



BEHAVIOR OF SELF COMPACTING CONCRETE SUBJECTED TO SULPHURIC ACID

Dr. Mohammed Mosleh Salman¹, Dr. Luma Abdul Ghani Zghair²

- 1) Prof., Civil Engineering Department, Mustansiriyah University, Baghdad, Iraq.
- 2) Lect., Civil Engineering Department, Mustansiriyah University, Baghdad, Iraq.

Abstract: Self-Compacting Concrete mixes (SCC) is increasingly being used in many application some of which are susceptible to an Aggressive Environment such as sulfuric acid solution. In this study SCC incorporating silica fume, chalk powder and hybrid fibers were used in casting twelve specimens with a dimensions of (1000× 200× 100) mm , in three groups. The specimens in the first group were cured in normal environment for 28 days, while those in the second and third groups were subjected to sulfuric acid solution of 0.5% for six and ten months, respectively. The flexural tests of the specimens were evaluated by testing the specimens under two-concentrated point loading until failure. The experimental results show that after chemical exposure for ten months, using of chalk powder or hybrid fibers enhances the resistance to sulfuric solution

Keywords: *self-compacting concrete, silica fume, sulfuric acid, hybrid fibers, flexural strength .*

سلوك الخرسانة الذاتية الرص المعرضة الى حامض الكبريتيك

الخلاصة: ازادت استخدامات الخرسانة الذاتية الرص في تطبيقات هندسية عديدة البعض منها معرضة الى بيئة قاسية مثل محاليل حامض الكبريتيك. تم في هذه الدراسة استخدام خرسانة ذاتية الرص حاوية على السيليكا فيوم، المسحوق الطباشيري و الالياف المختلطة في صب اثنا عشر نموذج ذوابعاد (100× 200×100) ملم في ثلاثة مجاميع النماذج في المجموعة الاولى تم معالجتها بصورة اعتيادية و لمدة 28 يوما بينما في المجموعتين الثانية و الثالثة عرضت الى محلول حامض الكبريتيك 0,5% و لمدة ستة وعشرة اشهر على التوالي. تم تقييم مقاومة الانحناء بفحص النماذج تحت تأثير حملين مركزين لحين الفشل . اظهرت النتائج بعد تعرض النماذج لحامض الكبريتيك لمدة عشرة اشهر، ان استعمال المسحوق الطباشيري او الالياف المختلطة قد حسن المقاومة ضد محاليل الكبريت.

1. Introduction

Concrete is an important versatile construction material, used in wide variety of situations. So, it is very important to consider its durability as it has indirect effect on economy, serviceability and maintenance. Concrete is not fully resistance to acids. Most acid solutions will slowly or rapidly disintegrate Portland cement concrete depending upon the type and concentration of acid. The most vulnerable part of the cement hydrate is Ca (OH)₂, but C-S-H gel can also be attacked. Concrete can attack by liquids with pH

*Corresponding Author Mmsalman56@yahoo.com

Value below 6.5, but the attacks are severe only at a pH below 5.5, below 4.5 the attack is very severe.

As the attack proceeds, all the cement compounds are evenly broken down and leached away [1]. Sulfuric acid fluids are classified as the most aggressive of natural threats to concrete structures. Generally, they arise from industrial operations, but they can be caused by urban areas activities. Large quantities of acids are existing in sewage systems. Acid attack is influenced by the processes of disintegration and leaching of cement paste constituent. A very important quantity of admixtures in SCC paste can negatively or positively affect its resistance to acid aggression. [2]

Many studies about the possibility of improving the quality and performance of concrete exposed to sulfuric acid solution have been completed. Bassuoni and Nehdi [3] examines the resistance to aggressive sulfuric acid solutions (pH of 2.5 and 1.0) by using a variable range of SCC mixtures single (cement only), binary (cement and silica fume), ternary (cement, silica fume and slag) and quaternary (cement, slag, fly ash and limestone powder) binders, with and without fiber reinforcement single and hybrid (macro steel + micro polypropylene). They concluded that: the resistance of SCC to sulfuric acid attack was improved by using binary, ternary, and quaternary binders. They also reported that, the inclusion of hybrid micro – and macro – fibers can be effective in retaining the cementitious matrix integrity and controlling disruptive pressures resulting from voluminous reaction product.

Bassuoni et al [4], investigated the resistance to sulfuric acid of various SCC mixtures incorporating different limestone material types, proportions and combinations. The study comprised twelve weeks of immersion of test specimens in (1, 3 and 5) % sulfuric acid solutions with a maximum pH threshold of 3, 2 and 1, respectively. The study revealed that the resistance to sulfuric acid of SCC incorporating limestone materials was dependent on the degree of solution aggression. While limestone filler contributed to increasing the resistance of SCC to the moderately aggressive solution (3% sulfuric acid), it accelerated the rate of mass loss in the highly aggressive solution (5% sulfuric acid).

2. Research Significance

Several concrete elements have been reported to be susceptible to the chemical attack of sulfuric acid, including, industrial floors of chemical plants, superstructures (due to acid rain), sewage pipe systems, etc., even though there has been an increased use of SCC in many concrete applications, a comprehensive review of literature indicates that there is lack of information of the role of hybrid fibers which can be inserted in SCC in such aggressive exposures and the effect of using these hybrid fibers on the flexural resistance of SCC samples after exposure to sulfuric acid

3. Material

The binders used included Ordinary Portland Cement (OPC), (ASTM C150 – Type 1) [5]. The cement was tested and checked according to IQS 5:1984[6], silica fume (SF) (ASTM C1240 -03) [7], and limestone filler (LF). The chemical and physical properties

for the various binders are shown in Table 1.

Table 1: Chemical and physical properties for the various binders [8] binders [8]

Oxides	cement	silica fume	Limestone powder
SiO ₂	18.79	96.68	2.24
Fe ₂ O ₃	3.9	0.069	0.12
Al ₂ O ₃	4.5	0.20	0.42
CaO	66.57	0.54	68.73
MgO	3.57	0.12	0.70
SO ₃	2.24	0.61	<0.07
specific gravity	3.2	2.13	2.42
specific surface area (m ² /g)	4.37	15.7	3.17

The binding materials content was kept constant at 500 kg/m³ conforming to common SCC mixture design guidelines [9] and [10]. The fine aggregate was natural sand with a fineness modulus of 2.6, a specific gravity of 2.65 Crushed coarse aggregate with a maximum nominal size of 10 mm, a fineness modulus of 2.6 a specific gravity of 2.62 was also used. To improve flowability of the SCC mixtures, copolymer-based Superplasticizer, (SP) designed for the production of SCC (Glenium 51) with relative density of 1.1 at 20°C was incorporated in all mixtures.

The dosages of SP was adjusted to maintain a slump flow of 650 - 750 mm, T50 (4 to 10) sec., L box index (>0.75) (3 Ø10 mm with 50 mm gaps) and V-funnel flow (3 to 25) sec. Three types of fibers were used, micro-reinforcement of polypropylene fibrillated fibers, with a specific gravity of 0.91, length of 12 mm, fiber thickness of 18 micron and tensile strength of 350 MPa were added at dosage of 0.2% by volume, macro reinforcement of crimped plastic fibers with a specific gravity of 1.14, length of 50 mm, aspect ratio of 63, and tensile strength of 250–350 MPa were used at dosages of 0.2 by volume and straight micro-reinforcement steel fiber with a density of 7800 kg/m³, length of 15 mm, diameter of 0.2 mm, the ratio of the length to the diameter of the fiber 75, and ultimate tensile strength of 2600 MPa were added at dosage of 0.3% by volume. Referring to trial mixes, these general shapes, dimensions, and of macro and micro-reinforcement materials have satisfied for performing the properties of flowability and passing ability of SCC with minimal fibers. The constituents of the selected SCC mixes are given in Table 2.

Table 2: Constituents of the selected SCC mixes [8]

Mix notation	cement kg/m ³	SF kg/m ³	Chalk powder	SP% wt. of cement	Fibers by volume %		
					steel	plastic	Polypropylene
SCC LP	350		150	7.3			
SCC LP SF	315	35	150	8.7	-	-	-
SCC LP SFHR1	315	35	150	11	0.3	-	0.2
SCC LP SFHR2	315	35	150	13	0.3	0.2	-

Note: for all mixes: water = 170l/m³, sand = 778 kg/m³, gravel = 890 kg/m³, and limestone powder = 150 kg/m³

For flexural test, large scale was used to get more accurate results, the nominal dimension of the tested samples were (1100mm) in overall length and (200mm) in

depth. All SCC specimens were tested under two concentrated points loading as shown in " Fig.1"



Figuer.1: Test specimens setup

As shown in Table 2. for all mixtures, the dosage of superplasticizer was adjusted to satisfy the SCC criteria. Table2. shows that, when using silica fume in concrete Mixtures incorporating hybrid fiber showed higher dosage of superplasticizer than those without fiber. This result can be attributed to increased internal resistance to flow, hybrid fibers can have more detrimental interference with aggregates obstructing flow, and in addition they were prone to cluster and to clog the V- funnel opening.[12] [13]

4. Preparation of Acid Solution

In the present study, chemical immersion tests were adopted to assess the resistance of SCC

All concrete specimens were cured in water for 28 days, after which they were immersed in acid solution. The initial pH (2.3) of the solution increased quickly. A digital portable pH meter was used for monitoring the pH levels of the sulfuric acid solutions. Specimens were fully immersed up to ten months, before immersion, the specimens were left to dry under 20 °C and 50% RH. Each group of mixtures had its own acid bath. This is to provide similar acidic environments for the different binder mixtures in each group of mixtures.

5. General Behavior of Tested Specimens

Photographs of the tested specimens are shown in "Fig. 2" to" Fig. 5" and the test results are given in Table 3.

Table 3: Test result of SCC Specimens

Mix notation	Before Exposure		After 26 week Exposure		After 41week Exposure	
	No. of Specimens	Ultimate load kN	No. of Specimens	Ultimate load kN	No. of Specimens	UL. kN
SCC LP	S1	15	S5	11	S9	7.5
SCC LP SF	S2	24.5	S6	20	S10	8.5
SCC LP SFHR1	S3	25	S7	24	S11	16.5
SCC LP SFHR2	S4	31.5	S8	27	S12	17.5

For specimens with non-fiber reinforcement (S1, S2, S5, S6, S9 and S10), the flexural cracks appeared directly in the mid span, and then a sudden tensile failure occurred shortly after formation of these crack as shown in "Fig. 2" and "Fig.3".

on the other hand, specimens with hybrid (S4, S7, S8, S11 and S12) fibers tend to behave differently, in fiber reinforced concrete, after cracking of matrices or brittle fracturing, ductile fibers continue to carry and transfer the loads to other fibers; hence they help keeping structural integrity and cohesion of material as shown in "Fig. 4", and "Fig.5" only in S3. (This is probably due to the fact that, small fibers may be pulled out after the main flexural crack are formed).

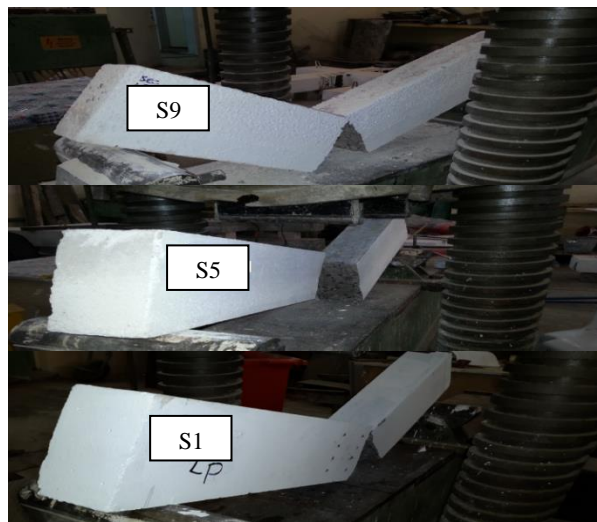


Figure2: Failure mode of the tested specimens SCC LP

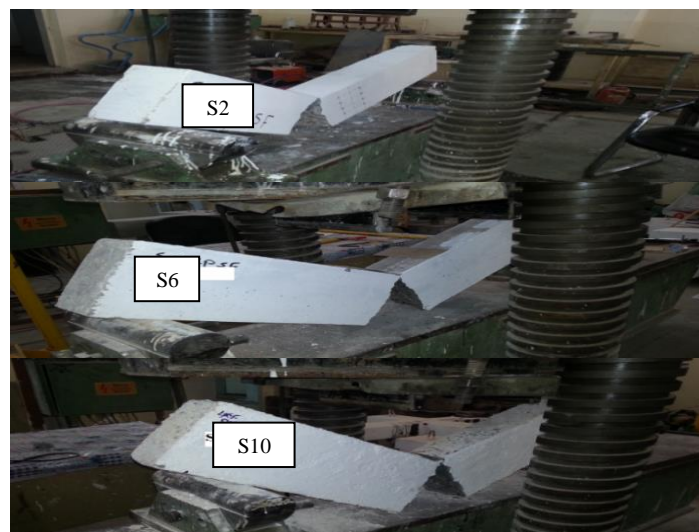


Figure. 3 Failure mode of the tested specimens SCC LP SF

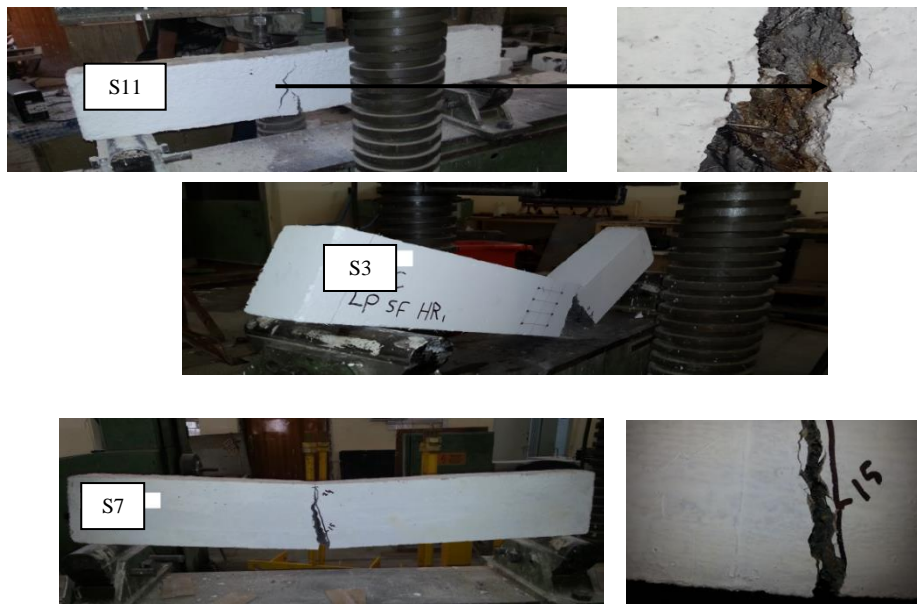


Figure. 4 Failure mode of the tested specimens SCC LP SF HR1

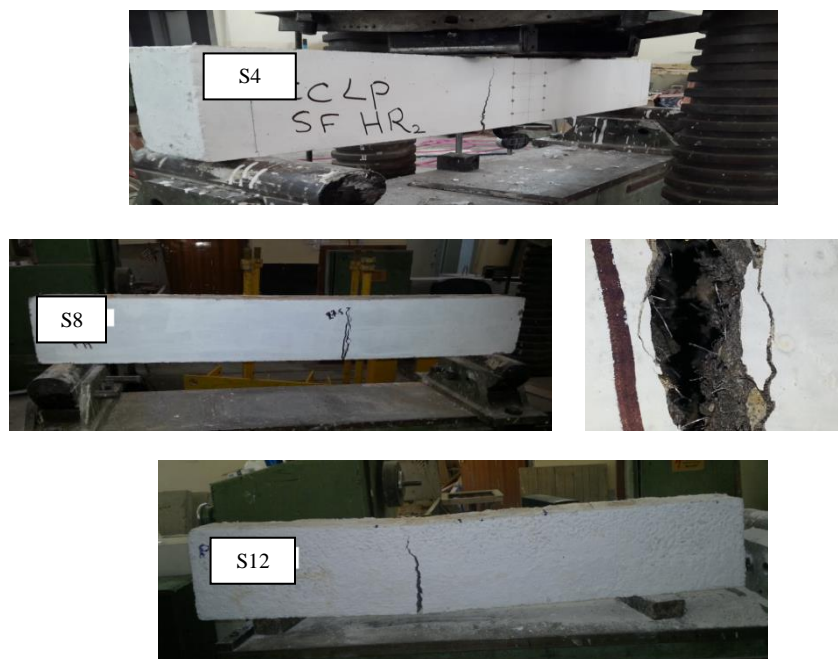


Figure. 5 Failure mode of the tested specimens SCC LP SF HR2

6. Flexural Strength for Tested Specimens before and After Immersion in H_2SO_4

The flexural strength for SCC specimens is presented in Table 3. Before chemical immersion, a comparison is made between (S2 and S1) as shown in "Fig. 6". Using of silica fume in S2 increases the ultimate load (63) %. This effect of (SF) results in densification of the SCC matrix, and improving the microstructure of SCC matrix, thus increase its ultimate load.

The effect of hybrid fibers was also studied; for specimens with non-hybrid fibers reinforcement (S1, S2), the flexural crack appeared directly in the middle span and then a sudden and violent complete flexural failure occurred after a short period of formation of the flexural crack at ultimate flexural force. Specimens with hybrid fibers (S3 and S4) tend to behave in a different way, the initiation of cracking indicates the starting of new phases in the material's behavior, but it does not indicate failure of the material. The load will continue to increase after cracking. As the load increases, these cracks expand and the macro fibers bridges through it and prevents further propagation subsequently, increasing the load carrying capacity. The initiation of cracks at higher deflections states that presence of fibers improved the tensile strength response of matrix. This finding is also reported by other researchers [13] [14]

As illustrated in "Fig. 7", using of hybrid fibers with micro and long fibers increased the ultimate load by about (12) % in S4 comparable S2. On the other hand for specimen S3 with short hybrid fiber, the effect of hybrid fibers on ultimate load was insignificant. The short fibers had limited effects on the ultimate load. After 182 days of exposure to sulfuric acid solution, as given in Table 3. a comparison is made between (S1, S2, S3, S4) and between corresponding corroded beams (S5, S6, S7 and S8). Using of silica fume or hybrid fibers enhances the resistance to sulfuric solution, the reduction in flexural was about 8% in S8, % 4 in S7, and % 14.3 in S6 while the reduction in flexural was about % 26 in S5. This is mainly attributed to that:

1. Silica fume can enhance particle packing and the permeability of concrete, thus, the durability of concrete will increase [15].
2. The inclusion of hybrid fibers can be effective in retention the cementitious matrix integrity and control the disruptive pressures resulting from voluminous reaction product.

After 289 days, the following were observed: -

For non-reinforcement hybrid fibers, the use of limestone powder only with cement was more effective in enhancing the resistance to sulfuric acid comparable with beams with silica fume. The reduction was (50%) for S9 while the reduction was (65 %) for S10. In addition, using of hybrid fiber in S11 and S12 was effective. The reduction was (34% and 44%), respectively comparable with S10 which has the same mix design as S11 and S12. The negative effect of pore densification (fine pores) by incorporating silica fume after exposure to acid attack may contribute an increase in the capillary suction resulting in solution which enters deeper into the concrete.

In spite of the total amount of solution taken up by the concrete is relatively small, the solution which intervention the concrete, is very aggressive and can dissociates into sulfate ions and due to pore densification, the solution will comes in contact with a larger concrete surface comparable with the same amount of aggressive solution is taking up by concrete in the case of large pores. Increase the surface area of the concrete-contact with the aggressive solution will lead to an increase in the reaction products. [16]

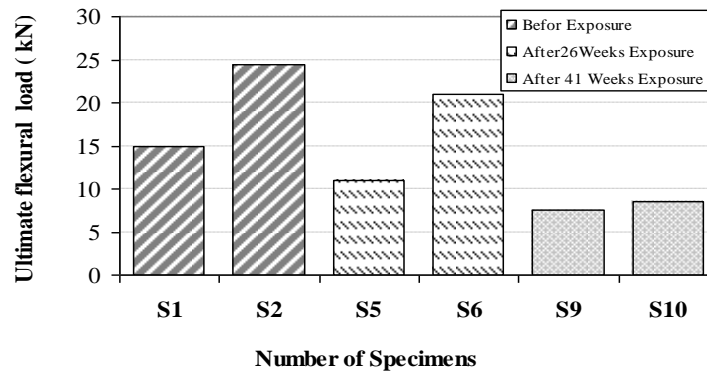


Figure6. Effect of acid solution on specimens with Silica fume

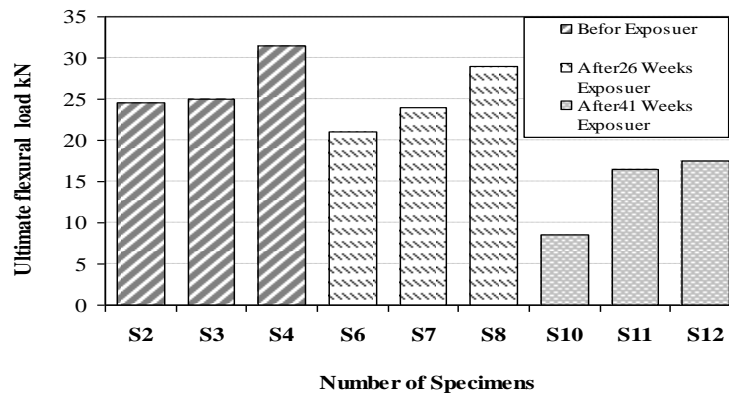


Figure. 7 Effect of acid solution on specimens with hybrid fiber

7. Conclusions

Based on the experimental result, the following conclusion can be drawn:-

1. SCC concrete mixes were susceptible to sulfuric acid attacks but differed in the level of deterioration depending on the type of concrete mixes, such as the type of admixtures used
2. The use of hybrid fibers and pozzolana (silica fume) in concrete mixtures, led to an increase in superplasticizer dosage comparable with reference mixes (chalk powder).
3. Using of hybrid fibers with micro and long fibers increased the ultimate load by about (12) % in S4 comparable S2. On the other hand for specimen S3 with short hybrid fiber, the effect of hybrid fibers on ultimate load was insignificant. The short fibers had limited effects on the ultimate load
4. After 182 days exposure to H_2SO_4 solution. Using of silica fume or hybrid fibers enhances the resistance to sulfuric solution, the reduction in flexural was about 8% in S8, % 4 in S7, and % 14.3 in S6 while the reduction in flexural was about % 26 in S5.
5. After 289 days, specimens with hybrid fibers, was effective in enhancing the resistance to sulfuric acid comparable with specimens without hybrid fibers
6. Concrete mixes with chalk powder only (SCC LP) has the best resistance to acid solution after immersion in acid solution up to (289 days).

8. References

1. Phani, S. S. , Seshadri , S. T., Rao, S. , Sravana, and Sarika , P., (2013). "*Studies on effect of mineral admixtures on durability properties of high strength self compacting concrete* " Volume: 02 Sep., pp 98 -104
2. Siad , H., Mesbah , H. A. , Khelafi , H. , Kamali , B. S., and Mouli , M. , (2010). "Effect of mineral admixture on resistance to sulphuric and hydrochloric attacks in self – compacting concrete " Can. Journal in civil engineering , 37 pp 441- 449
3. Bassuoni , M.T. and Nehdi , M. L. , (2007). " Resistance of self-consolidating concrete to sulfuric acid attack with consecutive pH reduction " Cement and Concrete Research 37 pp 1070-1084
4. Bassuoni, M. T., Nehdi, M. , and Amin, M., (2007). "*Self-compacting concrete: using limestone to resist sulfuric acid* " Proceedings of the ICE - Construction Materials, Volume 160, August pp 113 –123
5. ASTM C150, (2002). "*Specification for Portland Cement*" Annual Book of ASTM Standard, Vol. 04-02,
6. Iraqi Specification, No. 5/1984., "Portland cement".
7. ASTM C1240- 03, (2003). " *Standard Specification For The Use of Silica Fume as a Mineral Admixture in Hydraulic Cement Concrete , Mortar and Grout* " , Vol. 4.2 , , 6p.
8. Zghair, L.,A.,G.,(2015). "*Behavior of Reinforced Self Compacted Concrete Exposed to Aggressive Solutions* " PH.D., Thesis , University of Technology, May, PP.1-159
9. EFNARC, (2002). "*Specification and Guidelines for Self-Compacting Concrete*" , , February, pp.32
10. The self-compacting concrete European project group, (2005) "*The European Guidelines for Self-Compacting Concrete*" May, pp 43-56
11. Krishna, A.V., Rao, B.K. and Rajagopal, A.,(2010). " *Effect of different sizes of coarse aggregate on the properties of NCC and SCC* " International Journal of Engineering Science and Technology , Vol. 2(10), pp 5959-5965
12. Aydin, A. C., (2007)."*Self compactability of high volume hybrid fiber reinforced concrete* " Construction and Building Material 21 pp 1149-1154
13. Jeenu, G., Reji, U. R. and Prakash , V. S. ,(2007). " *Flexural Behaviour Of Hybrid Fibre Reinforced Self Compacting Concrete* " 28 - 29 August pp 1-10
14. Rambo , D. A. S. , Silva, F. A. and Filho , R. D. T.,(2014). "*Flexural behavior of hybrid steel fiber reinforced self-consolidating concretes*" Rem: Rev. Esc. Vol.67 no.1 Minas Ouro Preto Jan. / March
15. Mucteba, U., and Kemalettin, Y., (2011)."*Effect of mineral admixtures on properties of self – compacting concrete*" cement and concrete composites 33, 771–776
16. Monteny J., De Bele N., and Taerwe L.,(2003). " *Resistance of different types of concrete mixtures to sulfuric acid* " Material and Structure Vol . 36, May, pp 242-249