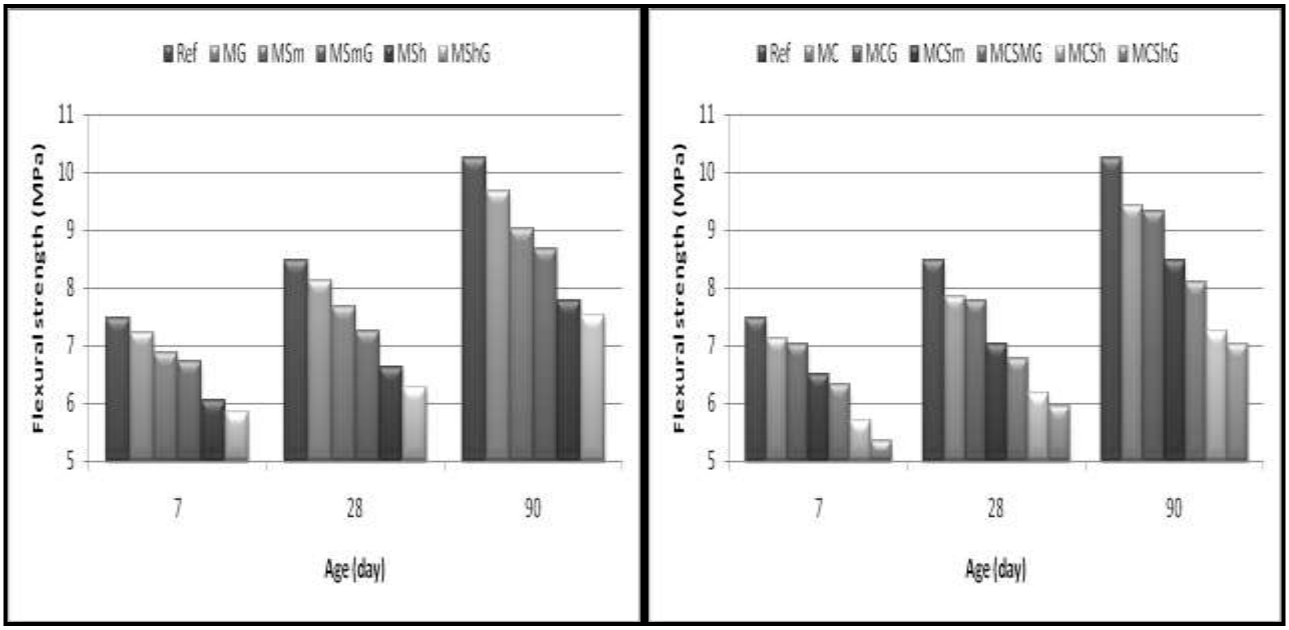
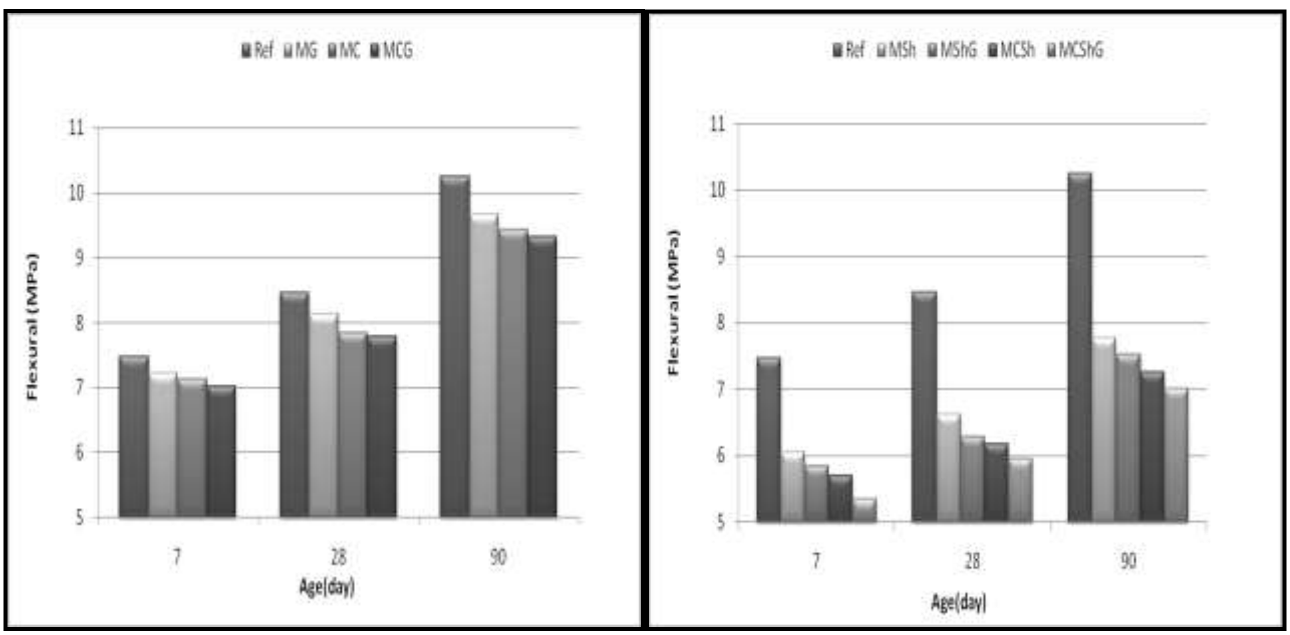


Figure 9. Relation between total SO_3% and reduction in flexural strength at different ages.

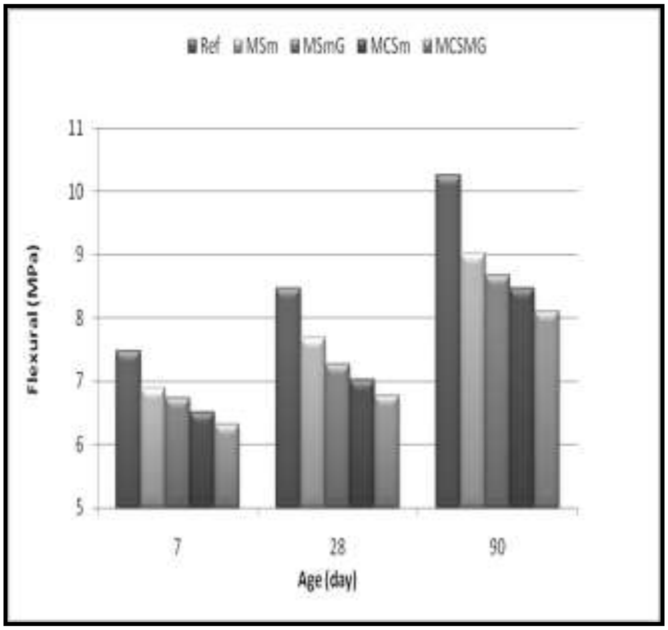


10. a. Cement 1 **10.b. Cement 2**

Figure 10. Effect of different sulfate content in cement on flexural strength at different ages.

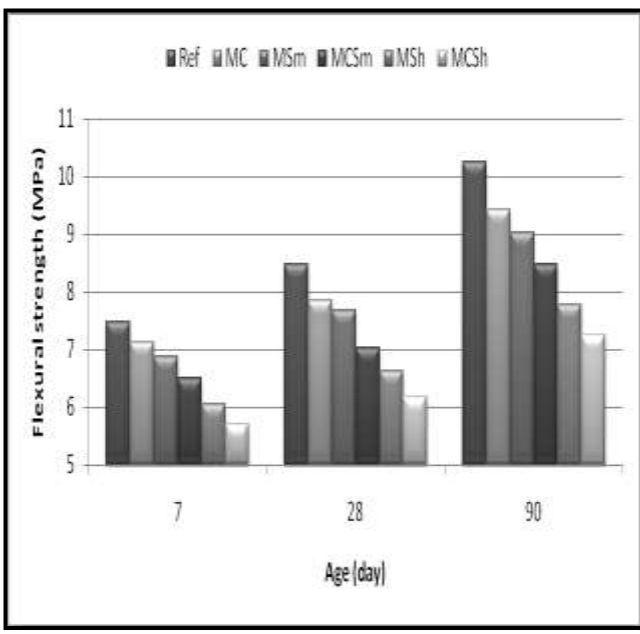


11.a. Sand 1 **11.b. Sand 2**

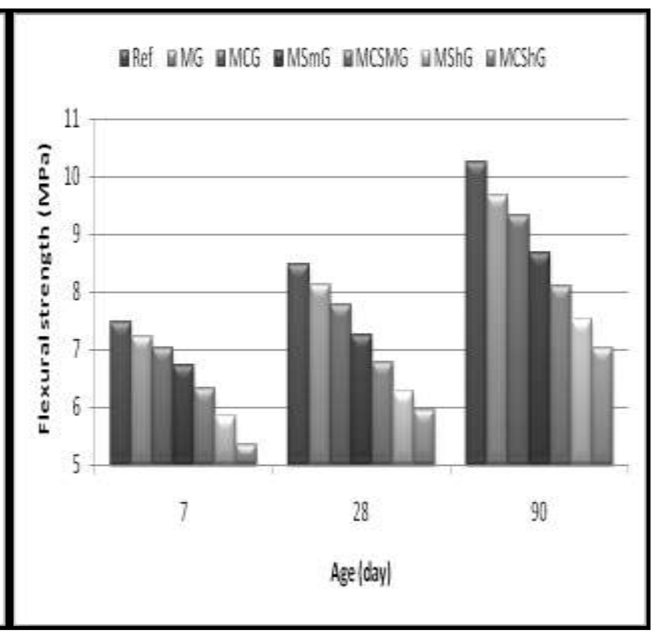


11.c. Sand 3 (mix sand 1 & sand 2)

Figure 11. Effect of different sulfate content in fine aggregate on flexural strength at different ages.

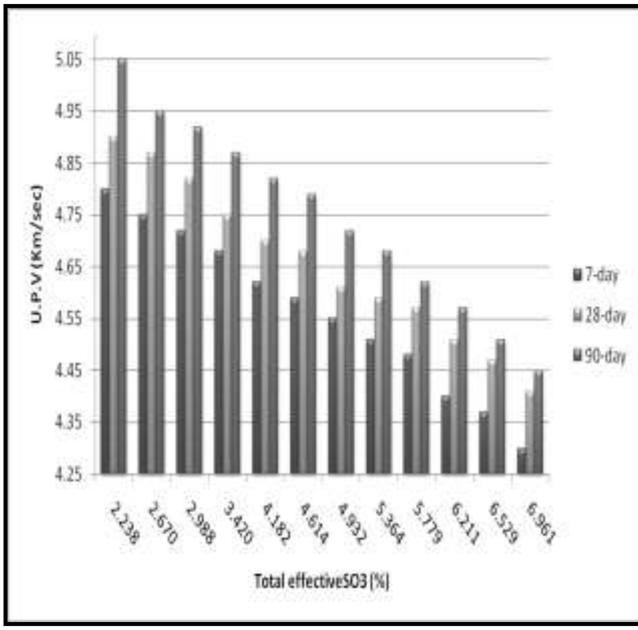


12.a. Gravel 1

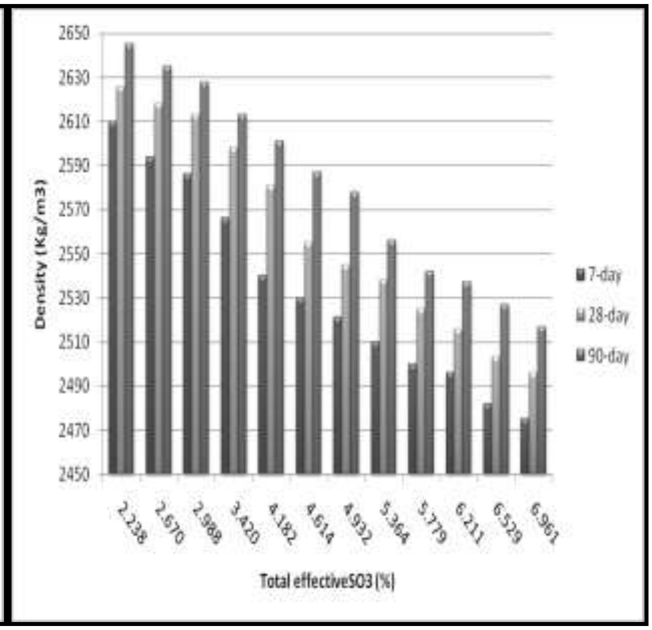


12.b. Gravel 2

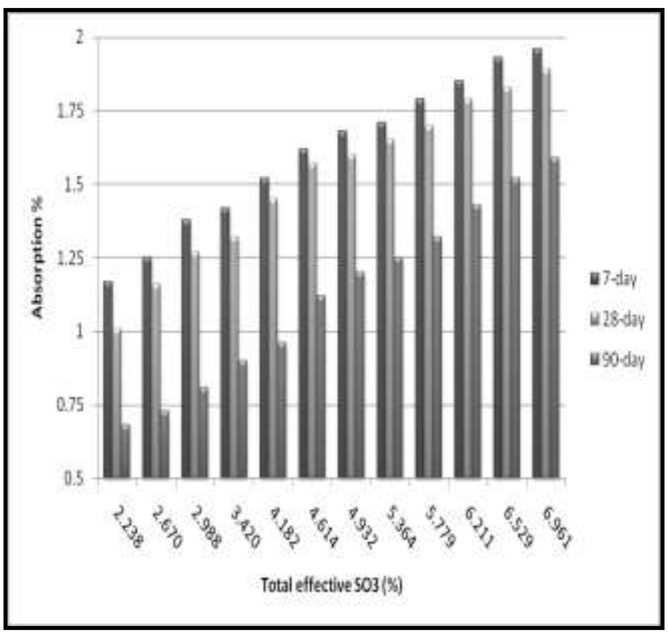
Figure 12. Effect of different sulfate content in coarse aggregate on flexural strength at different ages.



13.a. U.P.V



13.b. Density



13.c. Absorption

Figure 13. Effect of total effective SO_3% sulfate content on U.P.V ,density & absorption at 7 , 28 and 90 days.