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Effect of aggregates with high gypsum content on the performance of concrete

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ABSTRACT

Sulfates in fine aggregate are a major problem when it exists in excessive amount especially in the Middle East and Iraq. Most of sulfate salts in fine aggregate are composed of calcium, magnesium, potassium and sodium sulfates. Calcium sulfates is the most common salt present in fine aggregate. It is usually finding as gypsum. It is difficult to obtain the specific sulfates content in fine aggregate within standard specifications. This research was conducted to investigate the effect of adding different contents of gypsum to fine aggregate as a replacement by weight on some properties of two types of concrete {self-compacted concrete (SCC) and high strength concrete (HSC)}. In these work three bases mixes of each type of concrete are used: mixes with different contents of metakaolin, mixes with different contents of gypsum and mixes incorporating different contents of metakaolin and gypsum. This study is devoted to determine the allowable content of sulfates in fine aggregate. Three levels of gypsum were tested (0.5, 1, 1.5) % by weight of fine aggregate and three levels of metakaolin were tested (5, 10, 15) % by the weight of cement. The experimental program is devoted to produce concrete with different levels of metakaolin and gypsum and determine its mechanical properties such as compressive strength and splitting tensile strength. The results arrived from this work show that the optimum gypsum content was 1.5% by weight of fine aggregates for mixes of SCC which gives increases in compressive strength and tensile strength, and 1% gypsum for mixes of HSC, results showed also that the metakaolin improved the properties of the two types of concrete and increased the loss which caused by sulfates. The best mix ever in SCC is 1% gypsum with 5% metakaolin, and 1% gypsum with 10% metakaolin for HSC.

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1. Introduction

Aggregates in Middle East contain high amounts of sulfates which considered a big problem. Most of sulfates in sand took the form of gypsum, which represents 95% of sulfates and the rest are sodium, magnesium, and potassium sulfates (National Center for Construction Laboratories of Iraq, 1981). Some international standers specify limits of SO_3 content in aggregates. For example, IQS 45 (Iraqi standard specification for aggregate, 1984) allows 0.5% and 1% of SO_3 in fine aggregates and coarse aggregates, respectively. In the complimentary British Standard to BS EN 206-1, it is reported that the maximum allowable SO_3 content in fine aggregate is 1%. However, due to the rareness of aggregates with low sulfate contents in Middle East, a lot of studies have been conducted to investigate the optimum content of sulfate in fine aggregates which improves properties of concrete and use of aggregate with SO_3 above the specified limits given by the international standards (Haider K. Ammash, 2013) investigated that the optimum gypsum content was 0.5% by weight of fine aggregates for all mixes which increases compressive strength by a range (5.9-10.1)% and in splitting tensile strength by a range (1.2-8.5)% for all mixes of self-compacting concrete with lime stone powder.

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Al-Rawi, R.S and Abdul–Latif (1993) suggested a new test called "compatibility test" to investigate the possibility of using sands with relativity high SO_3 contents with suitable cement without deleterious effect on concrete. This work was carried out on seven cements, three ordinary cement, three sulfate resisting cement 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 30MPA at 28 days. The results show that SO_3 contents in sand gives the maximum concrete strength which differs from one cement to other ranging from (0.18% to 1.5%) depending on the chemical composition and fitness of cement. Gesoglu et al. (2016) reported that the effect of gypsum did not have a significant effect on the compressive and splitting tensile strength of UHSC: however, there was a slight reduction in strengths at a largest gypsum content of 11.55%. 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.

Alwash (2005) found the percentage 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 the reduction 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. The influence of sulfates on elastic modulus and indirect tensile strength was found to be somewhat likely to that influence on compressive strength.

Hussain (2008) investigated some mechanical properties of self-compacting concrete and effect of internal sulfates in fine aggregate on it with several filler types of such as powder of limestone, pigment and hydrated lime. The mechanical properties were flexural strength, modulus of elasticity, compressive strength, the ultrasonic pulse velocity, indirect tensile strength and schmidtrebound hammer tests. He found the optimum gypsum content at which the strength is maximum. Further increase in SO3 content beyond the optimum causes a decrease in strength and nondestructive tests. Dinakar (2012) This study presents the effect of incorporation metakaolin (MK) on the mechanical and durability properties of high strength concrete for a constant water/blinder ratio of 0.3. Four different mixtures (MK0, MK5, MK10, MK15) were employed to examine the influence of low water to binder ratio on concrete containing MK on the mechanical and durability properties. The control mixture (MK0) did not include MK. In mixtures (MK5 , MK10, and MK15) cement content was partially replaced with 5, 10, and 15% (MK) by mass, respectively . Trial mixture were conducted for target of strength and slump of 90 MPa and 100 25 mm. From the results, it was observed that 10% replacement level was the optimum level in terms of compressive strength. Beyond 10% replacement levels, the strength was decreased but remained higher than the control mixture. Compressive strength of 106 MPa was achieved at 10% replacement. Splitting tensile strength and elastic modulus value have also followed the same trend. In durability tests MK concretes have exhibited high resistance compared to control and the resistance increase as the MK percentage increases. This investigation reports that the local MK has the potential to produce high strength and high performance concrete.

The study of Alsallami (2016) aims to obtain the influence of adding Nano metakaolin on some mechanical properties of hardened concrete. She used three levels of SO_3 in sand .These levels were (0.27, 0.5 and 1% by weight of fine aggregate). One level of Nano metakaolin replacements (1% by weight of cement) were used in this work .The total of 6 NC mixtures were made, all based on the same control mixture. The mix proportions and w/c ratio kept constant for all mixes, the only variation in the mixture were the Nano metakaolin and SO_3 content in sand so as to investigate only the effect of sulfates on NC with various Nano metakaolin contents on its properties in hardened state and compared its behavior with the behavior of plain NC. The ratio of w/c was 0.5 to give slump 80 10%. Curing time was three ages (28, 60, 90) days. The experimental results show that there is an optimum gypsum content in sand (SO_3 = 0.5 % by weight of fine aggregates) which gives the highest results in compressive strength, splitting strength and modulus of elasticity of NC. As gypsum content increases beyond this limit, the above mechanical properties will be decreased.

2. Experimental Program

The research is devoted to enhancement of some properties of SCC and HSC with fine aggregate contains internal sulfates by a partial replacement of gypsum to fine aggregate by weight. This study is bifurcate of two types of concrete they are: first is effect of gypsum on performance of concrete and second is effect of incorporation of gypsum with metakaolin on performance of concrete. Three levels of gypsum content in fine aggregate were investigated; these levels were 0.5%, 1% and 1.5% by weight of sand. Three levels of metakaolin were investigated (5%, 10% and 15%) by weight of cement. In order to view the differences in behavior during the fresh state as well as the hardened state, some of tests were performed. The slump test, V-funnel and J-ring were performed on concrete in the fresh state. The tests for compressive strength, splitting tensile strength, flexural strength and modulus of elasticity were carried out on concrete specimens in the hardened state.

3. Materials

The materials used were obtained from local sources. These materials are described as follows:

Cement: Portland cement type I (CEMI42.5N), provided by the Suez Cement Co, meeting the requirement of E.S. 7417/2001, Table 1.

Fine aggregates: Natural siliceous sand from El-khatatba, Table 2.

Coarse aggregate: Dolomite size 10mm and 20mm.

Fly ash: Fly ashes complies with chemical and physical requirements of American specification (ASTM C618), Europe specification (EN450), Table 3.

Silica fume: Micro silica (silica fume) is by-product material resulting from industry of Ferro silicon alloys. The product is a rich silicon dioxide powder where the average particles size is around 0.1micrometers. Mechanical and physical properties are given in Table 4.

Gypsum: Gypsum is added to fine aggregate to obtain the required SO_3 content. The added gypsum is natural gypsum rock (brought from Sina factory). It was crushed and grounded to obtain nearly the same graduation of fine aggregate used in mix.

Metakaolin: Metakaolin is a pozzolanic material. It is obtained by calcination of kaolintic clay at a temperature between 500° C and 800° C, Table 5.

Super plasticizer: (1) Sikaviscocrete 3425 was used as viscosity enhancing agent (VEA). Its products to achieve the dual action effect of high-range water reducer and viscosity-modifying admixture, respectively. It meets the requirements for super plasticizers according to Swiss specification (SIA162(2989)), EUROPE specification (EN934-2), and American specification (ASTM-C-494) type G and F, Table 6. (2) Sikament 163M the second type of superplasticiser which used to provide the necessary workability for HSC. It complies with ASTM C494 type F, and B.S. 5057 part 3.

Water: Tap water without taste, smell, color, or turbidity was used for mixing and curing the cellular concrete product.

Table 1. Chemical component of OPC.

Constituents	Concentration in weight (%)
Silica as SiO_2	19.8
Alumina as AL_2O_3	5.6
Iron as Fe_2O_3	2.4
Potassium as K_2O	0.58
Calcium as Cao	65.9
Sodium as Na_2O	0.29
Sulphur as SO_3	2.8
Loss in ignition	1.2
Insoluble residue	0.4
Free lime	0.9
Lime saturation factor	100.4
Lime combination factor	98.9
Silica ratio	2.48
Alumina ratio	2.33
Tricalcium Silicate (C_3S)	65.1
Dicalcium Silicate (C_2S)	7.6
Tricalcium Aluminate (C_3A)	10.8
Tetracalcium Aluminate Ferrite (C_4AF)	7.3

Table 2. Sand gradation.

Sieve size (mm)	9.5	4.75	2.36	1.18	0.61	0.31	0.16
% passing	100	95-100	80-100	50-85	25-60	5-30	0-10
% passing used sand	100	100	94	80	50	15	0

Table 3. Typical chemical and physical properties of fly ash.

Physical properties	Value
Colour	Light gray
Specific gravity	2.2
Specific surface area	8m / gm
PH	1.2
Chemical analysis	Value
Silicon (SiO_2)	93.0
Aluminium (Al_2O_3)	34.0
Iron (Fe_2O_3)	3.5
Manganese (Mn_2O_3)	0.2
Calcium (CaO)	4.5
Magnesium (MgO)	1.5
Titanium (TiO_2)	0.6
Sulphur (SO_3)	0.3

Table 4. Typical chemical and physical properties of silica fume.

Typical chemical analysis		Physical properties		Particle size	
Silica SiO_2	53.5%	Relative density	2.2	Top cut, 90% passing	11 um
Aluminate AL_2O_3	34.3%	Theoretical surface area (cm^3/ gm)	13000	Top cut , 99% passing	25 um
Iron Fe_2O_3	3.6%	ph , in water	11-12		
Calcium CaO	4.4%	Moisture content	<0.2		
Potassium K_2O	0.8%	Color	Light grey		

Table 5. Typical chemical composition of metakaolin.

	Percentage of by mass
SiO_2	51.52
AL_2O_3	40.18
Fe_2O_3	1.23
CaO	2.0
MgO	0.12
K_2O	0.53
SO_3	0.0
TiO_2	2.27

Table 6. Typical properties of Viscocrete 3425.

Properties	Value
Appearance	Clear liquid
Density	1.08 kg/It (ASTM C494)
PH Value	4.0
Solid content	40% by weight
Chloride content	Zero

Table 7. Concrete mix design (high strength concrete 60 MPa).

Materials	Mixture proportion	Dry weight [Kg/m^3]
Standard type 10 Portland cement	1.00	500
Sand	0.86	430
Dolomite (10mm)	0.86	430
Dolomite (20mm)	1.718	859
Water	0.30	150[L/m^3]
Portland silica fume cement	0.15	75[Kg/m^3]

Table 8. Concrete mix design (self compacting concrete 40 MPa).

Materials	Content
Cement (Kg/m^3)	425
Fine aggregate (Kg/m^3)	686
Coarse aggregate (Kg/m^3)	838
Fly ash (Kg/m^3)	85
Water	148 [L/m^3]
Viscocrete	17 [L/m^3]

4. Preparation of Concrete Mixes

The required amount of gypsum was added to fine aggregate, in order to obtain the demand level of SO_3 in the sample then the fine aggregate and gypsum were mixed until a homogeneous mix is obtained. Metakaolin powder was mixed with the quantity of cement until the metakaolin particles were thoroughly dispersed between cement particles. Mixing procedure is important to obtain the required workability. Before starting to mix, it is necessary to keep the mixer clean, moist and free from previous mixes. The procedure used for mixing was as follows:

1- Adding the fine aggregate to the mixer with 1/3 water, and mixing for 1 minute.

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 1/3 mixing water and 1/3 of superplasticizer, and mixing for 1.5 minute then the mixture is left for 1.5 minute for rest. Then the remaining 2/3 of the superplasticizer is added and mixed for 1.5 minute.

The all experimental program as shown in Fig. 1.

4.1. Tests of fresh SCC

In this research, it is necessary to make fresh concrete tests. SCC is defined by its behavior when it is in fresh state. The slump flow, V-funnel, V-funnel at T5 and G-ring are all used for all mixes of SCC (Fatma El-Zhraa, 2007).

Slump flow test: The slump flow test is the most widely used method for evaluating concrete consistency and filling ability in the laboratory and at construction sites. The flowing ability of fresh concrete is described by slump flow investigated with a cone, Fig. 2.

V-Funnel and V-Funnel at T5 minutes tests: The V-funnel is used to measure the filling ability of SCC and can also be used to evaluate the material segregation resistance, Fig. 3.

J-Ring test: The J-ring test is used to assess the passing ability of self-compacting concrete to flow through tight opening including spaces between reinforcing bars, Fig. 4.

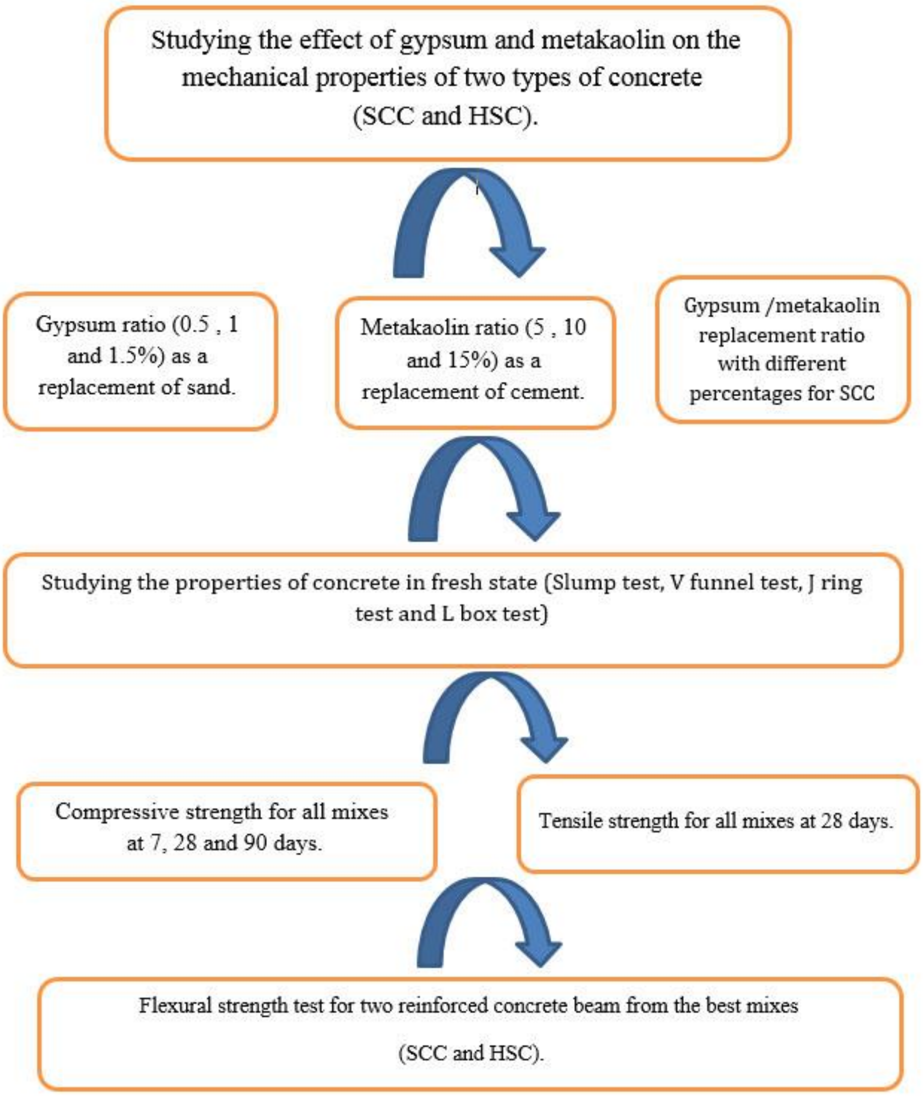

Fig. 1. Reinforcement details of all slabs.

Fig. 2. Slump test.

Fig. 3. J.Ring test.

Fig. 4. V-funnel test.

4.2. Tests of hardened concrete

Compressive strength: The compressive strength was conducted on cubes(15x15x15cm) at ages of (7, 28 and 90 days) by using a hydraulic compression machine with a capacity of 2000 KN. The average of three test cubes was adopted for each mix, Fig. 5.

Splitting tensile strength: This test was conducted on cylindrical concrete specimens (100x200 mm) after 28 days. Each splitting tensile strength value was the average of two specimens.

Fig. 5. Slump test.

5. Results and Discussion

5.1. SCC

5.1.1. Compressive strength

The compressive strength test results of concrete specimens were tested at ages (7, 28 and 90 days), three cubes are tested at each age. Compressive strength of SCC with various percentages of gypsum and metakaolin are shown in Table 9 and Fig. 10.

It can be seen that for all mixes, there as an optimum SO_3 content at which the compressive strength is maximum. The present data indicates that the optimum SO_3 content for these mixes is about (1.5%) by weight of sand Fig. 7.

From the results of compressive strength, it can be noticed that:

1- When gypsum content in fine aggregate increase to 0.5%, this leads to a decrease in compressive strength in the range (3.23 and 2.28)% at ages (7 and 28)days respectively and an increase at age of 90 days by 8.75%.

2- When gypsum content increase from (0.5 to 1)% , this leads to an increase in compressive strength in the range (2.27 and 0.88)% at ages (7 and 28) respectively and a slight reduction at age of 90 days by 0.94%.

3- When gypsum content in fine aggregate increases to 1.5% , this leads to an increase in compressive strength in the range (6.4, 17 and 7.8)% at ages (7,28 and 90) days respectively.

Also, results showed that the use of metakaolin(MK) improved the compressive strength of concrete for all sulfates content and for all ages as shown below (Fig. 8):

1- When MK added to cement by 10% without gypsum in fine aggregate, this leads to an increase in compressive strength in the range (4.5 , 12.8 and 14.7) at ages (7, 28 and 90) days respectively.

2- When MK added to cement by (5, 10 and 15)% for the mix of 0.5 % gypsum, the best level of MK was 15 % which leads to an increase in compressive strength in the range (2.8, 11.45 and 5.6) at ages (7, 28 and 90) days respectively.

3- When MK added to cement by (5, 10 and 15)% for the mix of 1% gypsum, the best level of MK was 5% which leads to an increase in compressive strength in the range (9.5, 13.2 and 21.6) at ages (7, 28 and 90) days respectively.

4- When MK added to cement by (5, 10 and 15)% for the mix of 1.5% gypsum, the best level of MK was 5% which leads to an increase in compressive strength in the range (0.6 and 5.8) at ages (28 and 90) days respectively.

The results indicated that the MK improved the properties the mixes of SCC and increase the compressive strength for the mixes with gypsum.

5.1.2. Splitting tensile strength

Results of splitting tensile strength at 28 days of SCC with various percentages of gypsum and MK are presented in Table 9. 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 SO_3 % which splitting tensile strength is maximum (Fig. 11). The present data indicates that the optimum SO_3 content for these mixes is about (1.5%) by weight of sand. From the results in Table 9, it can be noticed that:

1- When SO_3 in fine aggregate increase to 0.5% , this leads to decrease in splitting tensile strength of the concrete by (21.8)% at age of 28 days.

2- When SO_3 in fine aggregate increase to 1%, this leads to decrease in splitting tensile strength of concrete by (31.25)% at age of 28 days.

3- When SO_3 in fine aggregate increase to 1.5%, this leads to an increase in splitting tensile strength by (6.25)% at age of 28 days.

In addition also, results showed that the use of 5% MK in SCC was the best compared with the mixes that contain gypsum only by improving splitting tensile strength loss for all sulfates content as shown below (Fig. 8):

1- When MK added to cement by 5% to the mix of 0.5% gypsum, this leads to an increase in splitting tensile strength by 12% at age of 28 days.

2- When MK added to cement by 5% to the mix of 1% gypsum, this leads to an increase in splitting tensile strength by 18% at age of 28 days.

3- When MK added to cement by 5% to the mix of 1.5% gypsum, this leads to decrease in splitting tensile strength by 11.7% at age of 28 days.

Table 9. Results of mixes of SCC.

MIX	GYPSUM	MK	Compressive strength (kg/cm^2)			Tensile strength (kg/cm^2)
			7 days	28 days	90 days	28 days
C1	0%	0%	430	570	650	43
C2	0%	5%	453	588.9	704	54
C3	0%	10%	449.4	643.2	745.5	38.2
C4	0%	15%	452.3	543.6	653.2	36.6
C5	0.5%	0%	416.1	557	708.8	33.4
C6	1%	0%	439.2	575	643.9	28.6
C7	1.5%	0%	457.5	667	702	46.2
C8	0.5%	5%	422.4	562.7	643.4	47.8
C9	0.5%	10%	439.5	594.2	672.5	38.2
C10	0.5%	15%	442.1	635	686.4	31.8
C11	1%	5%	470.9	645.2	790.4	51
C12	1%	10%	458.5	610.4	732.5	44.6
C13	1%	15%	460.3	556.6	667.9	39.2
C14	1.5%	5%	473.3	573.4	687.7	38.2
C15	1.5%	10%	449.8	539.7	647.8	41.4
C16	1.5%	15%	4565	547.5	656.9	46.2

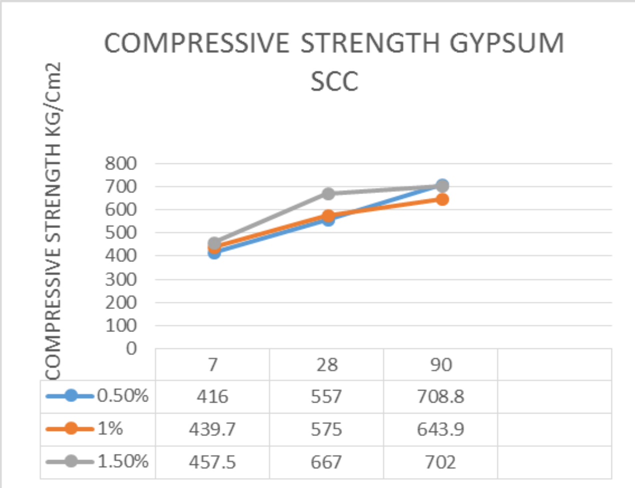

Fig. 6. Compressive strength for gypsum mixes of SCC.

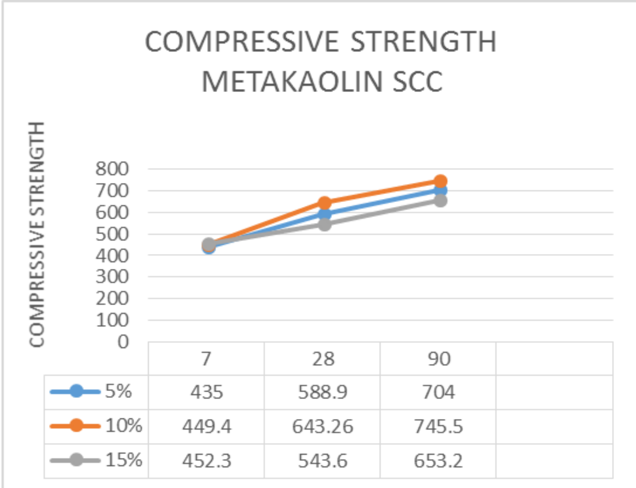

Fig. 7. Compressive strength for MK mixes of SCC.

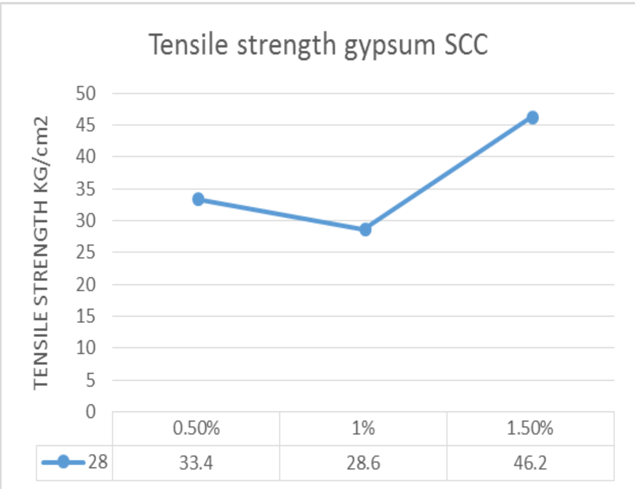

Fig. 8. Tensile strength for gypsum mixes of SCC.

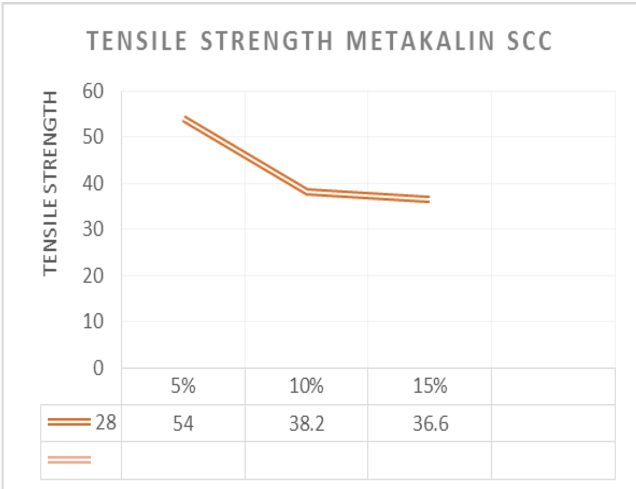

Fig. 9. Tensile strength for MK mixes of SCC.

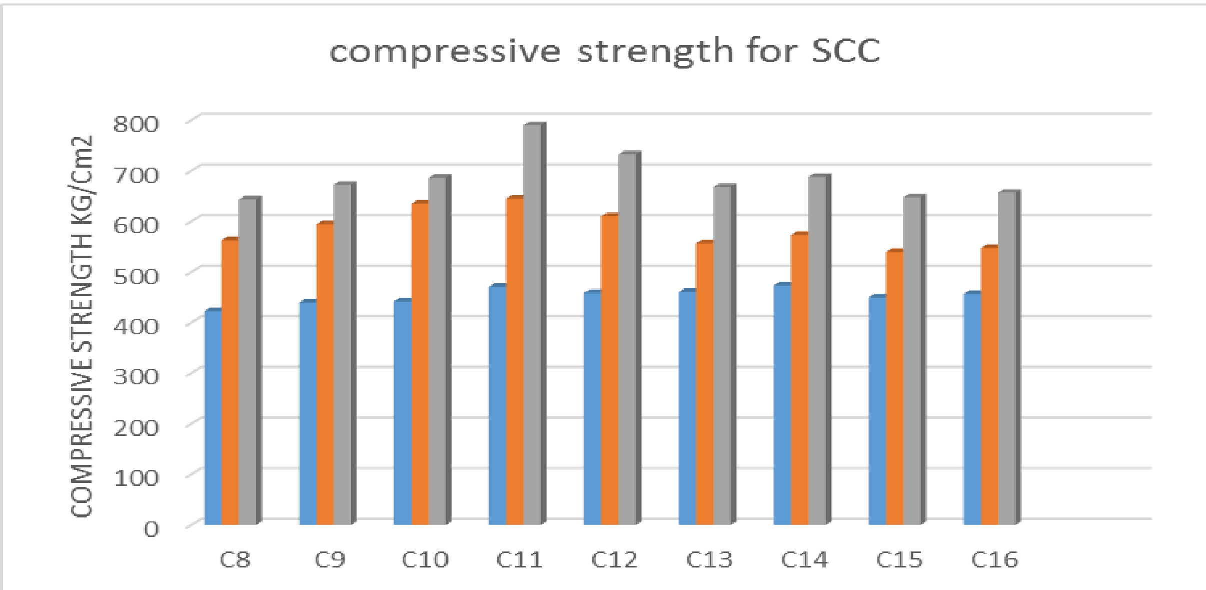

Fig. 10. Compressive strength for mixes of SCC.

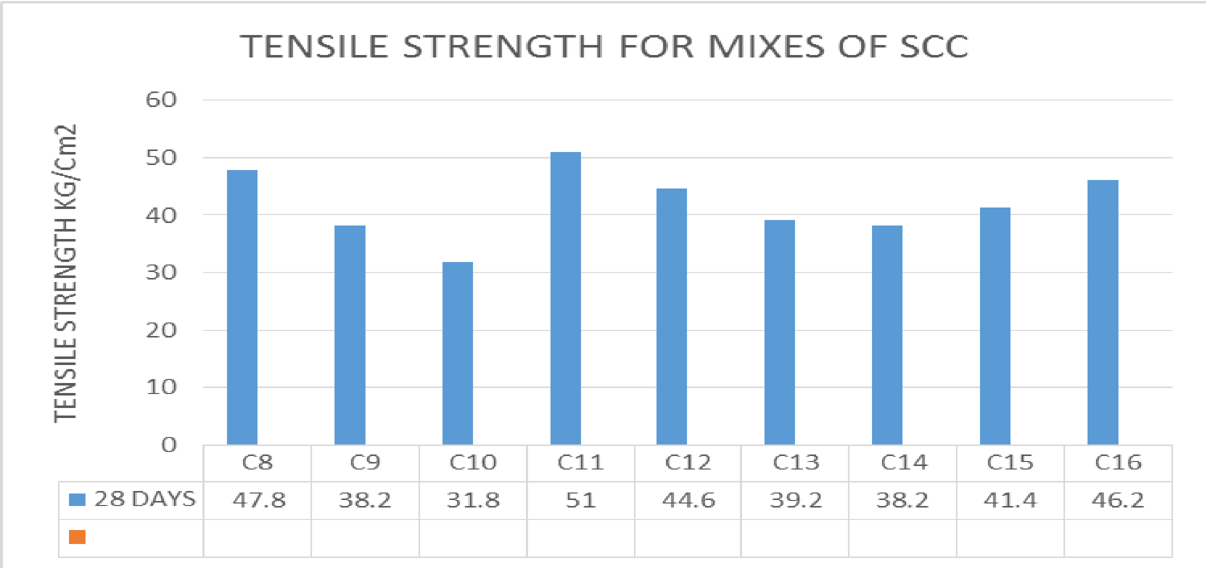

Fig. 11. Tensile strength for mixes of SCC.

5.2. HSC

5.2.1. Compressive strength

The compressive strength test results of the concrete specimens were tested at ages (7, 28 and 90 days), three cubes are tested at each age. Compressive strength of HSC with various percentages of gypsum and metakaolin are shown in **Table 10 and Fig. 16.**

It can be seen that for all mixes, there as an optimum SO_3 content at which the compressive strength is maximum. The present data indicates that the optimum SO_3 content for these mixes is about (1.5%) by weight of sand **(Fig.12).**

From the results of compressive strength, it can be noticed that:

When gypsum content in fine aggregate increase to 0.5%, this leads to a increase in compressive strength in the range (9.5, 11.48 and 14)% at ages (7 , 28 and 90) days respectively

2- When gypsum content increase from (0.5 to 1)% , this leads to an increase in compressive strength in the range (17.5 ,20.3 and 25.33)% at ages (7 , 28 and 90) days respectively.

3- When gypsum content in fine aggregate increases to 1.5%, this leads to an increase in compressive strength in the range (26.4, 30.7 and 36.4)% at ages (7,28 and 90) days respectively.

Also results of use metakaolin improved the compressive strength of concrete for all sulfates mixes as shown below **(Fig. 13):**

1- When MK added to cement by 10% without gypsum in fine aggregate, this leads to an increase in compressive strength in the range (10.5 , 21.3 and 25.4) at ages (7, 28 and 90) days respectively.

2- When MK added to cement by (5, 10 and 15)% for the mix of 0.5 % gypsum, the best level of MK was 10 % which leads to an increase in compressive strength in the range (14.6, 22.5 and 60) at ages (7, 28 and 90) days respectively.

3- When MK added to cement by (5, 10 and 15)% for the mix of 1% gypsum, the best level of MK was 5% which leads to an increase in compressive strength in the range (13.4, 28.4 and 55) at ages (7, 28 and 90) days respectively.

4- When MK added to cement by (5, 10 and 15)% for the mix of 1.5% gypsum, the best level of MK was 5% which leads to an increase in compressive strength in the range (6.8, 14.6 and 18.7) at ages (7, 28 and 90) days respectively. The results indicated that the MK improved the properties the mixes of HSC and increase the compressive strength for the mixes with gypsum.

5.2.2. Splitting tensile strength

Results of splitting tensile strength at 28 days of HSC with various percentages of gypsum and MK are presented in **Table10** and **Fig. 17**. It is clear that there is an optimum SO_3 % which splitting tensile strength maximum. The present data indicates that the optimum SO_3 content for these mixes is about (1%) by weight of sand. From the results in **Table 10** and F**ig. 14** it can be noticed that:

1- When SO_3 in fine aggregate increase to 0.5% , this haven't any changes in splitting tensile strength of the concrete at age of 28 days.

2- When SO_3 in fine aggregate increase to 1%, this leads to increase in splitting tensile strength of concrete by (38.8)% at age of 28 days.

3-When SO_3 in fine aggregate increase to 1.5%, this leads to an increase in splitting tensile strength by (33.3)% at age of 28 days.

Also, results showed that the use of 10% metakaolin (MK) improved the tensile strength of concrete for all mixes which contain MK only without gypsum **Fig. 15,** and the use of 10% MK in HSC was the best compared with the mixes that contain gypsum only by improving splitting tensile strength loss for all sulfates content as shown below:

1- When MK added to cement by 10% to the mix of 0.5% gypsum, this leads to an increase in splitting tensile strength by 55.5% at age of 28 days.

2- When MK added to cement by 10% to the mix of 1% gypsum, this leads to an increase in splitting tensile strength by 66.6% at age of 28 days.

3- When MK added to cement by % to the mix of 1.5% gypsum, this leads to increase in splitting tensile strength by 60.2 at the age of 28 days.

Table 10. Results of mixes of SCC.

MIX	GYPSUM	MK	Compressive strength (kg/cm²)			Tensile strength (kg/cm²)
			7 days	28 days	90 days	28 days
H1	0%	0	490.2	603.3	724.4	28.7
H2	0%	5%	544.4	653.3	790.5	35
H3	0%	10%	418.9	515.3	618.4	39.8
H4	0%	15%	576.1	720.2	864.3	33.4
H5	0.5%	0%	556.8	668.2	801.8	28.7
H6	1%	0%	570.2	724.8	871.5	39.8
H7	1.5%	0%	654.3	799.5	900.4	38.2
H8	0.5%	5%	558.7	670.4	905	42.9
H9	0.5%	10%	585.2	702.2	906	44.6
H10	0.5%	15%	551.1	661.4	793.6	35
H11	1%	5%	670.2	804.1	900	42
H12	1%	10%	622.9	747.5	897.1	47.8
H13	1%	15%	566.3	679.5	815.4	33.7
H14	1.5%	5%	601.6	751.98	903.4	42.6
H15	1.5%	10%	504.3	722.4	867.5	47
H16	1.5%	15%	570.6	684.7	823.4	35.7

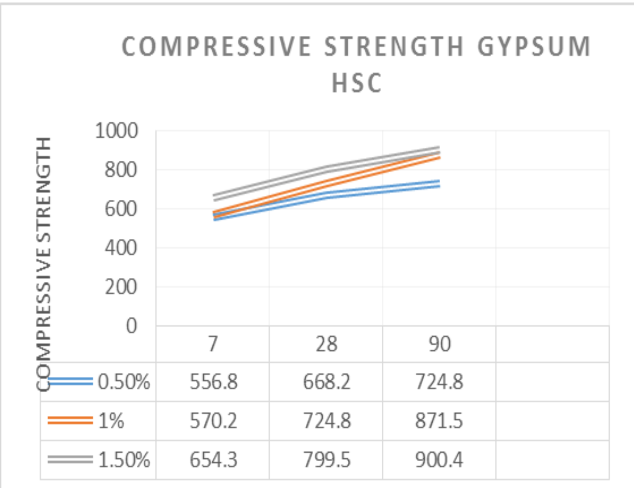

Fig. 12. Compressive strength of gypsum mixes for HSC.

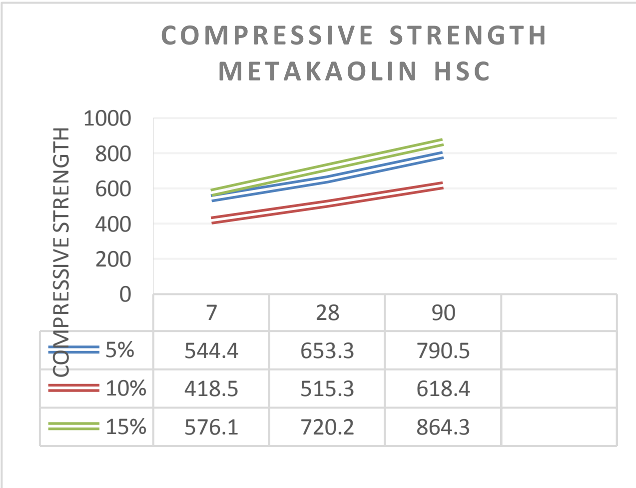

Fig. 13. Compressive strength of MK mixes for HSC.

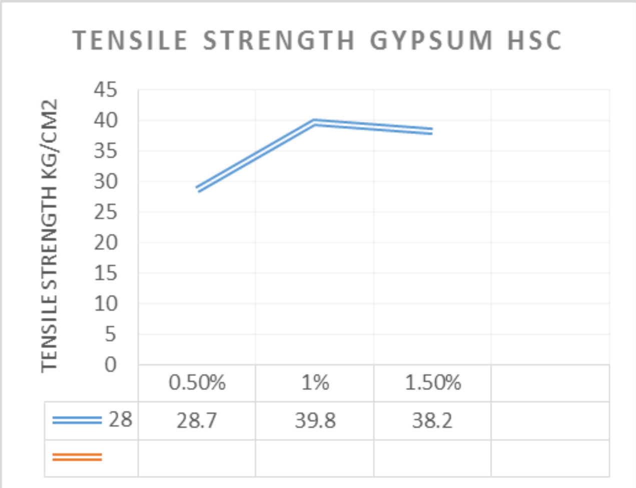

Fig. 14. Tensile strength of gypsum mixes of HSC.

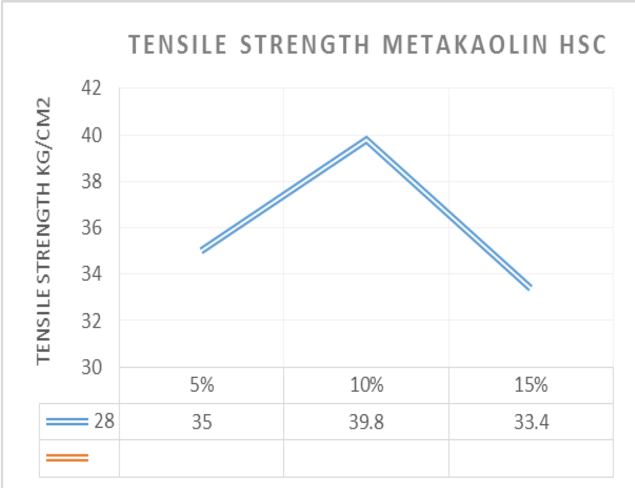

Fig. 15. Tensile strength of MK mixes of HSC.

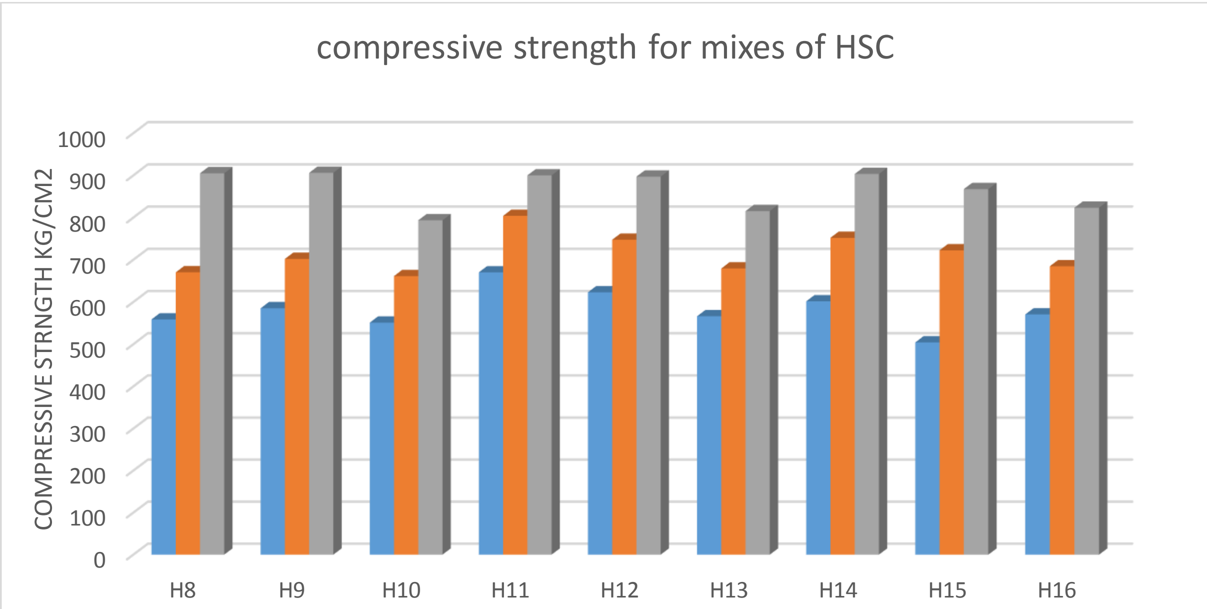

Fig. 16. Compressive strength for mixes of HSC.

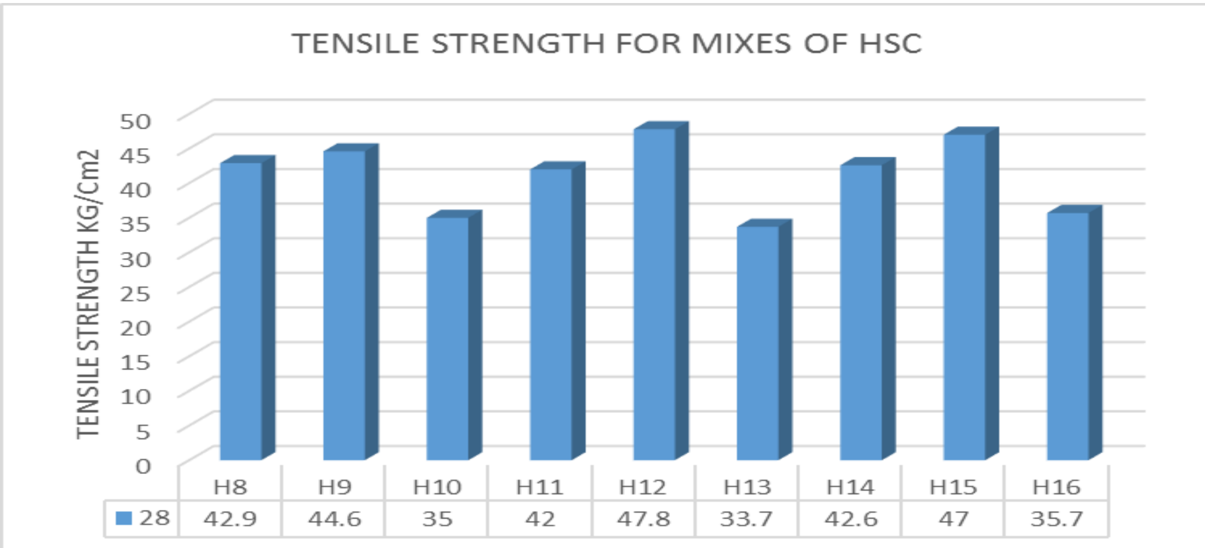

Fig. 17. Tensile strength for mixes of HSC.

5.3. Results of flexural test of beams

Two reinforced concrete beams were cast and tested (one cast with HSC using mix No.(H15) and another with SCC using mix No.(C16)) ,with cross section of 15*20 cm and a total length 100 cm, and tested under four lines loadings with span 90 cm until failure. The two beams reinforced with 2 Φ12mm at the bottom, and 2 Φ8mm at the top in and number of stirrups 5 Φ6mm/m.

The two beams were test after 28 days of curing; the beams were tested with using ELE calibrated flexural testing machine of capacity 100 KN. During testing process deflections and tensile and compressive strains were measured by using dial gauges and mechanical strain gages. Cracking patterns were detected with their loadings. And ultimate loads were recorded at each load increment; four readings were recorded for strain, and deflection .The test devices and arrangements shown in Fig. (21).

Results indicated that the beams of best mixes are a stiff beams which carried a maximum load of 65.20 KN (of SCC) mix and 79.40 KN of (HSC mix). Fig 19. It is interesting to note from Fig. 19 that the first crack loads of beam SCC and beam HSC were 30 and 40 KN respectively while the serviceability loads of beam SCC and beam HSC were reached 54 and 62KN respectively. The ductility ratio of beam SCC and beam HSC achieved 54, 62 KN respectively while the calculated energy absorption of beams SCC and HSC arrived 211.33 and 323,58 KN.mm respectively, therefore there is increase in first crack loads, serviceability loads, ductility ratio for HSC beams compared with those of SCC beams.

Fig. 18. ELE flexural 100KN testing machine.

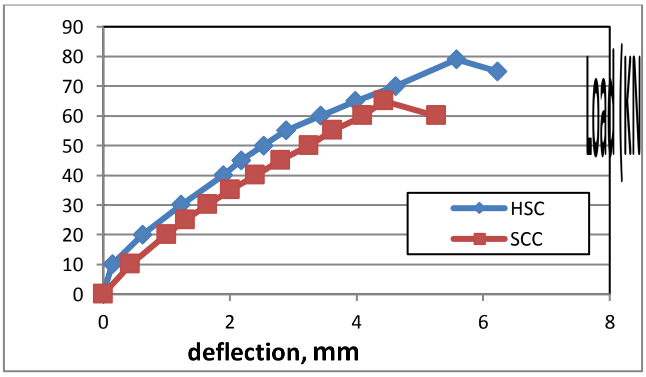

Fig. 19. load deflection curve for beams (HSC, and SCC).

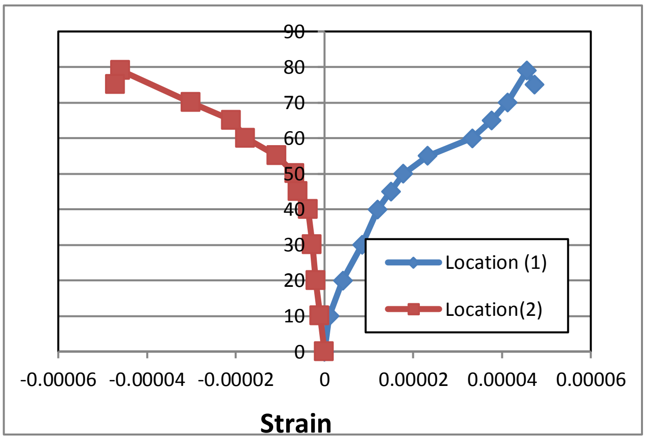

Fig. 20. Concrete strains curves for HSC beam.

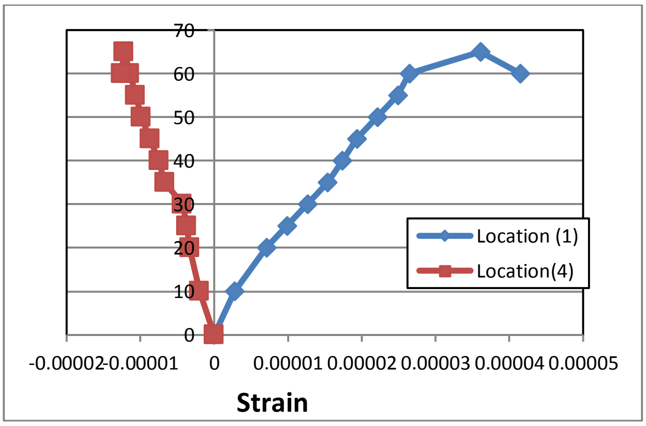

Fig. 21. Concrete strains curves for SCC beam.

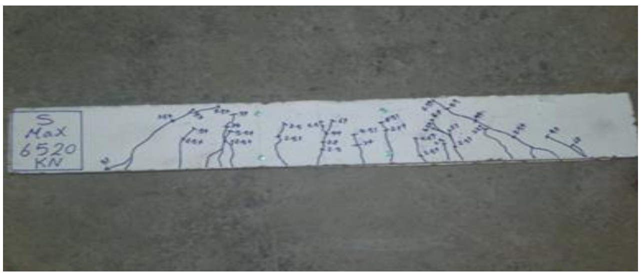

Fig. 22. Crack Pattern of beam SCC.

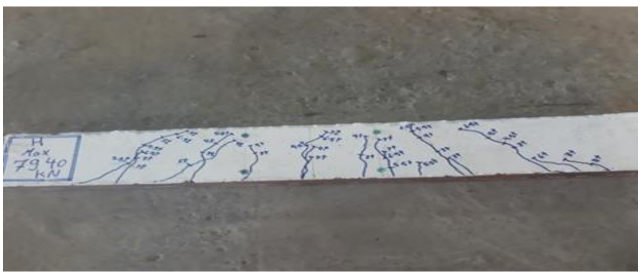

Fig. 23. Crack Pattern of beam HSC.

6. Conclusions

6.1. SCC

- Mixes with gypsum content in fine aggregate as a replacement by 1.5% are the best content which played actual role to improve both compressive and tensile strengths.
- Mixes with metakaolin 10% and 5% replacement of cement increase compressive strength and indirect tensile strength respectively.
- Mix with 1% gypsum and 5% metakaolin was found to be the best mix which increased the compressive strength at ages 7, 28 and 90 days and increased indirect tensile strength in 18% at 28 days age.

6.2. HSC

- Mixes with gypsum content in fine aggregate as a replacement by 1.5 % are the best which increase the compressive strength at all ages of 7,28 and 90 days and 1% gypsum content for indirect tensile strength at all age 28 days.
- The best content of MK for mixes without gypsum is 10% as a replacement of cement.
- Mixes with 5% MK and 1% gypsum is the best mix which increase the compressive strength at all ages, and the mix of 0.5% gypsum with 5% and 10% MK are the best mixes which improve the compressive strength at age 90 days.
- Mixes with 1% gypsum and 10% MK improve indirect tensile strength at age 28 days.
- Tested beams SCC and HSC emphasized high ductility and energy absorption properties which are very useful for dynamic applications. The energy absorption of beam HSC is1.53 times that of beam SCC.
- There is no spalling of concrete cover of the tested beams at failure, this is predominant.
- The developed cracks at failure were fine crack widths resulting from employing the proper designed mix.

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