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Durability of Robust Self Compacting Hybrid Fiber Reinforced Concrete

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Abstract: In the current study we analyze the behavior of Robust Self Compacting Concrete in addition of Hybrid Fibers with fine aggregate of quartz sand as 100% replacement of river sand. Apart from achieving high strength it is necessary for the structures to be more durable. In this regard laboratory tests were conducted on with the addition of hooked end steel fibers and glass fibers to check for abrasion resistance, permeability and durability studies were conducted. Experimental findings revealed that addition of hybrid fibers to specimen will result in additional loss of material when compared to specimen cast without fibers, permeability results show in the favor of specimen with fiber and durability tests indicate that percentage loss is compressive strength when immersed in 5% and 10% HCL concentration is 9.8% for without fibers and 8.5% for with fibers, and when placed in 5% and 10% H_2SO_4 concentration is 28.7% without fibers and 25.7% with fibers, the average loss of material for abrasion resistance test is observed to be high when fibers are added, permeability is 18ml for with fibers & 20ml for without fibers.

Index Terms: Durability, Hybrid Fibers, Quartz Sand, Self Compacting Concrete.

I. INTRODUCTION

Concrete with high strength is being commonly utilized as construction material for decades. Hence, the publications on Self Compacting Concrete and Fiber Reinforced Concrete are considered in the literature. Many empirical formulae and different relative methods and designs are available for design of SCC but only a few limited studies proposed the tests on Fiber Reinforced Self-Compacting Concrete (FRSCC). However, FRHSSCC is a new concrete in which, the components of the mix proportions and the mechanical properties are not considered amply [19]

FRHSSCC is a new type of concrete which is increasingly investigated in different approaches for different parts of the world. Numerous works are being carried in Asia and Europe continuously on FRHSSCC since the latest decade. Though, Africa and Australia have evoked to study on FRHSSCC in recent years, it is observed that USA is not interested in the study [19] Self Compacting Concrete possesses great workability and high strength properties as per IS: 456-2000. Application and importance of high strength concrete in construction industry is very high, hence research is of utmost importance on high strength self compacting concrete. Generally concrete with compressive strength ranging from 30-55 N\mm^2 are termed as standard concrete and concrete whose strength is greater than 55 N/mm^2 are termed as High Strength concrete or High performance concrete. Buildings which are made of high strength concrete requires to be heavily reinforced, usage of such heavy reinforcement may lead to congestion, under such situations compaction of concrete becomes challenging. Therefore, a concrete with special properties is required which can be easily spread between reinforcement, there comes the application of Self Compacting Concrete (SCC).

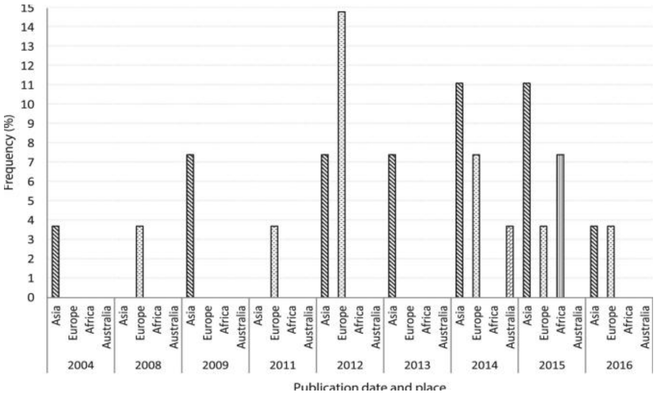

Figure I: utilization of SCC around the world [19]

SCC was originated in 1983 in Japan to reduce the problem of achieving durability due to skilled labour shortage [1]. This concrete which was then newly developed was designated as 'super-workable concrete' which achieved resistance against deformability and segregation. Without the use of vibrators, the SCC could be compacted in heavily reinforced formworks. After a few preliminary laboratory examinations it was observed that SCC possesses high durability properties after hardening [6]. Later, [2] did some research on this high performing concrete flow and its workability and termed it as Self Compacting Concrete. SCC is able to flow under the influence of its self weight by effectively filling formwork and achieving 100% compaction even in the reinforcement congestion without segregation [2]. Different factors were considered to prove that SCC is beneficial economically. These factors include construction speed, minimum use of site manpower, improved surface finishes, easier placing, better durability, greater freedom in designing of thinner concrete sections, reduced noise levels, absence of vibration and safer working environment [1].

The properties of SCC are affected by the properties of materials and mix proportions [2].

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The finer particles like micro silica and quartz powder increase the strength and also full replacement of fine aggregate with quartz sand can be done for effective improvement of strength properties of high strength self compacting concrete [5]. Quartz sand is a common inert silicate mineral in mine tailings [20], it is crushed from many types of rocks, its common constituent is granite, sand stone, limestone and other rocks. It can be readily available at close range, reducing the cost of transportation, thus further reducing the cost of construction. Quartz sand can act as alternative for river sand, due to rapid growth of construction industry, demand for sand has increased tremendously, causing deficiency of suitable river sand in most part of the world. Due to the reduction in quantity of good quality river sand for the use in construction, use of alternative materials can be recommended. In the present study, in order to achieve high strength concrete it is chosen for replacing fine aggregate completely with quartz sand. In order, to achieve high strength it is necessary to further improve the strength from conventional grade by addition of fibers. Upon investigations it has been revealed that structural characteristics of concrete such as compressive strength, flexural strength, impact strength, tensile strength, ductility and durability can be significantly improved by the addition of fibers [4]. Addition of fibers will enhance the tensile and ductile behavior of concrete with brittle nature. [9]. Fiber reinforced concrete has considerably enhanced toughness and strain at the peak stress due to bonding forces at the fiber-matrix interface. Almost all the commercially available fiber reinforced concretes are normally manufactured using a particular type of fiber. [17]. Fibers modify and enhance the mechanical properties and behaviour of concrete during its application. Fiber can be used with admixture such as super plasticizer, air entraining, retarding, accelerating etc and all type of cement and concrete mixtures. Fibers provide an effective secondary reinforcement for shrinkage and crack width control. Macro-cracks and potential problems are prevented and blocked when micro-cracks intersect fibers as concrete hardens and shrink. Crack width can be controlled by employing fibers in concrete. [17]. It is proven that implementation of glass fibers in concrete mixes can improve the 28-day compressive strength by 20-25% [7]. These Glass fibers are available in continuous or broken lengths, have good tensile strength and elastic modulus but are observed to be brittle and low creep at room temperature. Glass fibers are usually cylindrical with varying diameters ranging from 0.005mm to 0.015mm. They can be bundled up to 1.3mm diameter by bonding glas fibers together [7]. Glass fiber in concrete not only improves the properties of concrete and a small economic gain but also provide a way to dispose the glass as environmental waste from the industry [8]. It was observed that adding glass fibers, improves the durability of self compacting concrete. The weight and compressive strength losses in cube specimens reduced with concrete age and in general the durability indicators of glass Fiber self-compacting concrete mixes were more than those of self-compacting concrete mixes [11]. For this study hooked end steel fibers of dia 0.5mm and length 30mm are considered. Obtaining high strength is not the only criteria for optimal performance of structure; it should also have long serviceability. Life span of structure is usually reduced by various factors such as permeability, acid attack, abrasion effect. For this reason it is necessary to study the durability properties of high strength self compacting fiber reinforced concrete with 100% replacement of river sand with Quartz sand. The resistance of concrete to acid attack was found by the percentage loss of weight of specimen and the percentage loss of compressive strength on immersing concrete cubes in acid water [15]. It is found a qualitative similarity of the level of concrete abrasion between laboratory simulations and measurements in the field [14]. Investigations indicated that weight loss is more in Conventional Concrete compared to SCC when immersed in H2SO4 (5% Concentrate) and HCl (5% Concentrate) solution. The average acid consumption is more to Conventional Concrete than SCC [10]. Denser microstructure of HSSCC contribute for a lower plastic settlement, higher bond between steel and concrete matrix, lower permeability to oxygen and lower chloride diffusion coefficient and higher tensile strength [12]. When the fiber content keeps at 1.0 %, the glass fiber concrete has the best impact resistance, subsequent by the carbon fiber concrete, and the steel fiber concrete is the worst. In the higher grade of the self compacting concrete, the resistance to the permeability is more in comparison with lower grade of the self compacting concrete [16]. SCC Specimens became more impermeable with increasing compressive strength [18].

In the current study Robust Self Compacting Hybrid Fiber Reinforced Concrete with full replacement of river sand with quartz sand of M100 grade is studied, laboratory tests were conducted to check for abrasion, cylinders of 300mm dia. and 100mm height, with and without fibers are checked for abrasion resistance. Abrasion [21] is determined for 12, 24, 48, 72 & 90 hours. Permeability of specimen [22] with and without fibers was determined by casting 100mm dia. and 100mm height and placed in permeability apparatus for 24hrs. Then cubes of 150x150x150mm only with fibers are casted and cured for 28 days and are placed in solutions of HCL & H_2SO_4 with 5% & 10% concentrations to determine resistance of acid attack and to obtain compressive strength, weight loss, (AAF) acid attacking factor, (ADF) acid durability factor and (UPV) Ultrasonic Pulse Velocity after 28, 56 & 90 days.

II. EXPERIMENTAL PROCEDURE

Durability properties of Robust Self Compacting Hybrud Hybrid Fiber Reinforced Concrete with complete replacement of Quartz sand was studied target strength was 100Mpa, hooked end steel fibers were utilized

RSCHFRC – Robust Self Compacting Hybrid Fiber Reinforced Concrete

A. Materials & Mix Proportions

Coarse Aggregate: Grading plays a very important role, while choosing coarse aggregate round sized aggregates were selected as they improve flowability, deformability and segregation resistance with sizes from 10-20mm

Table I – Coarse Aggregate Properties

S.No	Property	
1	Specific Gravity	2.68
2	Bulk Density (Kg/m^3)	1483.66
3	Flakiness	2.96%
4	Elongation	18.62%

Fine Aggregate: Quartz sand is used as fine aggregate, size of fine aggregate is 0.3-0.8mm.

Table II – Fine Aggregate Properties

S.No	Property	
1	Specific Gravity	2.46
2	Bulk Density (Kg/m^3)	1526.87
3	Fineness Modulus (F.M)	2.2
4	Colour	Grayish - White
5	Odour	Odourless
6	Melting Point (Fahrenheit)	2912
7	Boiling Point (Fahrenheit)	4000

Cement: OPC-53 Grade cement was used in this study, Specific gravity – 3.1 & Fineness – 2800 cm^2/gm

Water: In self compacting concrete instead of water/cement ratio we take into consideration binder ratio; this means the water content used in SCC is proportionate to the total quantity of binders used.

Mineral Admixtures: Pozzolanic additives were used to generate high performance concrete in terms of strength, workability and durability. Micro Silica is a pozzolonic material with the following characteristics

Table III – Micro Silica Properties

S.No	Property	Percentage
1	Silica (SiO_2)	92.00
2	Alumina (AL_2O_3)	0.65
3	Iron oxide (Fe_2O_3)	1.62
4	Lime (CaO)	0.36
5	Magnesia (MgO)	0.75
6	Sulphur trioxide (SO_3)	0.40
7	Loss on ignition	2.50
8	Na_2O	0.72
9	K_2O	0.93

Also quartz powder used is of order 0-10µm and specific gravity 2.635

Table IV – Quartz Power Properties

Name	Percentage
Colour	White
Odour	Odourless
Melting Point	2912
Boiling Point	4000
Mohr's hardness @ 20^o Celsius	7
Specific Gravity	2.635

Fibers: Hooked End Steel Fibers of length 3 cm & 0.5 mm diameter with aspect ratio 60 are utilized & cem-fil anti crack glass fibers of length 6 mm & 14 µm diameter are also added

Super Plasticizers: In the present investigation as super plasticizer namely Master Glenium ACE 30 and VMA namely Glenium stream 2 were used. The normal dosage of Master Glenium ACE 30 per 100 kg of cement (Cementations material) is between 0.5 and 1.5 litres, Glenium Stream 2 is recommended between 0.5 – 1 litre/cum and is batched on the total of fines below 0.1 mm. The information obtained from M/s Degussa Construction chemical (India) Pvt. Ltd., Mumbai, the manufacturer of these admixtures.

Chemicals:

Hydrochloric Acid (HCl): Hydrochloric Acid of 35 – 38% LR with Specific gravity = 1.18 kg/lit. Different concentrations viz. 5% and 10% was adopted in this work.

Sulphuric Acid (H_2SO_4): Sulphuric Acid of 98% LR – Merk. M = 98.08 g/mol. Specific gravity = 1.84 kg/lit. Concentrations of 5% and 10% were adopted in this work.

Mix Proportion:

Self compacting concrete mix is built using Cement of 640 kg/m^3, Micro Silica of 64 kg/m^3 and Quartz Powder of 160 kg/m^3. 1.5% of cementitious material is used as Super Plasticizer and 0.25% of cementitious material is used as Viscosity Modifying Agent (VMA). Fibers are computed to 1.5% of cementations material

Table V - Mix Proportions utilized

Ingredient	Value
Cement	640 (Kg/m^3)
Micro Silica	64 (Kg/m^3)
Quartz Powder	160 (Kg/m^3)
Quartz Sand	887 (Kg/m^3)
Coarse Aggregate	797.53(Kg/m^3)
SP (% of PC)	1.5 %
VMA (% of PC)	0.5 %
W/P Ratio	0.21
Percentage of Steel Fibers (% of PC)	0.75 %
Percentage of Glass Fibers (% of PC)	0.75 %

The materials are weighed exactly with their proportions and are stacked on a water tight platform for preparing the concrete mix. They are first mixed thoroughly and water is then added as per the water - binder ratio. The mix prepared is then used immediately for testing the workability of self compacting concrete.

III. RESULTS

Workability: Tests were carried out for the ability of Filling, Passing and segregation resistance. In accordance with the tests for self-compacting concrete, it typically fits into the confined flow and free flow test categories.

V-Funnel Test: To measure the filling ability of Self-Compacting Concrete, the V-funnel test [23] is used and can also be used to judge segregation resistance.

Slump Flow Test: The simplest and most widely used test method for self-compacting concrete is the slump flow test (Kuroiwa et al. 1993; EFNARC 2002; Bartos, Sonebi, and Tamimi 2002). The test, which was developed in Japan, was originally used to measure underwater concrete and has also been used to measure highly flowable concretes.

L-Box Test: The L-box test (EFNARC 2002; Bartos, Sonebi, and Tamimi 2002) measures the filling and passing ability of self-compacting concrete. Originally developed in Japan for underwater concrete, the test is also applicable for highly flowable concrete

Table VI – Flow properities

S.No	FLOW TABLE	L-BOX	V FUNNEL
1	Diameter =715mm	H2 / H1 = 0.87	T_f (seconds) =7
2	T_{500} =5 seconds		T_5 (min second)=9

Casting: After having checked for the satisfaction of the fresh properties of self compacting specifications as per EFNARC [2002], the Self Compacting Concrete mix is cast into cube moulds of size 150 x 150 mm, cylindrical moulds of size 100mm diameter x 100mm height and cylindrical moulds of 300mm diameter x 100 mm height. The moulds were fabricated with cast iron. Moulds were provided with base plates, having smooth surface to support. The mould is filled without leakage and proper care was taken to ensure that there were no leakages.

Curing: After specimens were casted they are stored in the laboratory free vibrations in moist air at room temperature for 24 hrs, after this period the specimens were removed from the mould and immediately immersed in clean, fresh water curing tank. The above climate was maintained for 28 days.

Table VII – Hardened Properties of RSCHFRC

Compressive strength (Mpa)		
7 Days	28 Days	90 Days
96.3	123.8	132.7
Split tensile strength(Mpa)		
7 Days	28 Days	90 Days
2.89	8.3	8.92
Flexural strength (Mpa)		
7 Days	28 Days	90 Days
8.6	12.38	13.6

We can see that the compressive strength, split tensile strength, flexural strength targeted are acquired by the addition of said components. This can be acquired due to the addition of the assumed components.

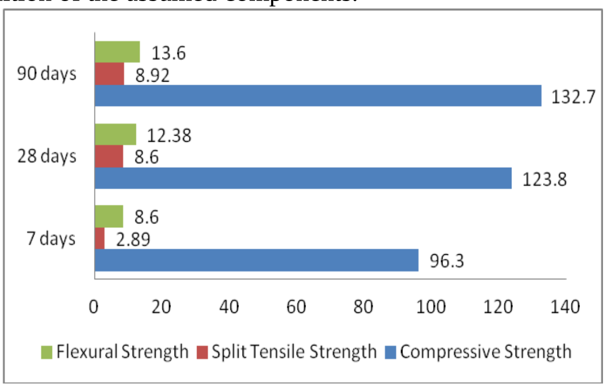

Figure II: Hardened Properties of RSCHFRC

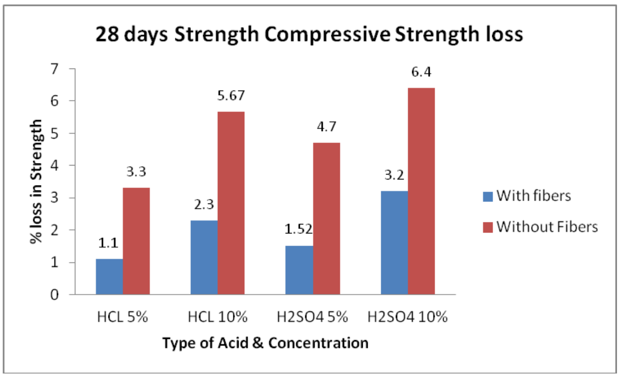

Figure III – Compressive Strength loss comparision for 28 days aging period

Percentage loss of compressive strength of concrete which included 1.1, 2.2 and 6 for 28, 56 & 90 days when immersed in HCL & H_2SO_4 of 5% & 10% concentrations respectively was plotted in figures III, IV, V respectively. When comparing the figures for durability the percentage loss of compressive strength was found more for cubes without fibers

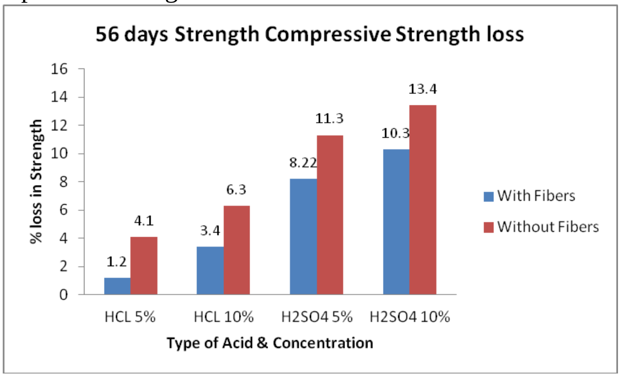

Figure IV – Compressive Strength loss comparision for 56 days aging period

We can observe that the strength loss when placed in H_2SO_4 solution is more when compared to cubes placed in HCL solution of different concentration, from this we can say that sulphites has more impact on durability on RSCHFRC than chlorides

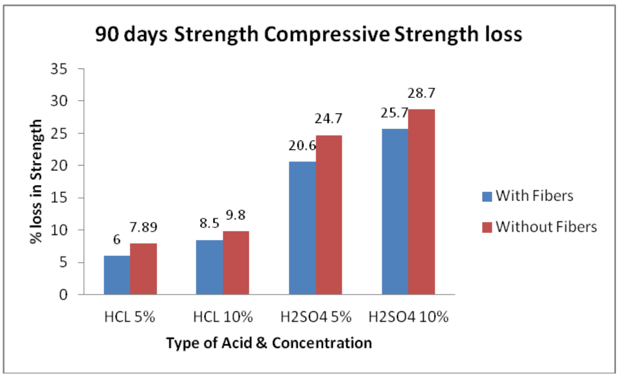

Figure V – Compressive Strength loss comparision for 90 days aging period

In this figure we can observe the 90 days aging period the compressive strength loss, we can see that loss is high for both HCL & H_2SO_4, the percentage difference is same for both concentration. The reaction due to sulphates can be noticed in the figure

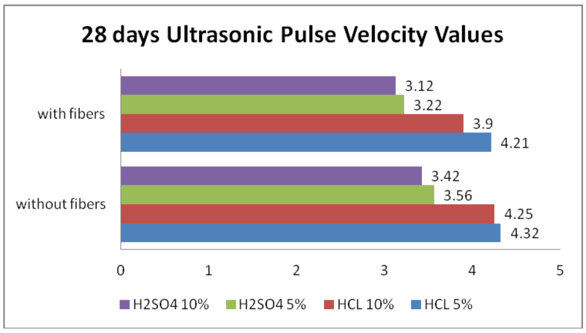

Figure V – UPV Values after immersion in HCL & H_2SO_4 for 28 days aging period

Ultrasonic Pulse Velocity (UPV) values can be observed to be high for without fibers for 28 days aging period, when placed in HCL & H_2SO_4 solution of different concentrations, higher values indicate that travel time or transient time is more and this can be implicated that chemical attack is more and so is disturbance in intigrity.

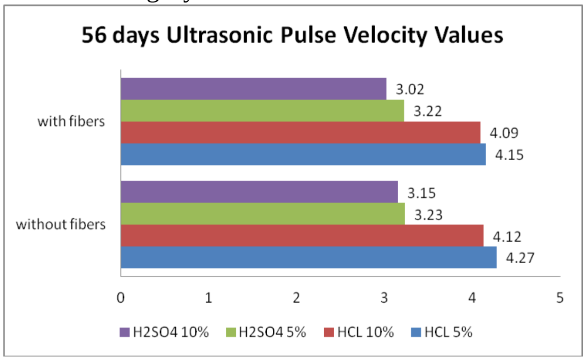

Figure VI - UPV Values after immersion in HCL & H_2SO_4 for 56 days aging period

This phenomena is observed in all different aging period, although there is no significant difference in values when placed in HCL & H_2SO_4 of different concentrations for 28 & 56 days aging period, but we can observe slight difference when placed in H_2SO_4 of 5% & 10% concentraions for 90 days aging period.

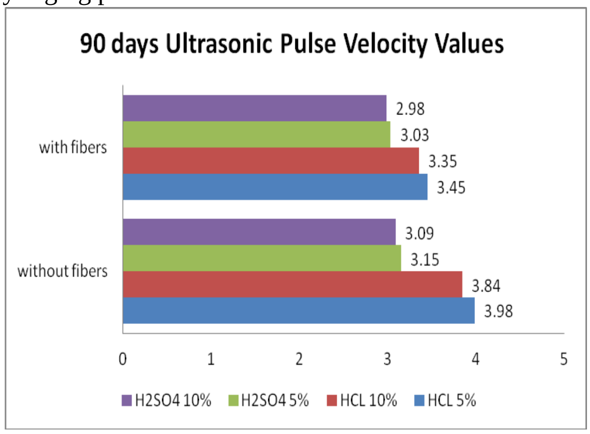

Figure VII - UPV Values after immersion in HCL & H_2SO_4 for 28 days aging period

This may be due to more chemical attack and disturbance in integrity of concrete, as discussed earlier the reaction with sulphites is more which results in lower UPV values. It can be seen from the Figure VII, IX, X that Acid Attacking Factor (AAF) is increased from 0.42 to 1.0 for 28 – 90 days aging period and for different concentrations the increase in factors can be noticed in the mentioned figures. The

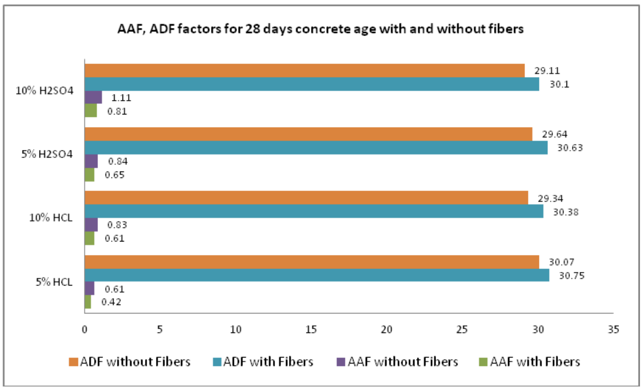

Figure VIII – AAF, ADF for 28 days aging period

Acid durability factor is also calculated for 28, 56, 90 days aging period of concrete and can be observed that the durability factor is high even when placed in higher levels of concentrations for both HCL & H_2SO_4 solutions, this can be implicated that the durability of the HSSCFRC is higher than conventional high performance concrete.

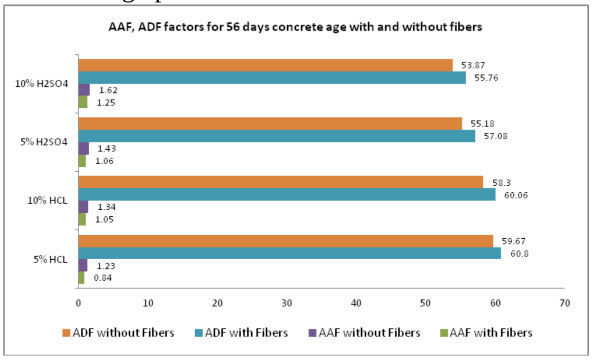

Figure IX - AAF, ADF for 56 days aging period

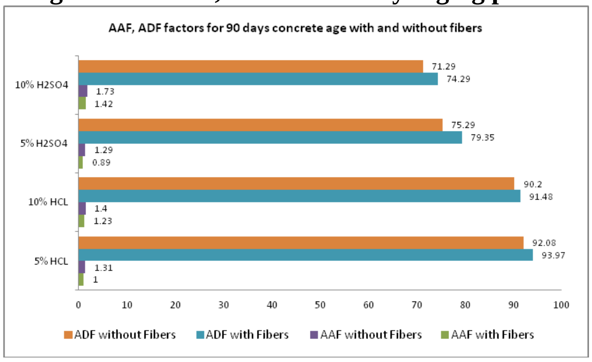

Figure X - AAF, ADF for 90 days aging period

The AAF increases with increase in number of Days of immersion, concentration of Acids, concrete without fibers showed greater AAF. The ADF increases with increase in number of days of immersion and it reduces with increase in concentration of Acids.

Abrasion: Abrasion Resistance test is conducted as per the specifications [21]. In the specimen caste with fibers the average depth of penetration is observed to be 1.358 mm and in the specimen caste without fibers the depth of penetration is observed to be 0.391 mm on imparting Abrasive effect for 90 hours.

Table VIII - Abrasion resistance values of specimens with & without fibers

Type of Specimen	With Fibers	Without Fibers
Duration of Charge	**Average depth of Abrasion (mm)**	**Average depth of Abrasion (mm)**
12 hours	0.315	0.119
24 hours	0.403	0.213
48 hours	0.530	0.221
72 hours	1.082	0.314
90 hours	1.358	0.391

The loss of material is observed to more in specimen cast with fibers compared to the specimens cast without fibers. From this we can concur that addition of fibers doesn't lead to resistance against abrasion.

Permeability: Tests were conducted as per specifications of [22], permeability through the specimen caste with fibers when a pressure of 5 kg/cm^2 is applied for 90 hours is found to be 18 ml and through the specimen caste without fibers the permeability is 20 ml.

Permeability through the specimen caste with fibers is less compared to the specimen caste without fibers ,the fibers helps in resisting the cracks specially the cracks occurred during hardening or drying of concrete and plastic shrinkage cracking.

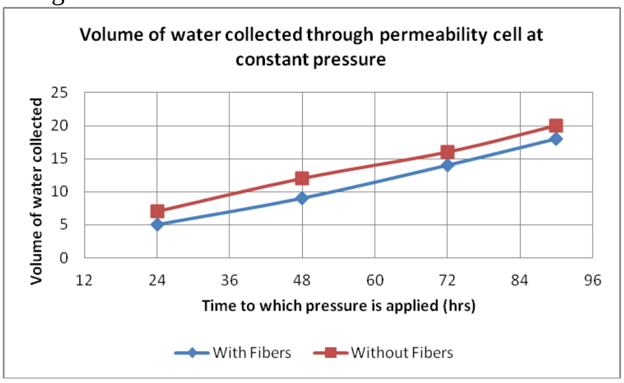

Figure XI – Volume of water collected through permeability cell at constant pressure.

IV. CONCLUSIONS

For Robust Self Compacting Fiber Reinforced Concrete we can see that strength can be acquired by completely replacing sand with quartz sand and by addition of hybrid fibers, glass fibers & hooked end steel fibers. It can be seen that durability properties have increased significantly for the specimens cast with fibers when compared to without fibers. We can Implicate that these can be utilized for places where high strength and high workability are required. RSCHFRC should not be used for places where abrasion is high

V. ACKNOWLEDGEMENT

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