Internal Sulphate Attack On Self Compacting Concrete

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Abstract:

Sulphate attack is a significant problem which locally affects concrete and other constructional materials. The aim of this research is to find the influence of Internal Sulphate Attack (ISA) on some mechanical properties of SCC (**Ali E. M., 2006**). The mechanical properties studied are compressive strength, splitting tensile strength and flexural strength at 28- days and 60- days respectively.

In this study, three levels of sulphates are added to the sand to investigate the influence of sulphates on SCC made from locally available materials and compared it with reference normal mix.

Based on the results of this study, it concluded that when the amount of SO_3 increased by (0.5-1.5) % by weight of sand, the (compressive strength, splitting tensile strength and modulus of rupture) decreases by (10-26) %, (9-29) % and (14-35) % at 28-days respectively, while they decreases by (12-51) %, (17-30) % and (23-43) % at 60-days respectively.

الخلاصة

تعد مهاجمة الاملاح الكبريتية مشكلة رئيسية تؤثر بشكل سلبي على الخرسانة والمواد الانشائية الاخرى. يهدف البحث لدراسة تأثير مهاجمة الاملاح الداخلية على بعض الخواص الميكانيكية للخرسانة ذاتية الرص. الخواص الميكانيكية التي تمت دراستها هي: مقاومة الانضغاط, مقاومة الانشطارو مقاومة الانثناء باعمار 28 و60 يوما على التوالي.

في هذه الدراسة, تم اضافة ثلاث نسب من الكبريتات الى الرمل لدراسة تأثير هذه الملاح على الخرسانة المرصوصة ذاتيا والمصنوعة من المواد المتوفرة محليا مع المقارنة بخرسانة مرجعية (خرسانة اعتيادية).

بناءا على نتائج هذه الدراسة, من الممكن ملاحظة النقصان الحاصل في مقاومة الانضغاط, ومقاومة الانشطار مع مقاومة الانثناء بمقدار يتراوح بين (10–26) % , (9–29) % و (14–35) % بعمر 28 يوما بينما كانت قيمة النقصان بمقدار (12–51) %, (17–30) % و (23–43) % بعمر 60 يوما على التوالي وذلك عند زيادة نسبة الاملاح الكبريتية بمقدار يتراوح بين (0.5– 1.5) % من وزن الرمل المستخدم.

1. Introduction

Solid salts do not attack concrete but, when present in solution, they can react with hydrated cement paste. Particularly common are sulphates of sodium, potassium, magnesium and calcium which occur in soil or in ground water (**Neville A.M, 1995**).

Ettringite formation is considered to be the cause of most of the expansion and disruption of concrete structures involved in the sulphate attack(**ACI Committee 201,1994**).However, not necessarily any sulphate attack is caused by ettringite formation (**Mehta P.K, 1993**).Moreover, ettringite formation can be advantageously used without any sulphate attack for the development of shrinkage- compensating concrete by using expansive cements (**Collepardi M., 1998**).

Ettringite formation is associated with expansion and many hypothesis of ettringite related expansion have been advanced (**Lawrence C.D, 1998**).However,not necessarily any ettringite- related expansion produces damaging disruption of concrete structures, as shown in Figure (1).

The term "sulphate attack", as used here, means deterioration of concrete involving any type of sulphate interactions with cement paste independently of the curing temperature and sulphate source. The resistance of concrete to attack by solutions of sulphate salts increased with reduction of C_3A content in the cement. High resistance was found for Portland cement containing not more than 5.5 % of C_3A (**Woods H., 1992**).

2. Internal Sulphate Attack (ISA)

The internal sulphate attack related damage is relatively "new" with respect to the "traditional" external sulphate attack since it was detected in the middle of 1980's. Two different mechanisms of Delayed Ettringite Formation (DEF) caused by internal sulphate attack:

1. Thermal decomposition and re-formation of ettringite in a saturated atmosphere at room temp.
2. Holistic approach based on micro-cracking, late sulphate release and exposure to water (**Collepardi M., 1998**).

There are three conditions mentioned by Alwash (**Alwash J.H., 2005**) for the internal sulphate attack to take place:

1. It needs preliminary micro cracks where deposition of ettringite crystals can occur.
2. It occurs in a sulphate- free environment for the late sulphate release from gypsum- contaminated aggregate, sulfur- rich clinker phase and high- sulphate cement.
3. It occurs in a moist environment favoring diffusion of SO_3 and other ions (ca++ and aluminate) through water- saturated capillary pores.

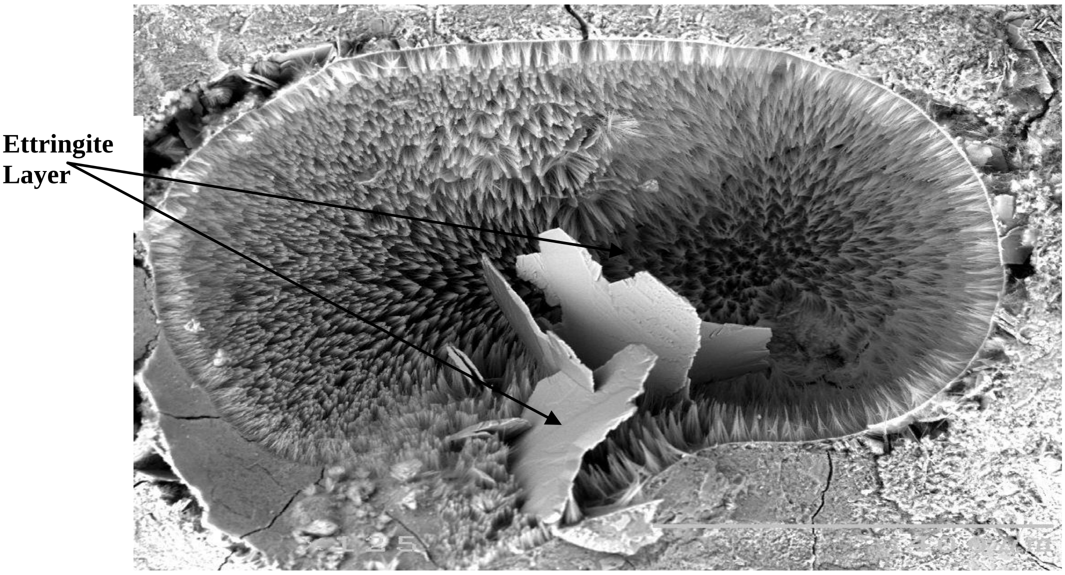

Figure (1):- Role of EEF in Cement Hydration (**Mehta P.K, 2007**).

3. External Sulphate Attack (ESA)

The external sulphate attack induced damage, which is the traditional sulphate attack, is determined by the chemical interaction of a sulphate, in rich soil or ground water, with the cement paste. Soils containing sodium, potassium, magnesium and calcium sulphates are the main sources of sulphate ions in ground water. Therefore, the three following conditions must be fulfilled:

1. High permeability of concrete.
2. Sulphate- rich environment.
3. Presence of water. Figures (3) and (4) show the ISA and ESA conditions.

The reactions of the various sulphates with hardened cement paste are as follows (**Neville A.M, 1995**):

1. Sodium sulphate attacks $Ca(OH)_2$:
   $Ca(OH)_2 + Na_2So_4 .10H_2o \longrightarrow CaSo_4.2H_2o + 2NaOH + 8H_2o$
   This is an acid- type attack. In following water, $Ca(OH)_2$ can be completely leached out but if NaOH accumulates, equilibrium is reached. Only a part of So_3 being deposited as gypsum. The reaction with calcium aluminate hydrate can be formulated as follows (**Lea F.M, 1970**):
   $2(3CaO.\ Al_2O_3.\ 12H_2o) + 3\ (Na_2So_4.10H_2o) \longrightarrow 3CaO.\ Al_2O_3 .3CaSo_4 .32\ H_2o + 2Al\ (OH)_3 + 6\ NaOH + 17\ H_2o$
2. Calcium sulphate attacks only calcium aluminate hydrate, forming calcium sulfoaluminate ($3\ CaO.\ Al_2O_3.\ 3CaSo_4 .32\ H_2o$), known as ettringite. The number of molecules of water may be 32 or 31, depending upon the ambient vapor pressure (**Dron R., 1989**).
3. Magnesium sulphate attacks calcium silicate hydrates, $Ca(OH)_2$ and calcium aluminate hydrate. The pattern of reaction is:
   $3CaO.\ 2SiO_2 + 3MgSo_4 + 7\ H_2o \longrightarrow 3CaSo_4.\ 2\ H_2o + 3Mg(OH)_2 + 2SiO_2 + x\ H_2o$

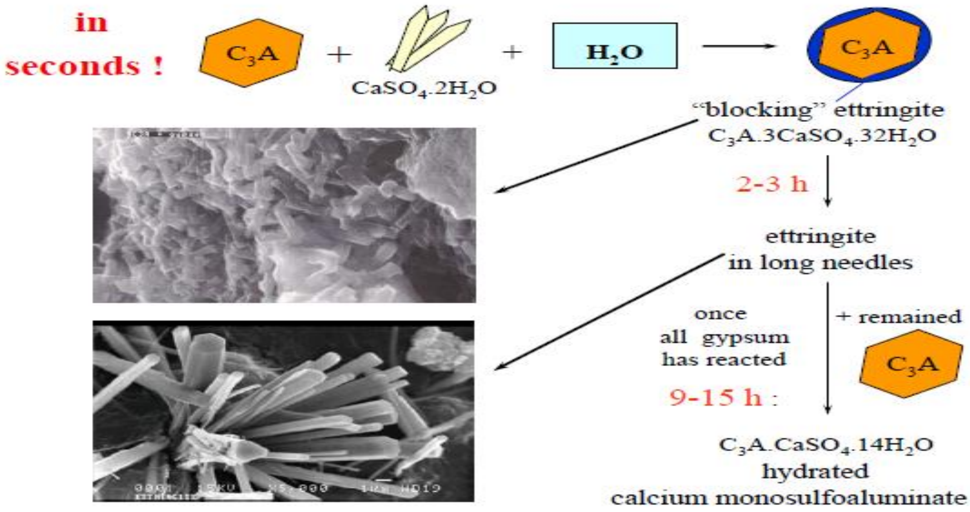

Figure (2):- comparison between **EEF** and **DEF** (**Mehta P.K, 2007**).

4. Research significance

The aim of this study is to find the influence of the internal sulphate attack on some mechanical properties of SCC made from locally available materials at 28 and 60 days respectively.

5. Materials

5.1 Cement

Sulphate resistance cement manufactured by Kerbalaa factory was used throughout this investigation. This cement was complied with the IQS No. 5/84 with SO_3content of 1.9 %.

5.2 Sand

Natural sand from Al-Akaidur region was used. It complied with IQS No. 45/84 zone 3, with SO_3content of 0.25%.

5.3 Gravel

The coarse aggregate was Al-Nibaee gravel with a maximum aggregate size of 19 mm. this aggregate was complying with IQS No. 45/84 with SO_3content of 0.08 %.

5.4 Water

Tap water was used for both mixing and curing of concrete.

5.5 Super- plasticizer

A super- plasticizer known as TufFlow SP603 was used in producing SCC. This SP was complying with ASTM C494 type D & G (retarding and water reducing SP for slump retention and high strength concrete). The dosage was range between 200-1400 ml per 100 kg of cement.

5.6 Limestone powder

Finely crushed limestone which has been brought from local market is used to increase the amount of powder content (cement + filler) in the SCC mixes. It is passing sieve size 0.0015mm (No. 400) sieve and it has SO_3 content equal to 2.9 %.

5.7 Gypsum

Gypsum was added to the sand to change the So_3 content. The added gypsum was natural gypsum rock (from Kufa cement factory) which crushed, sifted and graded just like sand.

The gradation of the added gypsum was the same as that of sand because it has been found that the gypsum has the same gradation as the sand which includes. The used gypsum has a 42 % SO_3 content.

6. Program of the work

In the present work, a study of the effect of sulphate contaminated fine aggregate (sand) on some mechanical properties of SCC was conducted. One concrete mix was considered and three levels of So_3 content in sand were investigated, these levels were 0.5 %, 1 % and 1.5 % by weight of sand.

The concrete mix was designed according to the Japanese mix design method that mentioned by **Ali E. M., 2006**, to satisfy the fresh requirements of this type of concrete. The proportions of concrete mixes are summarized in Table (1).

Table (1): Mix proportions.

Mix No.	Cement (Kg/m^3)	Filler (Kg/m^3)	Sand (Kg/m^3)	Gravel (Kg/m^3)	w/c %	SP by wt of Cement %	SO_3 by wt of sand %
1	450	75	725	750	45	4	0
2	450	75	725	750	45	4	0.5
3	450	75	725	750	45	4	1
4	450	75	725	750	45	4	1.5

7. Moulds

The moulds used in this study were as follows:

1. (150*150*150) mm cubes to obtain concrete specimens for compressive strength.
2. (100*200) mm cylinders to obtain concrete specimens for splitting tensile strength.
3. (100*100*400) mm prisms to obtain concrete specimens for flexural strength.

8. Testing of concrete specimens

8.1 Compressive strength test

For the hardened concrete, the compressive strength test was carried out according to BS 1881 part 116:83. A total number of 48 cubes were tested by using a hydraulic compression machine of 2000 kN. All specimens were cured in water until testing age. Each compressive strength value was the average of six specimens.

8.2 Splitting tensile strength test

The splitting tensile strength was determined according to the procedure outlined in BS 1881 part 117:83. Cylinders were cast, demolded and cured in a similar way as the cubes. Each value was the average of six specimens.

8.3 Flexural strength test

This test was carried out according to BS 1881 part 118:83 procedure using two point load test and calculated from the simple beam bending formula:

$$R = \frac{PL}{bd^2} \text{---------} (1)$$

Where:

P= max. applied load (N), L= span length (mm)
b= specimen width (mm), d= specimen depth (mm)

All specimens were cast, demolded and cured in a similar way as the cubes. Each flexural strength value was the average of six specimens.

9. Results and discussion

The test results of the 28 and 60 days compressive strength, splitting tensile strength and flexural strength of SCC with various percentages of gypsum content in sand are shown in Table (2) and Figures (5), (6) and (7) respectively.

From these results it can be seen that the decrease in the compressive strength was by (10-26) % and by (12-51) % when the amount of sulphates increased from (0.5-1.5) % by w.t of sand at 28 and 60 days respectively, also it can be seen that the splitting tensile strength decreased by (9-29) % and by (17-30) % at 28 and 60 days respectively. Moreover, this increase in the SO_3 content leads to a decrease in the flexural strength by (14-35) % and by (23-43) % at 28 and 60 days respectively.

Ettringite formation resulting from the reaction between sulphates and C_3A is associated with expansion. When ettringite occurs homogeneously and immediately (within hours), it does not cause any significant localized disruptive action, (EEF). This type of harmless ettringite formation happens, for instance, when gypsum reacts with anhydrous calcium aluminate in a through solution reaction and acts as a set of retarded in PC mixture:

$$C_3A + 3(CaSo_4.\ 2\ H_2o) + 26\ H_2o \longrightarrow C_3A.\ 3CS.H_{32}$$

This retardation has been attributed to the early formation of an ettringite layer which acts as a coating over the surfaces of the cement grains, (Figure 1) soon after mixing; this is called “Primary” ettringite as opposite to “secondary” ettringite which forms after several months (DEF), the related homogenous expansion can produce cracking and spalling. This disruptive effect is due to the non-uniform expansion localized only in the area of SCC structure where ettringite forms. Therefore, Delayed Ettringite Formation (DEF) and not Early Ettringite Formation (EEF), is associated with a damaging sulphate attack.

The consequences of sulphate attack include not only disruptive expansion and cracking, but also loss of strength of concrete due to the loss of cohesion in the hydrated cement paste and of the adhesion between it and the aggregate particles. This damage usually starts at edges and corners and is followed by a progressive cracking and spalling which reduce the concrete strength.

10. Conclusions

The present work is an attempt to study the influence of internal sulphate attack on some mechanical properties of SCC. On the basis of observations made in the present work, the following conclusions can be drawn:

1. Increasing the amount of sulphate content in the concrete mix decreases the strength of SCC at later ages (28 days and more).

2. Early Ettringite Formation (EEF) is advantageously used for setting time retardation of PC at early ages, while Delayed Ettringite Formation (DEF) can produce cracking and spalling in concrete after months.
3. When the amount of SO_3 increased by (0.5-1.5) % by weight of sand, the compressive strength decreases by (10-26) % at 28-days while at 60-days it decreases by (12-51) %.
4. When the amount of SO_3 increased by (0.5-1.5) % by weight of sand, the splitting tensile strength and modulus of rupture decreases by (9-29) % and (14-35) % at 28-days while they decreases by (17-30) % and (23-43) % at 60-days respectively.

11. Recommendations

For the prevention of Ettringite Formation, these issues involve both compositional limits on binder materials, and transport properties could take place:-

1. Limits on C_3A.
2. Use of Supplementary Cementitious Materials by the Use sufficient level of:
   - Fly ash (Class F or Class C)
   - Slag
   - Metakaolin
3. Limits on W/C with implied limits on “Permeability”.
4. Proper Compaction and Curing.

12. References

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Tab. (2): Mechanical properties results.

Mix No.	SO_3 %	Compressive strength (MPa)		Splitting tensile strength (MPa)		Flexural strength (MPa)	
		28	60	28	60	28	60
1	0	41.8	50.8	7.88	8.52	9.25	11
2	0.5	38.4	44.9	7.16	7.08	8	8.5
3	1	33.5	30.6	6.21	6.53	7.25	8
4	1.5	30.9	24.9	5.57	6	6	6.25

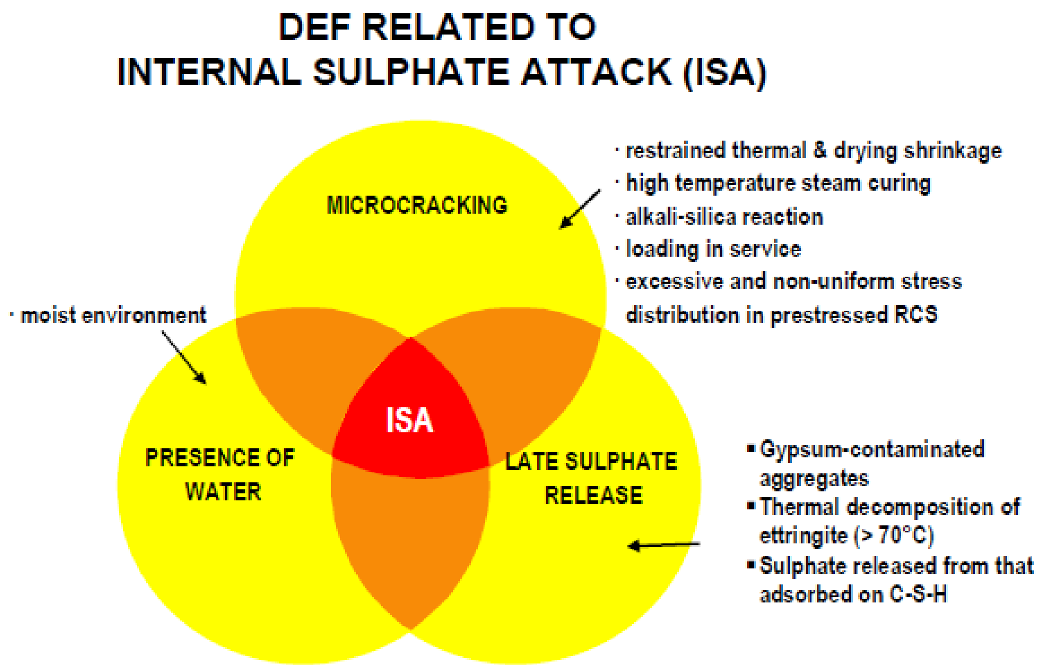

Figure (3):- Ternary representation of the DEF related to ISA.

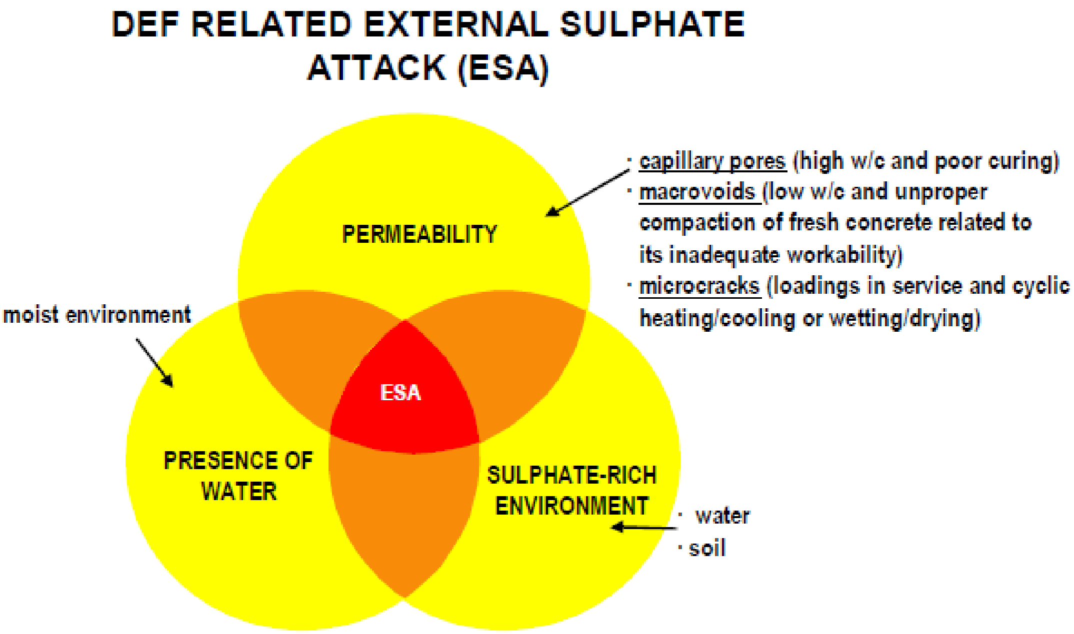

Figure (4):- Ternary representation of the DEF related to ESA.

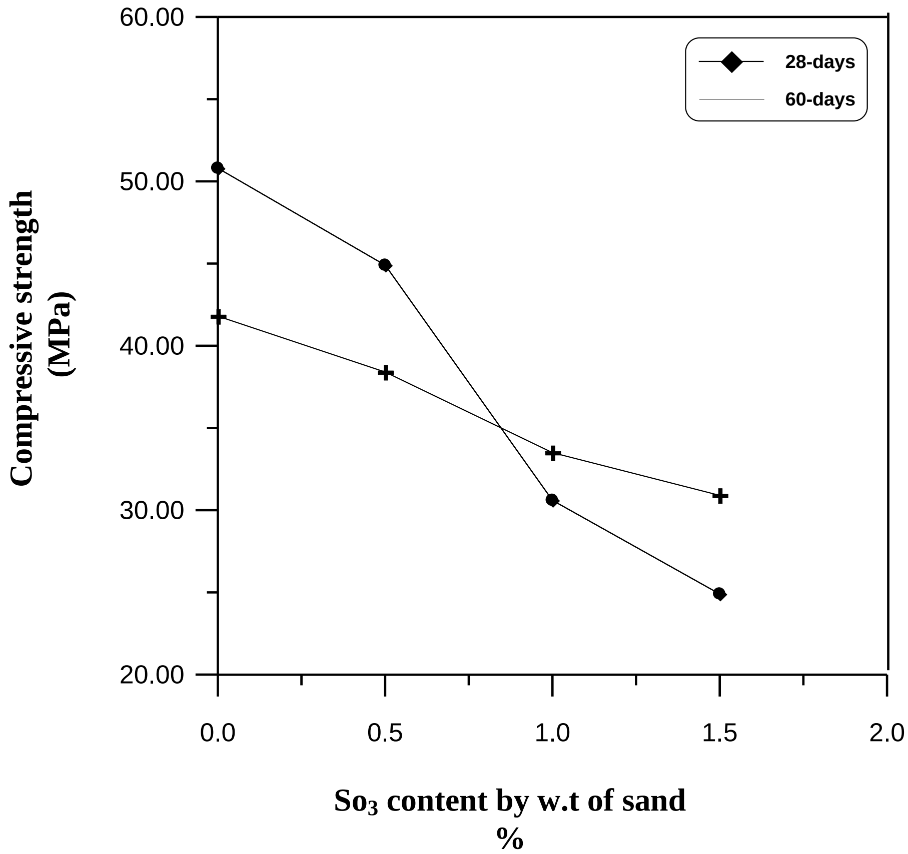

Fig. (5): Relationship between compressive strength and So_3 content.

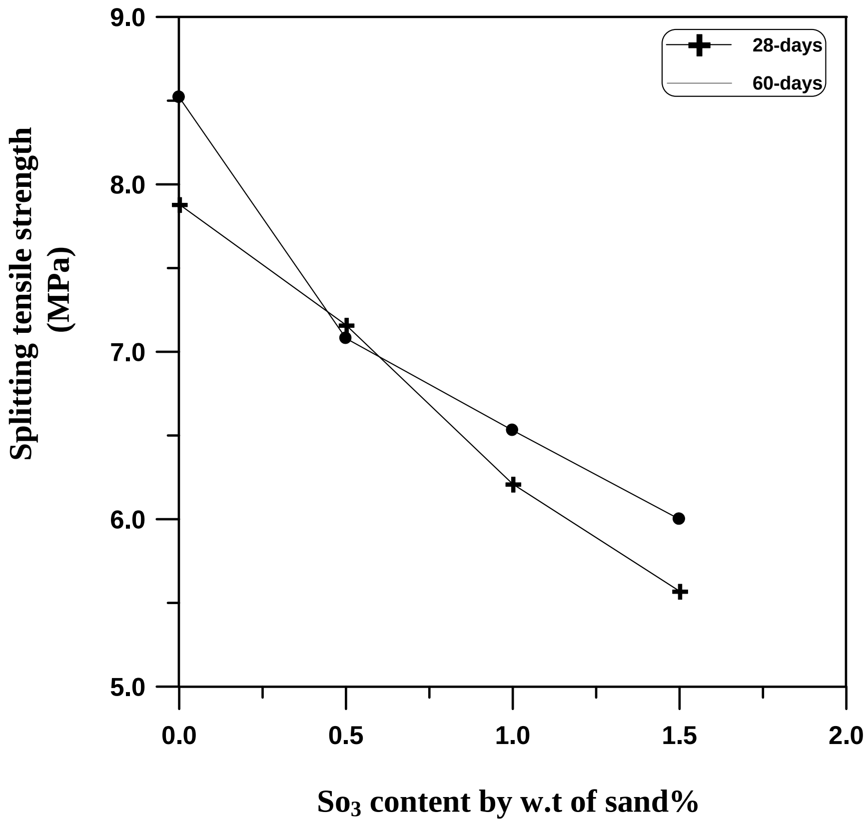

Fig. (6): Relationship between splitting tensile strength and So_3 content.

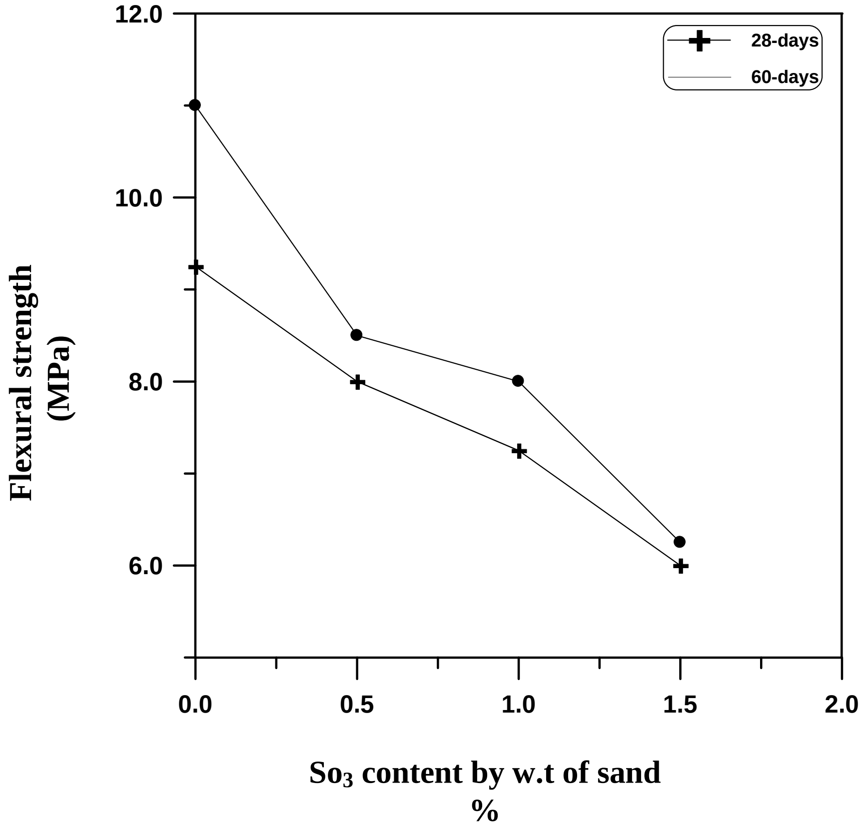

Fig. (7): Relationship between flexural strength and So_3 content.