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Durability Performance of Hybrid Fibre Reinforced Self Compacting Concrete Containing Class F Fly ash

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ABSTRACT

This paper presents mechanical properties and durability performances of self-compacting concrete(SCC) and hybrid fibre reinforced self-compacting concrete(HYSCC). The Portland cement was replaced with 40% of flyash. In this article two different types of fibres namely Glass Chopped Fibre Strands (CS) and Polypropylene fibres(PP)were used in combination. The SCC mixes were prepared with 0.06% of CS (CSSCC) in combination with polypropylene fibre varying from 0.1, 0.2 and 0.3 %(CSPSCC) of Volume of Concrete.A strength based mix proportion of self-compacting concrete was performed by Nan-Su method and the proportion was fine tuned by EFNARC guidelines. The influence of fly ash and hybrid fibre additions on the fresh properties, mechanical properties, chemical resistance (HCL,H_2SO_4) sulphate resistance (Na_2SO_4) ,Marine environment, sorptivity and Rapid chloride permeable test on SCC, CSSCC and CSPSCCs were studied.It was observed that addition of flyash and hybrid fibres to SCCmixes gives economical and Technical benefits.

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INTRODUCTION

In the recent decades, the issue of durability is being looked because it is essential for concrete structures to perform well not only their strength requirements but also within their durability aspects. It has been severely overlooked both in research scholars and in building codes (Antonios K *et al*.,2012). It is not possible to deliver the project having the concept of sustainable development involving the use of high performance, environment friendly materials produced at reasonable cost. So it is necessary to identify less expensive cement substitutes. From the last decades many researchers established that the use of supplementary cementitious materials like fly ash, blast furnace slag, silica fume, metakaolin , rice husk ash etc., can improve the various properties in fresh, hardened states of concrete.(Dinakar *et al*., 2008)

The three fundamental elements for supporting on environmentally friendly concrete technology for sustainable development are the conservation of primary materials, the enhancement of durability of concrete structures and holistic approach to the technology. Regarding the conservation of materials, partially uses of waste materials and Industrials by products are the principal action to be taken in order to reduce the utilization of non-renewable resources (Mehta,1999). Researchers also attempt to produce high volume flyash SCCs by replacing up to 60% of Portland cement with class F flyash , achieving a strength of about 40 Mpa(Bouzoubaa and Lachemi,2001).Inclusion of cement replacement materials improves further the durability potential of the produced mixture, due to the packing of the particles within the microstructure even for larger water content (W/P 0.60).(Antonios K *et al*.,2012).All high volume F class fly ash SCCs showed significantly lower chloride ion permeability than normal concretes. The deterioration of concrete subjected to 3% H_2SO_4 solution showed that the weight loss significantly decreases with increasing fly ash replacement in SCC(Dinakar *et al*., 2008).

The ASTM limits for aluminates to a max of 8% is moderate sulphate resistance (MSR) and to a max of 5% is high sulphate resistance(HSR). The introduction of the MSR class allows due appreciation of other blended cement containing granulated slag or other Pozzolanic materials either natural or synthetic like flyash, silica fume. Bassuoni *et al* (2009) concluded that, the classical form of sulphate attack involves alkali sulphate such as sodium sulphate(Na_2 SO_4) which reacts with portlandite (CH), monosulphate and unreacted C_3A

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to form gypsum (CSH) and ettringite ($C_6AS_3H_{32}$) which can cause expansion, cracking and deterioration of concrete.

RILEM Technical Committee (2008) reported that, the deterioration rate and grade during sulphate attack are influenced by the C_3A content of the cement. Incorporation of pozzolan materials into concrete such as silica fume, fly ash and blast furnace slag is an effective way to densify the microstructure and reducing the capillary pore sizes. In most cases this physical effect is slowing down the rate of deterioration significantly.

The fibre addition proved to be very effective in counteracting drying shrinkage of self compacting concrete. Due to the very low porosity of its cementitious matrix, the rate of chloride ion diffusion was low (Corinaldesi and Moriconi, 2004). Srinivasa Rao *et al*(2009)**,** made an attempt to study Durability Studies On Glass Fibre SCC, addition Of Glass Fibres Improved Durability Of SCC . The loss in weight and loss in compressive strength of the cube specimens improved with age. Higher the durability, higher will be the resistance to acid and sulphate attacks. The water absorption and permeable voids decreased with an increase in strength and increase in dosage of fibre. In 3% concentration of sulphuric acid the leaching is more and High Performance Concrete with addition of 0.3% of Polypropylene fibre(FPPF)shows enhanced resistance by providing a weight loss on 28 days and 64.5% on 56 days. In 3% concentration of HCL acid the leaching is less in all the mixes with addition of 0.3% FPPF shows enhanced resistance by providing a weight loss 49% on 28 days and52% on 56 days (Maruthachalam *et al.*, 2011).

Research Significance:

The main objective of this present experimental work was to study the strength and durability performance of self compacting concrete with varying dosage level of hybrid fibre with constant (40%) dosage level of Class F flyash. The durability properties were investigated through water absorption, Permeability, RCPT, Acid attack, Sulphate attack and marine environment.

Experimental Investigation:

Materials:

Ordinary Portland cement (53 grades- similar to ASTM Type I) was used. Its physical properties are given in Table 1.Fly ash from Tuticorin Thermal Power Station, Tamil Nadu, India is used as partial cement replacement (40%) material. The properties of fly ash is confirming to IS 1727 :1967 and ASTM C 618.The specific gravity is 2.05.The percentage of finess of fly ash is 0.5.Crushed angular granite metal of 8 to 12.5 mm size from a local source is used as coarse aggregate. River sand of 2.36 mm size sieve passed is used as fine aggregate in this investigation. Physical properties are given in Table 2.The Chemical Composition of Cement and Fly ash were shown in figure 1 and 2.

The High range water reducer (HRWR), the Modified Polycarboxylated Ether based Super Plasticizer complying with IS 9103:1999 and ASTM C 494 - type F is used in this experimental work. It is light brown in Color and is a free flowing liquid. A Viscosity modified admixture (VMA) also used for complying with EFNARC VMA guidelines 2006. Table 3 gives properties of Chemical admixture.

Table 1: Physical Properties of Cement and Fly ash.

Physical Properties	IS Code Specification	Cement	Class F -Fly ash
Specific gravity	IS 4031(11) - 1988	3.152	2.05
Percentage of finess (%)	IS 12269-1987 (Max 10)	0.2	0.5
Specific Surface m^2/kg	IS 4031(2) - 1999 IS 4031(11) -1988	270	365
Initial setting time	IS 12269-1987 (30 Min.)	35Minutes	-
Final setting Time	IS 12269-1987(600 Min.)	480 Minutes	-

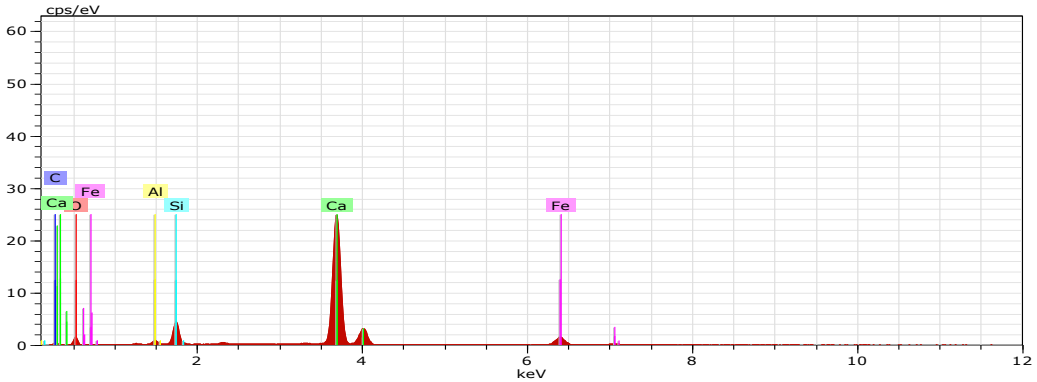

Fig. 1: EDX graph shows the elemental composition of Cement.

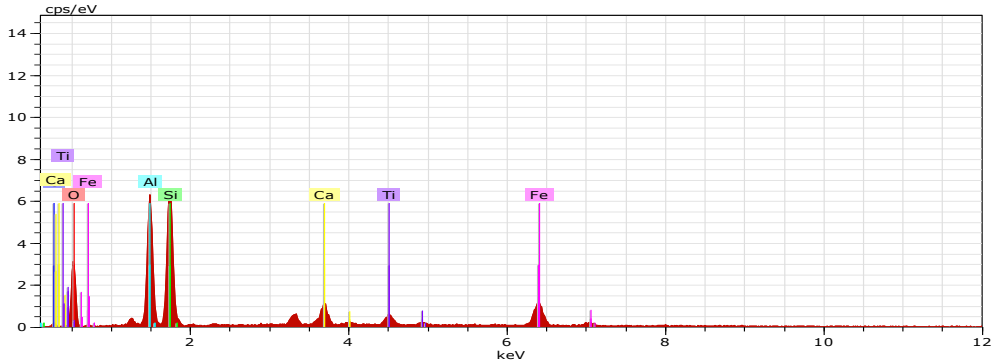

Fig. 2: EDX graph shows the elemental composition of Fly ash.

Table 2: Physical properties of Fine and Coarse Aggregate (as per IS 383:1970 &IS 2386 part III)

Properties	Fine aggregates	Coarse aggregates
Specific gravity	2.64	2.77
Water absorption (%)	0.36	0.3
Fineness modulus	3.38	3.7
Bulk density (loose) (kg/m^3)	1560	1450
Bulk density (compacted) (kg/m^3)	1650	1560

The 6 mm length Chopped Strands are chopped from continuous glass fibres. The bulk density (without compaction) of Chopped Strands is 617 kg/m^3 and the aspect ratio is 200. The chopped strands are free flowing, water dispersion and are designed to resist the rigors of compounding whilst allowing the finished moulding to develop satisfactory mechanical properties. The 12mm length polypropylene fibre prevents the micro shrinkage cracks developed during hydration, making the structure component inherently stronger. The bulk density (without compaction) of polypropylene is 175 kg /m^3 and the aspect ratio is 316.

Table 3: Properties of chemical admixture.

Chemical admixture	Specific gravity	pH	Dosage used	Chloride Content
SP	1.08	5.7	1.2%	< 0.2%
VMA	1.01	5.8	0.1%	

Mix Composition:

Five concrete mixes are made, having total powder content to 506 kg/m^3 (cement + fly ash). Coarse aggregate content is fixed at 31% by volume (700kg/m^3) of concrete and fine aggregate content at 40% by volume of concrete (872kg/m^3). The W/P ratio is kept at 0.4 by weight with air content being assumed to be 2% (Nan Su, 2001).The various SCC mixes including fly ash with Chopped fibre strands as 0.06% (CSSCC) with Polypropylene 0.1%,0.2%,0.3% (CSPSCC 1,CSPSCC 2, and CSPSCC 3) by Volume of concrete are developed. The dosage of super plasticizer is fixed at 1.4% of weight of powder and dosage of VMA is fixed at 0.2% of weight of powder. The Packing factor of all mix is 1.1 which meets the rank R1 requirements specified by the Japanese mix design.

Requirements of SCC:

The concrete mix can only be classified as Self Compacting Concrete if fulfilled by Filling ability, Passing ability, Resistance to segregation Characteristics as per EFNARC standards.

These characteristics are determined by Slump flow, T50 Slump, V-Funnel, V funnel at T_5, L-box and U-box test. Table 4 shows the test results against EFNARC Standards.

Table 4: Workability Test Result for SCC and CSPSCC Mixes.

SCC Mixes	Slump flow (mm)	T_{50} Slump Flow (sec)	U – box (mm)	L-box (mm)	V- funnel (sec)	V- funnel at T_5 (sec)
SCC	700	3	13	0.95	8	11
CSSCC	680	3	12	0.91	9	9
CSPSCC 1	670	4	8	0.92	9	8
CSPSCC 2	665	4	14	0.90	10	11
CSPSCC 3	660	4	16	0.88	10	12

Properties of SCC, CSSCC and CSPSCC Mixes In Fresh State:

All the SCC, CSSCC and CSPSCC mixes satisfies EFNARC standards. The filling ability, passing ability and segregation resistance values of CSSCC and CSPSCC mixes are compared to SCC mixes which indicate the presence of Chopped fibre strands and polypropylene and do not show any

pronounced effect up to CSPSCC 3. This may be due to low dosage of fibre addition and high dispersing nature of the hybrid fibres.

Preparation and Casting of Test Specimens:

After testing the SCC, CSSCC and the CSPSCC in fresh state, the concrete is poured in moulds of cubes (150mm x150mm x150mm), cylinders (150mmX 300mm), and prisms (100mm x 100mm x 500 mm). After 24 hours of casting, the specimens are de-moulded and placed in water for curing. After 28,56 and 90 days of curing the specimens are taken out from water and are allowed for surface drying. For each SCC, CSSCC and the CPSSCC mixes, cubes, cylinders, prisms are casted.

Characteristics of SCC Mixes in Hardened State:

Compressive and Splitting tensile strength tests are carried out, as per IS 516:1959 by using a compression testing machine of 2000 KN capacity. Flexural strength tests are carried out on prisms as per IS 516:1959 on flexure testing machine of capacity 100 kN. Table 5 gives the test results on hardened concrete.

All the mixes have strength above 30MPa, which is the required strength. The mix, without fibres and CSPSCC3 has shown lower compressive strength when compared to other mixes. The mix with CSSCC and CSPSCC 1 has shown an improvement in compressive strength by 11% and 16% respectively at 90 days .The Tensile strength of mixes is obtained (i) by conducting split tensile test on standard cylindrical specimens as per IS 5816 and also (ii) by conducting two point bend test on standard prisms. The results indicated that the incorporation of hybrid fibre into the SCC mixes increased the split tensile strength and flexural strengths by 11% and 40% respectively with the mixes of CSPSCC 1 and CSPSCC 2 at 90 days. The increase is significant and it may be due to high tensile strength of Hybrid Fibres.

Table 5: Tests on Hardened Concrete (Compressive, Splitting tensile and Flexural Strength Tests).

Specimens	Compressive strength (N/mm²)			Splitting Tensile Strength (N/ mm²)			Flexural Strength (N/ mm²)		
	28 days	56 days	90 days	28 days	56 days	90 days	28 days	56 days	90 days
SCC	31.53	34.44	35.88	2.15	2.22	2.78	4.75	5.6	6.13
CSSCC	37.20	38.37	39.93	2.57	2.57	2.80	5.6	6.9	8.55
CSPSCC 1	38.37	40.11	41.42	2.64	2.64	3.10	6.55	7.05	8.63
CSPSCC 2	33.57	34.44	35.00	2.36	2.91	2.92	7.9	8.2	8.45
CSPSCC 3	30.21	30.77	31.78	2.36	2.80	2.89	7.15	7.7	7.95

Water absorption and Permeable Voids:

It is usual practice to assess the water permeability characteristics while studying the durability characteristics. In this Investigation percentage of water absorption and percentage of permeable voids were determined as per the procedure given in ASTM C 642 - 97.For determination of water absorption of the cured samples, specimens of size 150 mm x 150 mm x 150 mm cube were used. The mass of water absorbed by the dry mass of specimen gives the capacity of water absorption. It is normally expressed in percentage,

Percentage of water absorption = (B-A / A) x 100

where, A = Mass of the oven dried sample ; B = Mass of the saturated sample.

The permeable voids were determined on cured samples, specimens of size 150mm X150mm X 150mm cube were used. The ratio of difference between the mass of saturated surface dry specimens (52 hrs) and the mass of the oven dried specimens at 105^{o}C to the volume of the specimens gives the permeable voids in percentage as given below

Percentage of Permeable = (A-B / V) x 100

Where, A = Mass of the saturated sample; B = Mass of the oven dried sample; V= volume of the specimens.

Concrete mixes with higher paste contents are bound to have higher absorption. It can be found that the Plain SCC showed higher absorption than hybrid SCC. This is due to the addition of non metallic hybrid fibres. Except CSPSCC1 mix specimen, all other SCC showed lower absorption values between 4.5% to 7.6%. The Permeable voids of mix CSPSCC1 showed 27% lower than control SCC. All other SCC showed 7.6% of lower Permeable voids. Table 6 shows the results on water absorption, Permeable and RCPT

Rapid Chloride Permeability Test:

The chloride permeability test was conducted in a water saturated 100 diameter × 50 mm length specimens. The specimen is subjected to a 60 volt applied DC voltage for 6 hours. One of the surfaces was in contact in a 3% sodium chloride solution and other with a 0.3M sodium hydroxide solution. The total charge passed indicating the degree of resistance of the specimen to chloride ion penetration according to ASTM C 1202. All the SCC mixes showed less than 1000 coulombs total charge passing and these were found as “very low” chloride permeability concretes as per ASTM C 1202 standards. The results clearly indicate that the small dosage level of hybrid SCC mixes performed much better in Rapid Chloride permeability test. From this result, Except CSPSCC 3, other CSSCC, CSPSCC1 and CSPSCC2 mixes showed 20 %, 10% and 22 % of lower values respectively. Due to very low

porosity of its cementitious hybrid fibre matrix, the rate of chloride ion diffusion was low.

Sorptivity Test:

The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogeneous material. Water was used as the test fluid. The casted cubes were immersed in water for 28 days curing. The specimen size 150 mm x 150 mm x 150 mm were dried in oven at temperature of 100 + 10 °C with water level not more than 5 mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating. The quantity of water absorbed in time period of 2,4,6,8,16,30,60,120,240,480,960,1920 and 6840 minutes was measured by weighting the specimen on a top pan balance. Surface water on the specimen was wiped off with a dampened tissue and each weighing operation was completed within 30 seconds. Sorptivity Coefficient (K) is a material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity. The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (t). Figure 3 shows the test results of Sorptivity.

$$\frac{W}{A} = k\sqrt{t}$$

W – the amount of water absorption in (Kg) ; A – Surface area(M^2) ; t – time in minutes.

Table 6: Investigation results on water absorption, Permeable and RCPT.

Specimens	Surface Saturated Specimens in grams	Oven dried Specimens in grams	Permeable Voids (%)	Water absorption (%)	Rapid Chloride Permeability Test	
					Values in Coulombs	As per ASTM C 1202
SCC	7.95	7.44	15.11	6.76	594	Very Low
CSSCC	8.2	7.71	14.5	6.47	491	Very Low
CSPSCC1	8.04	7.64	11.88	5.34	540	Very Low
CSPSCC2	7.96	7.49	14.04	6.41	485	Very Low
CSPSCC3	7.99	7.52	13.9	6.28	715	Very Low

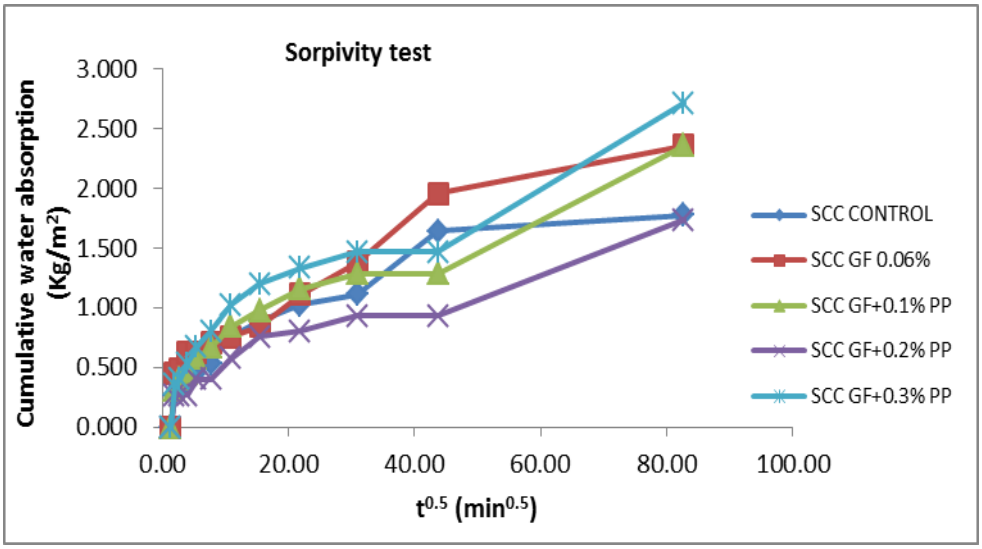

Fig. 3: Sorptivity Test Results.

Acid Attack (H_2SO_4 and HCL):

The acid attack studies are done in terms of weight loss and compressive strength after immersing the specimens in acids at 28 and 56 days after curing in normal water after 28 days. Acid attack was determined by immersing specimens of size 150mm x 150mm x 150mm test cubes in Sulphuric acid (H_2SO_4) 5% solution and a Hydrochloric acid (HCL) 5% solutions. It is reported in Table no 8.The specimen is weighed and immersed immediately after 28 days. The solution was replaced at regular intervals throughout the experiment to maintain the pH value = 4. The deterioration concrete specimens were measured as percentage reduction in weight 28, and 56 days, and percentage reduction in compressive strength of concrete at 28 and 56 days.The Acid attack is primarily related to the actual cement content in all the SCC mixes, Fattuhi and Hughes,(1988) reported earlier that, the acid attack decreased with decrease in cement Content .It is found that all the SCC mixes decreased weight loss in $H_2SO_4$with increasing percentage of hybrid fibre from 18 to 22% at 56 days immersion than control SCC.

Sulphate Resistance (Na_2SO_4):

The Sulphate resistance of concrete was determined by weight loss and compressive strength after immersing of specimen at 28 and 56 days immersing 150mm x 150mm x 150mm cubes at 10% sodium sulphate solution (Na_2SO_4) . The specimen is weighed and immersed immediately after curing in normal water after 28 days. The deterioration concrete specimens were measured as percentage reduction in weight 28 and 56 days after immersion, and compressive strength of concrete at 28 and 56 days after immersion in chemicals. Compressive Strength at 28 days and 56 days after immersing in respective solutions reported in figure 4 and figure 5. When SCC was subjected to 10 % Sodium Sulphate, the mass variation was not observed much, maximum of 1.31 % at 56 days of immersion. It seems to be negligible. The inclusion of hybrid fibre enhances the sulphate resistance in concrete.

Marine Environment:

The test was carried to study the effect of sea water on the durability of concrete, the specimen includes the cubes size of 150mm x150mm x150mm.The specimens immediately after 28 days of curing were weighed and kept in the prepared Composition of Marine water. The composition of marine water prepared in the laboratory as per ASTM. Table 7 gives the Composition for Marine Water as per ASTM D 1141**.** The percentage of loss in mass determined for 28, 56 days after immersion. The Compressive strength of concrete 28 and 56 days after immersion were determined.

Table 7: Composition for Marine Water as per ASTM D1141.

COMPOSITION	CONCENTRATION (g/lit)
NaCl	24.53
Magnesium chloride	5.2
Sodium sulphate	4.09
Calcium chloride	1.16
Potassium Chloride	0.695

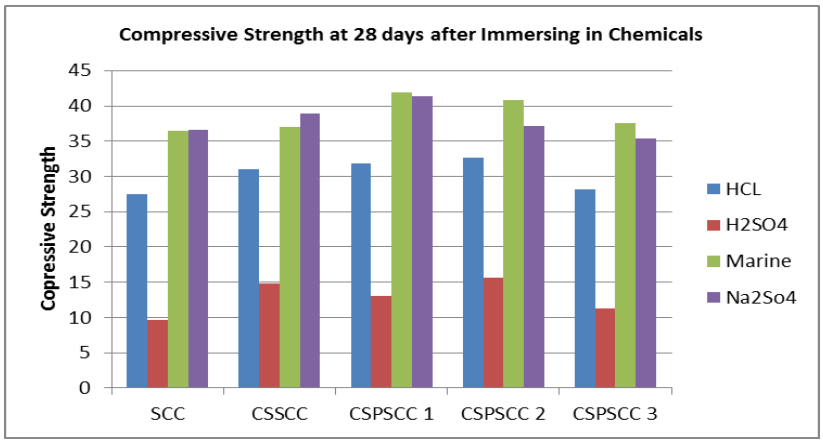

Fig. 4: Compressive Strength at 28 days after Immersing in Respective Solutions.

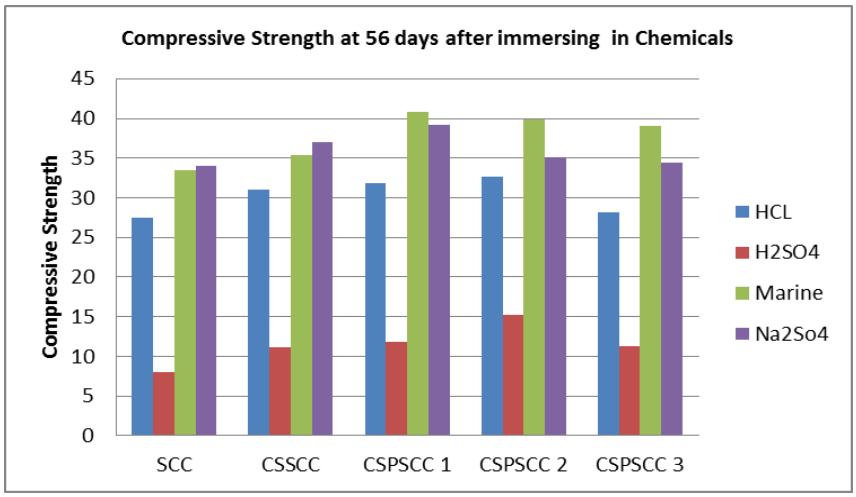

Fig. 5: Compressive Strength at 58 days after Immersing in Respective Solutions.

Table 8: Percentage of Losses in Cubes after Immersing in Respective Solutions.

Specimens	HCL		H_2SO_4		Marine Environ ment		Na_2SO_4	
	28 days	56 days	28 days	56 days	28 days	56 days	28 days	56 days
SCC	0.26	1.30	14.8	20.6	0.15	1.11	0.26	1.30
CSSCC	0.36	1.06	14.6	16.86	0.29	2.65	0.36	1.06
CSPSCC 1	0.40	1.08	9.9	17.8	0.54	1.61	0.4	1.02
CSPSCC 2	0.65	1.1	11.93	13.42	0.42	1.43	0.64	1.1
CSPSCC 3	0.80	1.26	13.5	17.4	0.98	2.01	0.81	1.29

Conclusions:

- All the SCC, CSSCC and the CSPSCCs mixes are developed and satisfy the requirements of self compacting concrete which are specified by EFNARC 2002.
- The results indicates that the use of hybrid fibres (glass strands and polypropelyne) which improves the mechanical properties of concrete. It is found out that the results obtained in mechanical properties of(GF 0.06% + PF 0.1 %) is 16% and 11 % more in compressive strength and split tensile strength respectively at 90 days when compared to the results obtained for other mixes. CSPSCC 2 (GF 0.06% + PF 0.2 %) is slightly more for flexural strength when compared to the results obtained for other mixes.
- All the SCC, CSSCC and the CSPSCCs mixes showed lower absorption values between 4.5% to 7.6%. The Permeable voids of mix CSPSCC1 showed 27% lower than control SCC.
- All other SCCs specimens showed 7.6% of lower Permeable voids.
- The RCPT results clearly indicate that the small dosage level of hybrid SCC mixes performed much better in Rapid Chloride permeability. Except CSPSC 3, other CSSCC, CSPSCC1 and CSPSCC2 mixes showed 20 %, 10% and 22 % of lower values respectively.
- The weight loss of concrete cubes increased with the number of days of immersion
- However the weight loss is more for the cubes immersed in 5% H_2SO_4 solution compared to HCL & other solutions. It is found that all the SCC mixes decreased weight loss in $H_2SO_4$with increasing percentage of hybrid fibre from 18 to 22% at 56 days immersion than control SCC.
- When SCC was subjected to 10 % Sodium Sulphate, the mass variation was not observed much, maximum of 1.31 % .It seems to be negligible.
- It is found that the loss in mass in the marine solution is less than 2.46 %, seems to be negligible.

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