EFFECT OF SULFATES IN FINE AGGREGATE ON SOME PROPERTIES OF SELF COMPACTING CONCRETE INCORPORATING HIGH REACTIVE METAKAOLINE

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ABSTRACT

Fine aggregate contaminated with interior sulfates is an important problem of concrete manufacture in Iraq. It is difficult to obtain well graded fine aggregate with sulfates content within standard specifications. The main objective of this study is to investigate the effect of internal sulfates in sand on some properties of self compacting concrete (SCC) by adding natural gypsum to fine aggregate as a partial replacement by weight. In this work, two basic categories of self-compacting concrete are used: (SCC) incorporating limestone powder (LSP) and SCC incorporating 10% high reactivity metakaolin (HRM) Class N plus limestone powder(LSP) .Four levels of sulfates contents in fine aggregate were investigated, these levels were (0.37, 0.5, 1.0, and 1.5)% which it is equal to(3.74, 3.99, 4.96 and 5.93)% by weight of cement for mixes contained limestone powder (LSP) and it is equal to (3.76, 4.01,4.98 and 5.96) % by weight of cement for mixes contains high reactivity metakaolin (HRM) Class N plus limestone powder(LSP). The experimental program is divided into two parts; the first part is devoted to produce self compacting concrete by using superplasticizers and fillers then determine the workability. Different test methods are adopted such as slump flow and T50 cm, V-funnel, V-Funnel at T5 minutes, L-box and sieve segregation test. The second part is devoted to study the mechanical properties such as the compressive strength and splitting tensile strength. The results obtained from this work show that the optimum gypsum content was 0.5% by weight of fine aggregate for all mixes which gives increases in the compressive strength by a range(5.9 -10.1)% and in the splitting tensile strength by a range (1.2 – 8.5)% for mixes of (SSC) with (LSP) and (LSP +HRM).

Keywords: SCC, limestone powder (LSP), high reactivity metakaolin(HRM), sulfates contents%, compressive strength , splitting tensile strength , L-box , V-funnel, slump flow test, sieve segregation test.

الخلاصة

إن وجود أملاح الكبريتات الداخلية هي من المشاكل المهمة التي تواجه صناعة الخرسانة في العراق. فمن ألصعوبة أيجاد ركام ناعم مطابق للمواصفات مع حدود المواصفات الحالية لحدود أملاح الكبريتات . ألهدف من هذا العمل هو دراسة تأثير أملاح الكبريتات في الركام الناعم على بعض الخواص الميكانيكية للخرسانة ذاتية الرص بإضافة الجبس الطبيعي إلى الركام الناعم كإحلال جزئي من وزنه. في هذا البحث تم استعمال نوعين أساسين من الخرسانة ذاتية الرص وهي : خرسانة ذاتية الرص حاوية على مسحوق الحجر الجيري و خرسانة ذاتية الرص حاوية على 10% ميتاكاؤلين عالي الفعالية و مسحوق الحجر الجيري تم دراسة أربع نسب لمحتوى الكبريتات .%(0.37, 0.5, 1.0, and 1.5) في الركام الناعم والذي يساوي (3.74,3.99,4.96,5.93)% من وزن الإسمنت للخلطات التي تحوي على الحجر الجيري كمادة مالئة ومساوي إلى(3.76, 4.01 ,4.98 and 5.96) % من وزن السمنت للخلطات التي تحوي 10% ميتاكاؤلين عالي الفعالية و مسحوق الحجر الجيري . برنامج

ألعمل يقسم إلى جزأين ; ألجزء الأول هو أنتاج خرسانة ذاتية الرص باستعمال الملدنات و المادة المالئة ثم أيجاد قابلية التشغيل . تم استخدام طرق فحص مختلفة مثل فحص جريان الهطول, القمع على شكل حرف V, القمع على شكل حرفV بعد مرور 5 دقائق , الصندوق على شكل حرف L فحص مقاومة الانعزال. ألجزء الثاني هو دراسةالخواص الميكانيكية مثل مقاومة الانضغاط و مقاومة شد الانشطار. أظهرت النتائج إن محتوى الجبس الأمثل في الخرسانة ذاتية الرص عند نسبة 0.5 % من وزن ألركام الناعم لكل الخلطات والتي تعطي زيادة في مقاومة الانضغاط تراوحت بين (5.9-10.1)% و(1.2- 8.5)% في مقاومة شد الانشطار. الزيادة الإضافية في محتوى الكبريتات بعد ألنسبة المثلى يسبب تناقص في المقاومة تتراوح بين (1.4 – 7.8)% في مقاومة الانضغاط و (2.1- 3.3)% في مقاومة شد الانشطار عندما تزداد نسبة الكبريتات في الركام الناعم من (0.37 – 1)% و (6.4- 9.9)% في مقاومة الانضغاط و (3.8-5.6) % في مقاومة شد الانشطار عندما تزداد نسبة الكبريتات في الركام الناعم من (0.37 – 1.5) % على التوالي.

INTRODUCTION

Self–compacting concrete (SCC) represents one of the most outstanding advances in concrete technology during the last decade. At first developed in Japan in the last 1980s, SCC meanwhile is spread all over the world with a steadily increasing number of applications **[Holschemacher, 2002]**.

Self compacting concrete (SCC) was developed to respond to the need for concrete that can improve durability while eliminating the need for compaction and vibration work. SCC can compact itself into complicated formwork and congested structural elements under its own weight without the need for mechanical vibration. It needs to be both highly deformable and resistant to segregation and bleeding **[Okamura, H. & Ouchi, 1999]**.

Due to the highly flowable nature of self – compacting concrete, care is required to ensure excellent filling ability, passing ability and adequate stability **[Sonebi, Grünewald , and Walraven , 2007]** this ability is achieved by ensuring suitable rheological properties of fresh concrete: a low yield stress value associated with adequate plastic viscosity.

Fresh concrete can easily attain high flowability by simply increasing the water-to-binder (w/b) ratio. However, increasing the w/b ratio alone could lead to concrete segregation and less durability. Thus, in order to successfully develop SCC, mineral and chemical admixtures, e.g., pozzolans, limestone powder, superplasticizer, and viscosity-modifying admixture (VMA), need to be added to the mix to prevent segregation and enhance the workability of SCC **[Suksawang, Nassif, Najm, 2006]**.

Sulfates cause concrete or mortar deterioration when it exists in excessive amount. This phenomenon is called sulfate attack. The sulfate reacting with $Ca(OH)_2$ and with calcium aluminate hydrate (C-A-H). The products of reactions, gypsum and calcium sulphoaluminate have a considerably greater volume than the compounds they replace, so that the reactions with the sulfates lead to expansion and disruption of the concrete. Sulfate in fine aggregate is a major problem encountered in the Middle and Southern part of Iraq. Most of the sulfate salts in fine aggregate are composed of calcium, magnesium, potassium and sodium sulfates. Calcium sulfate is the most predominant salt present in Iraqi fine aggregate. It is usually found in fine aggregate as gypsum. About 95% of sulfates in fine aggregate are in the form of calcium sulfates because of the low solubility of this type of sulfate **[Al-Samerai ,1977]**.

Sulfates may come either from raw materials and or from gypsum added to cement at grinding stage. **[Al-Qaisi, W.A.,-1989]** Stated that the activity of gypsum is dependent on its fineness. In their study on the effective sulfate content in concrete ingredients **[Al-Rawi, Ali, Shallal, and Al-Salihi,1997]**,pointed out that the effect of SO_3 existing in cement on compressive strength of concrete is about two times more that in fine aggregate and effect of the latter is about two times more that in coarse aggregate. They attributed this to the fine particle size distribution of cement compared with fine aggregate and coarse aggregate. In a later study by **[Al-Rawi, 2000]**, to develop the concept of effective sulfate content, he found that the effectiveness of sulfates increased with increased fineness of fine aggregate. He suggested a formula to account for the effectiveness of sulfates in fine aggregate depending on its fineness modulus. He showed also that the same formula is applicable. The sulfate content in fine aggregate contains sulfate higher than the acceptable limits in most of the fine aggregate in Middle East countries **[Al-Kadhimi and Hamid, 1983]**.

[Al- Rawi ,1997], investigated the effect of the gypsum content of cement on several engineering properties of concrete cured by accelerated and normal methods. He stated that increased gypsum content results in a significant decrease in the slump of concrete and that there is an optimum gypsum content, considerably higher for accelerated cured concrete than for normally cured concrete, at which maximum strength is obtained. The optimum gypsum content under accelerate curing conditions may be used without risk of reduction in the durability of concrete caused by excessive, delayed expansion.

[Al- Rawi and Abdul - Latif ,1998], suggested a new test called "Compatibility test" to investigate the possibility of using sands with relatively high (SO_3) contents with suitable cement without deleterious effect on concrete. The work was carried out on seven cements, three ordinary Portland cement, three sulfate resisting cements and white cement. The sand used had SO_3 contents between 0.18% and 1.5% and the mix is designed to give a compressive strength of 30 MPa at 28 days. The results show that the SO_3 content in sand gives the maximum concrete strength which differs from one cement to the other ranging from (0.18% to 1.5%) depending on the chemical composition and fineness of cement.

[Alwash, 2005] , the percentage reduction in compressive strength of the mix with OPC and sand of zone 2 which contains sulfate of 1.5% by weight of it compared with the reduction in strength of the mix with OPC and sand of zone 4 which contains sulfate of 1.5% by weight of it at ages 7, 28 and 56 days was (30.86%-37.7%), (10.47%-17.9%) and (2.29%-8.16%) for air curing and (23.6%-28.4%), (7.7%-13.4%) and (5.8%-5.5%) for moist curing and the influence of sulfates on the splitting tensile strength and static modulus of elasticity is found to be somewhat similar to that of compressive strength.

[Hussain, 2008], investigated the effect of internal sulfates in fine aggregate on some mechanical properties of self compacting concrete with different types of filler such as limestone powder, pigment and hydrated lime. The investigated mechanical properties were compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, the ultrasonic pulse velocity and schmidt rebound hammer tests. The author founded that there is an optimum gypsum content at which the strength is maximum .Further increase in SO_3 content beyond the optimum causes a decrease in strength and non destructive tests.

High reactivity metakaolin is a supplementary cementitious material (SCM) that conforms to ASTM C 618 – 05, 2005 **[ASTM C 618-05]** *Class* N pozzolana specifications. High reactivity metakaolin is unique in that it is not the by – product of an industrial process nor it is entirely natural; it is derived from a naturally occurring mineral and it is manufactured specifically for cementing applications **[Caldarone, M.A., Gruber, K.A. and Burg, R.G.,-1994]**. Unlike by – product pozzolans which can have variable composition, high reactivity metakaolin is produced under carefully controlled conditions to refine its color, remove inert impurities and control particle size distribution **[Brooks and Johari, 2001]**.

[Wild, Khatib and Jones, 1996] Reported that the strength of high reactivity metakaolin – superplasticizer mixes were greater than the strength of superplasticizer mixes at all ages. They tested concretes ranging from 1 to 90 days in age, produced at a w/cm of 0.45. They found that 20% replacement with HRM was optimal for achieving maximum long – term strength enhancement.

1. EXPERIMENTAL WORK

The purpose behind this study is to find out the effect of internal sulfates in sand on some properties of self compacting concrete (SCC) by adding natural gypsum to fine aggregate as a partial replacement by weight of fine aggregate. Two basic of self-compacting concrete mixes are used: (SCC) incorporating (LSP) and SCC incorporating (10% (HRM) Class N+ (LSP)) and curing time for (28, 56 and 90 days) were conducted. Four levels of SO_3 contents in fine aggregate were investigated; these levels were 0.37%, 0.5%, 1.0% and 1.5% by wt. of fine aggregate. The tests were conducted in order to view the differences in behavior during the fresh state as well as the hardened state. The slump flow, L-box, V funnels and sieve segregation test were performed on concrete in the fresh state. The concrete specimens were tested at ages (28, 56 and 90 days) for compressive strength and splitting tensile strength. The details of each concrete mix were summarized in (**Table 1)**.

2. MATERIALS

2.1 Cement

The used cement was ordinary Portland cement named as Tasluja Bazian. The cement was tested and checked according to **(**IQS No.5 /1984). The chemical and physical tests were conducted in Construction Materials Laboratory of Babylon University.

2.2 Fine Aggregate (Sand)

Al-Akhaider natural fine aggregate with fineness modulus (2.64) was used throughout this work. . Results indicate that the fine aggregate grading, physical properties and the sulfate contents are within the requirements of the Iraqi specifications (IQS No.45 /1984).

2.3 Coarse Aggregate (Gravel)

Rounded coarse aggregate of passing sieve size 10 mm from AL- Nibaee quarry is used. The coarse aggregate was washed, and then stored in air to dry. The grading of this aggregate which conforms to the Iraqi Specification (IQS No.45/1984). The specific gravity and sulfate content and absorption of coarse aggregate are within the requirements of the Iraqi specifications (IQS No.45 /1984).

2.4 Water

Tap water is used throughout this work for both mixing and curing of concrete.

2.5 Superplasticizer

Superplasticizer (SP) is an essential component for SCC production. It is used to achieve high workability and stability for (SCC). According to (ASTM C494), this SP is classified as type Glenuim 51.

2.6 Limestone Powder (Lsp)

Limestone powder is a white ground material from limestone that found in different regions in Iraq, and usually used in the construction processes. Limestone powder which has been brought from local market is used to increase the amount of powder (cement + filler), the fraction less than 0.125mm will be of most benefit. This filler conforms to (BS 7979). The chemical analysis of LSP is listed in (**Table 2)**.

2.7 Gypsum

Gypsum is added to the fine aggregate to obtain the required SO_3 content. The added gypsum is natural gypsum rock (brought from Kufa cement factory). It was crushed and ground to obtain nearly the same gradation set of fine aggregate used in the mix. This gypsum was used as a partial replacement by weight of fine aggregate with limited percentages. The quantity of natural gypsum was calculated and added to the fine aggregate according to the following equation **[Al-Kadhimi, T. K. and Hamid, F. A.,- 1983]**:

$$W=(R - M)\,S / N \qquad (1)$$

Where:

W= the weight of natural gypsum needed to be added to fine aggregate.
R= the percentage of SO_3 % desired in fine aggregate.
S = the weight of fine aggregate in mix.
M = the actual SO_3 in fine aggregate (0.37 %).
N= the percentage of SO_3 % in the used natural gypsum.

2.8 High Reactivity Metakaolin (Hrm)

High reactivity metakaolin is one of the recently developed supplementary cementing materials. It is produced by calcining purified kaolin clay at a specific temperature range to drive off the chemically bound water and destroy the crystalline. The used (HRM) was prepared by burning the kaolin clay at 700°C for whole one hour then left to cool down. The Chemical and physical properties of (HRM) are listed in (**Table 3)**.

3. MIXING PROCEDURE

The required amount of gypsum was added to the fine aggregate, in order to obtain the desired level of SO_3 in the sample then fine aggregate and gypsum were mixed until a homogeneous mix is obtained. High reactivity metakaolin powder was mixed with the quantity of cement with the aid of trowels, until the HRM particles were thoroughly dispersed between cement particles. Mixing procedure is important to obtain the required workability and homogeneity of the concrete mix. Concrete was mixed in drum laboratory mixer, with a capacity of $0.05m^3$. Before starting to mix, it is necessary to keep the mixer clean, moist and free from previous mixes.
The procedure used for mixing the batches was as follows **[Emborg M., -2000]**:

1- Adding the fine aggregate to the mixer with 1/3water, and mixing for 1minute.
2- Adding the powder (cement + filler) with another 1/3 mixing water, and mixing for 1 minute.
3- After that, the coarse aggregate is added with the last 1/3mixing water and 1/3 of superplasticizer, and mixing for 1.5 minute then the mixture is left for 1.5 minute for rest.
4- Then, the remaining 2/3 of the superplasticizer is added and mixed for 1.5 minute. The SCC mix Proportions are summarized in (**Table 4).**

4. TEST METHODS FOR FRESH (SCC)

Fresh concrete tests are necessary in this study. SCC is defined by its behavior when it is in the fresh state, and it is determined whether concrete meets certain requirements, while flowability is an essential property in qualifying concrete as SCC or not. The slump flow, L-box, V-funnel, V-Funnel at T5 minutes and sieve segregation test are all used for all mixes of this study.

4.1 Slump Flow And T50cm Tests

The slump flow test is the most widely used method for evaluating concrete consistency and filling ability in the laboratory and at construction sites and can indicate segregation resistance of SCC to an experienced user. The flowing ability of fresh concrete is described by slump flow investigated with Abrams cone. (**Table 5)** shows the slump spread values and T500 for the produced mixes.

4.2 L-Box Test

The L-box test measures the passing ability of self-compacting concrete. Originally developed in Japan for underwater concrete. (**Table 5)** shows the value of BL (H2/H1) which represents the blocking ratio and the value of T400 represents the time of concrete to reach 400 mm flow.

4.3 V-Funnel Test And V-Funnel At T5 Minutes Tests

The V-funnel is used to measure the filling ability (flowability) of SCC and can also be used to evaluate the material segregation resistance. (**Table 5)** shows the results of V-funnel test. These results are within the limits pointed out in the literature, no blocking or segregation behavior was observed in all mixes.

4.4 Sieve Segregation Resistance Test

The sieve segregation test is used to assess the resistance of (SCC) to segregation. Table 5 shows the value of segregation resistance results test of (SCC) mixes.

5. TESTING OF HARDENED CONCRETE

5.1 Compressive Strength

The compressive strength test was accomplished according to (B.S.1881). This test was conducted on 150 mm cubes by using a hydraulic compression machine with a capacity of 2000 kN. The average of three cubes was adopted for each test.

5.2 Splitting Tensile Strength

The splitting tensile strength was determined according to the procedure outlined in (ASTMC-496). Cylindrical concrete specimens (100x200 mm) were used. Each splitting tensile strength value was the average of two specimens.

6. RESULTS AND DISCUSSION

6.1 Compressive Strength

The compressive strength test results of the concrete specimens were tested at ages (28, 56 and 90 days), three cubes are tested at each age for compressive strength determination of self compacting concrete with various percentages of gypsum content in fine aggregate are shown in (**Table 6)** and (**Figures 1 and 2)** .

It can be seen that for all mixes, there is an optimum SO_3 content at which the compressive strength is maximum, beyond which content the compressive strength has decreased. The present data indicates that the optimum SO3 content for these mixes is about (0.5) % (by weight of sand) and it is equal to 3.99 % by weight of cement for mixes which contain limestone powder filler and it is equal to 4.01% by weight of cement for mixes which contain limestone powder filler and Metakaolin.

From the results of compressive strength shown in Table 6, and Figures 1 and 2 it can be noticed that:

1. When SO_3 in fine aggregate increases from (0.37 to 0.5) %, this leads to an increase in compressive strength of the concrete cubes in the range (5.9, 7, and 8.7) % for DL1 at ages (28, 56 and 90) days respectively.
2. When SO_3 in fine aggregate increases from (0.37 to 1) %, this leads to a decrease in compressive strength of the concrete cubes in the range (5.4, 6.8 and 7.7) % for DL2 at ages (28, 56 and 90) days respectively.
3. When SO_3 in fine aggregate increases from (0.37 to 1.5) %, this leads to a decrease in compressive strength of the concrete cubes in the range (8.2, 8.8 and 9.9) % for DL3 at ages (28, 56 and 90) days respectively.

This was expected since several researchers as mention above had referred to the presence of optimum gypsum content. The increase in compressive strength of the concrete can be attributed to the ettringite formation which is produced by a chemical reaction between SO_3, C_3A and water. It fills some of the voids inside the cement past and increases the strength. But more ettringite formation induces internal stresses and decreases the compressive strength. But more ettringite formation induces internal stresses and decreases the compressive strength.

Also, results showed that the use of 10% high reactivity metakaolin (HRM) in self compacting concrete was the best compared with other mixes that contain limestone powder (LSP) by improving compressive strength for all sulfates contents and for all ages as shown below :-

1. When SO_3 in fine aggregate increases from (0.37 to 0.5) % this leads to an increase in compressive strength of the concrete cubes in the range (7.7, 8.6 and 10.1) % for DML1 at ages (28, 56 and 90) days respectively.
2. When SO_3 in fine aggregate increases from (0.37 to 1) %, this leads to a decrease in compressive strength of the concrete cubes in the range (1.4, 5.2 and 6.0) % for DML2 at ages (28, 56 and 90) days respectively.
3. When SO_3 in fine aggregate increases from (0.37 to 1.5) %, this leads to a decrease in compressive strength of the concrete cubes in the range (6.4, 7.4 and 8.2) % for DML3 at ages (28, 56 and 90) days respectively.

The results indicated that the (SCC) with(HRM+LSP) yielded the lowest compressive strength loss when compared (SCC) with (LSP), this can be attributed to the fact of the incorporation of (HRM) in SCC mix leads to minimized compressive strength loss compared to mixes without (HRM) This behaviour is due to the pozzolanic reaction of (HRM) which reacts with the calcium liberated during the hydration of cement and contributes to the densification of the concrete matrix resulting in a considerable increase in strength and reduction in permeability. Besides, the pore-size and grain size refinement process associated with pozzolanic reaction can effectively reduce the microcracking and strengthen the transition zone **[Neville, A.M., -1995]**.

6.2 Splitting Tensile Strength

Results of the (28, 56 and 90 days) splitting tensile strength of concrete SCC with various percentages of SO_3 content in sand are presented in (**Table 7)** and (**Figures 3 and 4)** for different mixes. It is clear that the effect of sulfates on the splitting tensile strength is somewhat similar to that on compressive strength. For all mixes, there is an optimum SO3% content at which the splitting tensile strength is maximum, beyond this content the splitting tensile strength has decreased.

From the results of splitting tensile strength shown in Figures 3 and 4 it can be it can be noticed that:

1. When SO_3 in fine aggregate increases from (0.37 to 0.5) %, this leads to an increase in splitting tensile strength of the concrete cylinders in the range (1.2., 4.5 and 6.4) % for ML1 at ages (28, 56 and 90) days respectively.

2. When SO_3 in fine aggregate increases from (0.37 to 1) %, this leads to a decrease in splitting tensile strength of the concrete cylinders in the range (3.3, 3 and 2.7) % for ML2 at ages (28, 56 and 90) days respectively.

3. When SO_3 in fine aggregate increases from (0.37 to 1.5) %, this leads to a decrease in splitting tensile strength of the concrete cylinders in the range (5.6, 5 and 4.8) % for ML3 at ages (28, 56 and 90) days respectively.

These results agree with that obtained by Alwash and Hussain.

In addition Also, results showed that the use of 10% high reactivity metakaolin (HRM) in self compacting concrete was the best compared with other mixes that contain limestone powder (LSP) by improving splitting tensile strength loss for all sulfates contents and for all ages as shown below :-

1. When SO_3 in fine aggregate increases from (0.37 to 0.5) % this leads to an increase in splitting tensile strength of the concrete cylinders in the range (4.7, 6.2, and 8.5) % for DML1 at ages (28, 56 and 90) days respectively.
2. When SO_3 in fine aggregate increases from (0.37 to 1) %, this leads to a decrease in splitting tensile strength of the concrete cylinders in the range (2.4, 2.6 and 2.1) % for DML2 at ages (28, 56 and 90) days respectively.

3. When SO_3 in fine aggregate increases from (0.37 to 1.5) % this leads to a increase in splitting tensile strength of the concrete cylinders in the range (4.5, 4.0 and 3.8) % for DML3 at ages (28, 56 and 90) days respectively.

7. CONCLUSIONS

Based on the experimental of the present work, the following conclusions can be Drawn:-

1. With a constant superplasticizer dosage and water content, (SCC) mixes with (LSP) had a better a filling ability, passing ability and segregation resistance than (SCC) mixes with (HRM+LSP) in the fresh state.
2. There as optimum gypsum content at which the both compressive strength and splitting tensile strength are maximum, beyond which content the compressive strength and splitting tensile strength decrease. The optimum gypsum content for these mixes is about (0.5% by weight of fine aggregate) and it is equal to (3.99% by weight of cement) for mixes containing (LSP), while it is equal to (4.01% by weight of cement) for mixes containing (HRM+LSP).
3. The (SCC) which contain 10% (HRM) as a partial replacement by weight of cement in mixes contain (HRM+LSP) was found to be effective in reducing compressive strength loss and splitting tensile strength loss due to interior sulfates contents in fine aggregate beyond optimum gypsum contact as compared with mixes contain (LSP).

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Table 1: Concrete mix designations

Mixes designation	Types of filler	Curing time (days)	SO_3 content in sand (by weight of sand) %	Total SO_3 content (by weight of cement) %
DL* 0 DL 1 DL 2 DL 3	Limestone Powder (LSP)	28, 56, 90	0.37 0.5 1.0 1.5	3.74 3.99 4.96 5.93
DLM *0 DLM 1 DLM 2 DLM 3	Limestone Powder plus High Reactivity Met kaolin (LSP+HRM)	28, 56, 90	0.37 0.5 1.0 1.5	3.76 4.01 4.98 5.96

DL*: Mixes of SCC with Limestone Powder Filler (LSP).
DLM* : Mixes of SCC with Limestone Powder Filler (LSP) plus 10% High Reactivity Metakaolin (HRM).

Table 2: Chemical analysis of the limestone powder (LSP)

Oxide	Content %	Oxide	Content %
SiO_2	1.34	MgO	0.13
Fe_2O_3	0.12	SO_3	1.90
Al_2O_3	0.69	CaO	55.13

Table 3: Chemical and physical properties of (HRM)

Oxides	Oxide content(%) Burning temperature 700 C°	Requirements of class N pozzolan ASTM C 618-05
SiO_2	65.84	≥ 70
Al_2O_3	19.44	
Fe_2O_3	0.2	
Na_2O	0.15	
K_2O	0.22	
CaO	5.92	
MgO	0.88	
SO_3	0.23	≤ 4
L.O.I	4.43	≤ 10
Physical Properties		
Fineness (Blaine method m^2/kg)	700	
Specific gravity	2.5	

Materials	Content	Limitation (Kg/m^3)

Table 4 : Mix proportions

Cement (kg/m^3)	400	350-450
Fine aggregate (kg/m^3)	775	710-900
Coarse aggregate (kg/m^3)	820	750-920
Filler (kg/m^3)	100	50-150
(Water / powder) ratio	0.42	0.33-0.62
SP (Liter/100kg cement)	3	-

Table 5: Results of Fresh Properties of SSC of all Mixes

Test	Units	Mix Notation		Typical range of Values
		DL	DLM	
Slump-flow	mm	740	680	600-800
T 50cm	sec	3	3.5	2-5
V-funnel	sec	6	7	6-12
V-funnel at $T_{5\ min.}$	sec.	7	9	+3 sec , max.
L-Box	(H2/H1)	1	0.9	0.8-1.0
SR	%	3	2	≤ 15%

Table 6: Effect of sulfate content in fine aggregate on compressive strength of SCC

Mix Notation	SO_3 content % by weight of fine aggregate	Total SO_3 content % by weight of cement	Compressive strength (MPa) for Ages		
			28 (days)	56 (days)	90 (days)
DL0	0.37	3.74	35.3	39.7	42.4
DL1	0.5	3.99	37.4	42.5	46.1
DL2	1.0	4.96	33.4	37	39.1
DL3	1.5	5.93	32.4	36.2	38.2
DLM0	0.37	3.76	44.0	50.1	54.5
DLM1	0.5	4.01	47.4	54.3	60.0
DLM2	1.0	4.98	43.4	47.5	51.2
DLM3	1.5	5.96	41.2	46.4	50.0

Table7: Effect of sulfate content in fine agg. on splitting tensile strength of SCC

Mix Notation	SO_3 content % by weight of fine aggregate	Total SO_3 content % by weight of cement	Splitting tensile strength (MPa) for Ages		
			28 (days)	56 (days)	90 (days)
DL0	0.37	3.74	3.36	3.58	3.76
DL1	0.5	3.99	3.40	3.74	4.0
DL2	1.0	4.96	3.25	3.47	3.66
DL3	1.5	5.93	3.17	3.4	3.58
DLM0	0.37	3.76	4.21	4.52	4.70
DLM1	0.5	4.01	4.41	4.80	5.1
DLM2	1.0	4.98	4.11	4.4	4.6
DLM3	1.5	5.96	4.02	4.34	4.52

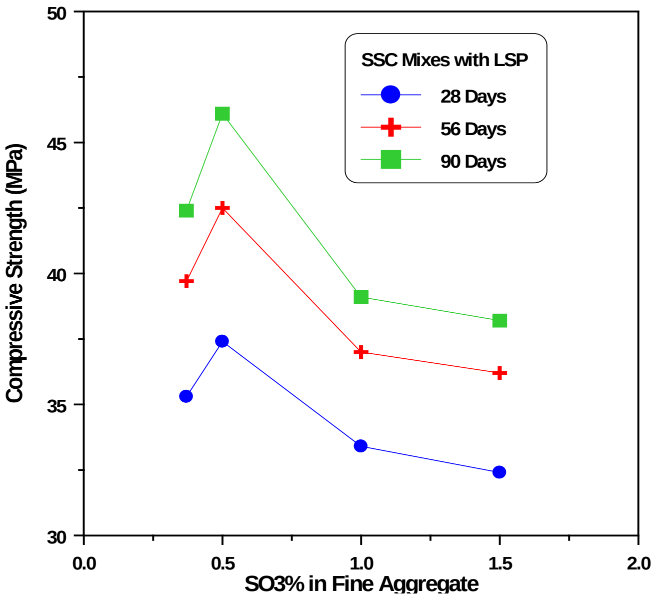

Figure 1: Relationship between Compressive Strength and SO_3 content in fine aggregate at different age with limestone powder filler.

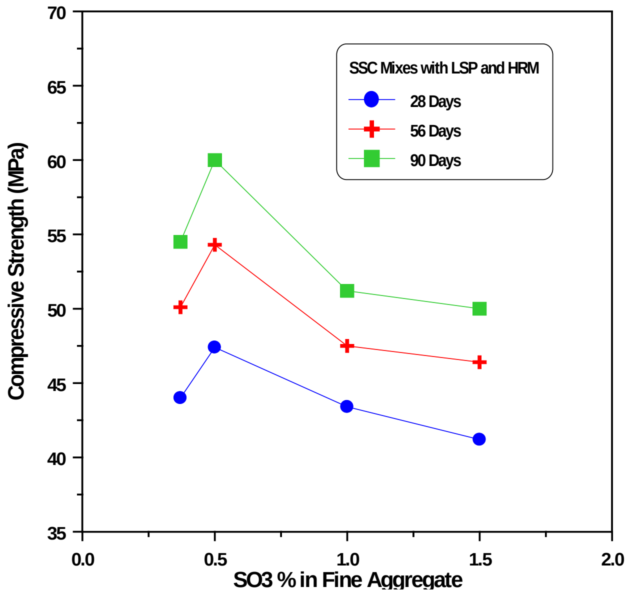

Figure 2 : Relationship between Compressive Strength and SO_3 content in fine aggregate at different age with limestone powder filler and Metakaolin.

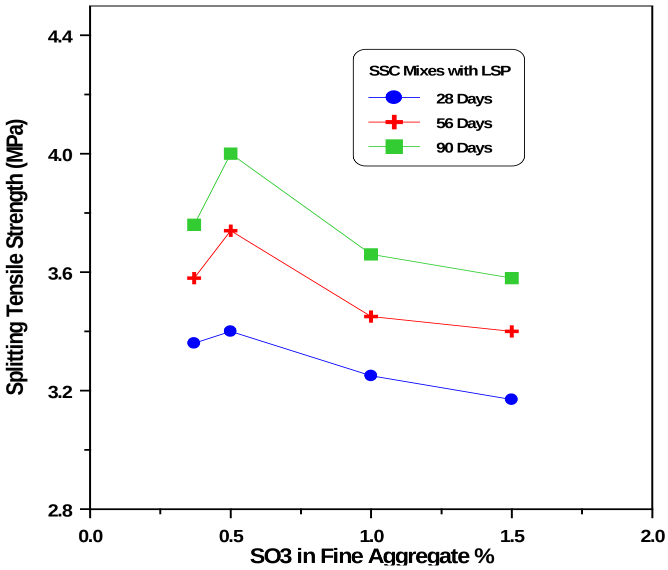

Figure 3: Relationship between splitting tensile strength and SO_3 content in fine aggregate at different age with limestone powder filler.

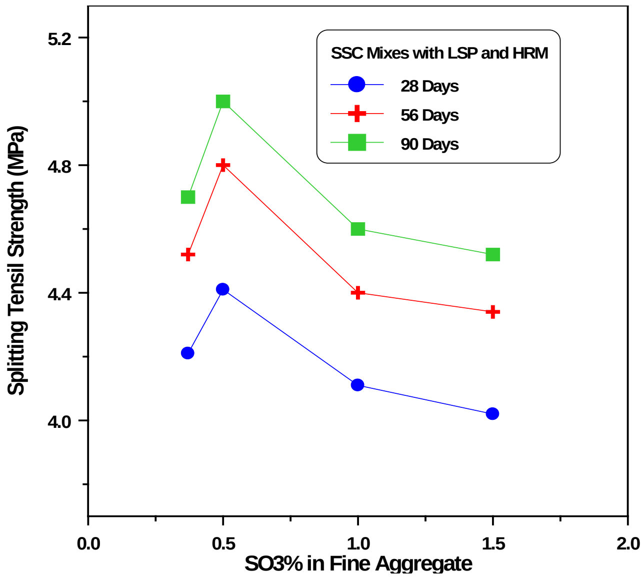

Figure 4 : Relationship between splitting tensile strength and SO_3 content in fine aggregate at different age with limestone powder filler and Metakaolin.