ISSN 2321-807X
Volume 12 Number26
Journal of Advances in chemistry

IMPACT OF AGGRESSIVE CHEMICAL ENVIRONMENT AND CORROSION ON DURABILITY CHARACTERISTICS OF FIBRE REINFORCED CONCRETE

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ABSTRACT

Durability characteristics of concrete play an imperative role in the performance of the buildings. Concrete despite its versatility is known to have several limitations. It is weak in tension, has limited ductility, shows little resistance to cracking, its permeability to liquids, has poor resistance to sulphate attack and subsequent reinforcement's corrosion are such restrictions. Research to overcome these limitations led to the development of special concretes like high performance concrete& fibre reinforced concrete. However when fibres are exposed to aggressive environment, rusting takes place and leads to corrosion of fibres which affects the durability of the structure. This can be reduced by using stainless steel fibres instead of steel fibre. An experimental study has been taken up to study the impact of various chemicals like sulphates, chlorides, acids and effects of corrosion on concrete. Also the influences of fibres in enhancing the durability characterisitics of concrete under such aggressive environment were studied. This experimental study proves that the Stainless Steel fibre reinforced concrete has several advantages over steel fibre reinforced concrete and has better durability & corrosion resistance.

Indexing terms/Keywords

Stainless Steel fibre, Durability, Half Cell potential, Corrosion.

Academic Discipline And Sub-Disciplines

Civil Engineering- Concrete Composites

SUBJECT CLASSIFICATION

Fibre Reinforced Concrete Composites

TYPE (METHOD/APPROACH)

Experimental and Comparative Study

1. INTRODUCTION

Concrete detoriation is due to a combination of various factors which affects its durability. The addition of reinforcement to the concrete which makes it a composite is mainly to overcome its low tensile strength and to make concrete more durable. Among the environmental agents that affect the long term durability of concrete structures are the chlorides (marine environment) and the sulphates (soil, ground water and sea water) tend to be more aggressive. Sulphates are found in the form of sodium sulphate (Na_2SO_4), Potassium Sulphate (K_2SO_4), Magnesium Sulphate ($MgSO_4$) and Calcium Sulphate ($CaSO_4$) which have higher degree of solubility. When sulphate salts are present above a certain threshold level (>1000ppm), they react with various phases of hydrated cement paste leading to the cracking and Spalling of concrete. The mechanism of acid attack in concrete is it dissolves the cement compounds (hydrated and unhydrated) and calcareous aggregate. The water-soluble compounds calcium which are formed by chemical reaction are then leached away.

Fibre-reinforced concrete has higher structural integrity due to the short distinct fibres that in concrete mix are oriented randomly and distributed uniformly. Fibres include steel fibre, glass fibre, synthetic fibre and natural fibre each of which impart varying properties to the concrete. Also, the quality of fibre-reinforced concrete depends on type fibre material, geometry, distribution, orientation, and density. The amount of fibres added to a concrete mix is expressed as a percentage of the total volume of the composite (concrete and fibres), termed "volume fraction" (V_f) and it typically ranges from 0.1 to 3%. For the present study the percentage of steel and stainless steel fibre are chosen as 1% of volume fraction of the composite [1]. Among all the fibres steel fibre performs better in terms of ductility under any loading type. Addition of steel fibre in concrete produces a tough composite with better crack resistance, enhanced ductility and strength characteristics prior to failure [2]. The inclusion of fibres results in increased load carrying capacity and large rotation capacity. The uniform distribution of steel fibre throughout the concrete provides isotropic strength properties which are not exhibited by conventional reinforced concrete [3]. Even though performance of the steel fibre is better than other fibres, it has limitations too such as poor durability and is vulnerable to corrosion [4]. In order to overcome these shortcomings, stainless steel fibre can be used since it has a passive film of chromium oxide which prevents corrosion inside the concrete. The present study is about comparison of durability characteristics of control concrete with steel fibre and stainless steel fibre. Stainless Steel Fibre is an alloy of steel with a minimum of 10.5% to 11% chromium content by mass and it does not readily corrode, rust or stain with water as ordinary carbon steel[9]. The main theme of this research was to evaluate the feasibility of using stainless steel fibre in concrete because carbon steel rusts when exposed to aggressive environments.

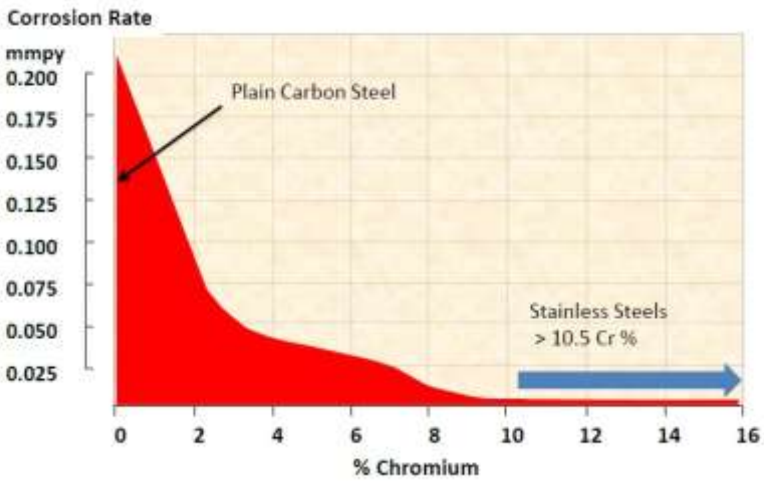

Figure 1: Chromium Content vs Corrosion Resistance of steel [9]

2. MATERIALS USED & METHODOLOGY

For the experimental Investigation, the cement used was OPC confirming to IS 564:1964 and its specific gravity was determined as 3.15. River sand (Zone-II) was used as fine aggregate with a specific gravity of 2.65 and confirming to IS 383:1970. Crushed stone aggregate of 20 mm size was used as coarse aggregate with a specific gravity of 2.71. Water used for mixing and curing of concrete is the potable water taken from the campus. Steel fibre with a diameter of 0.5 mm, length 22 mm, gives an aspect ratio of 60 and its corresponding tensile strength is 1250 MPa and Stainless steel fibre with a diameter of 0.4 mm, length 30 mm has an aspect ratio of 55 and corresponding tensile strength is 1100 MPa were used.

Figure 2: Stainless Steel Fibre

Figure 3: Steel Fibre

3. RESULTS & DISCUSSIONS

3.1 Sulphate Attack Test

To study the influence of sulphate exposure on concrete, concrete cubes of size 150 x 150 x 150 mm were cast, cured, weighed and then immersed in Na_2SO_4 solution with 5% concentration up to 28 days. After 28 days of immersion, the concrete cubes were taken out and observed visually for deterioration if any due to sulphate attack in concrete. The specimens were weighed again. The cubes were tested for compression and their corresponding compressive strength following sulphate attack was found.

Table 1. Loss in Weight & strength Due to Sulphate Attack

S.No	Mix	Average % Loss in Weight (%)	Strength (N/mm^2)		Average % Loss in strength
			Before Attack	After Attack	
1	Control concrete	3.38	39.50	37.66	4.65
2	Stainless steel fibre	1.5	56.28	55.20	1.86
3	Steel fibre	3.45	60.20	58.60	2.65

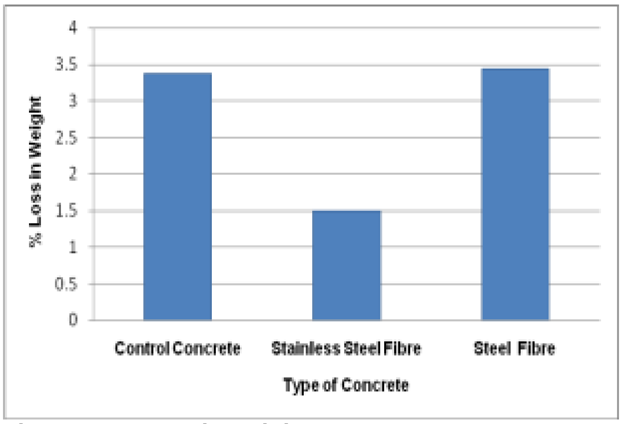

Figure 4: % Loss in weight vs concrete type

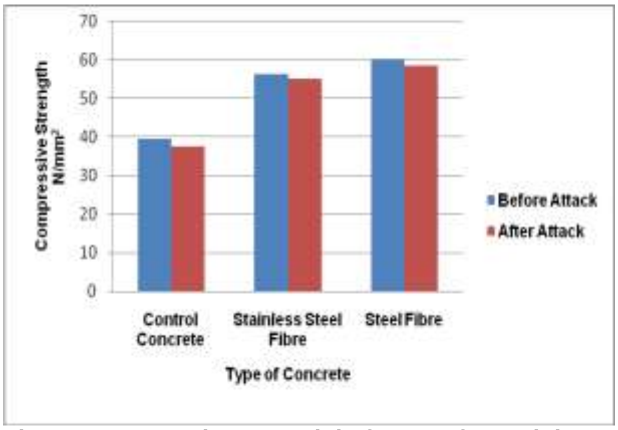

Figure 5: % Loss in Strength before & After Sulphate attack vs Concrete type

3.2 Chloride Attack Test

Sodium Chloride (NaCl) solution was selected for the experimental study of chloride attack on concrete. NaCl solution with a concentration of 3.5% was prepared by adding sodium chloride to distilled water. The solution was prepared in a non-porous container and stirred well until the Sodium chloride gets dissolved completely in water. For chloride attack too the concrete cubes with a size of 150 x 150 x 150 mm were cast and cured for 28 days. After curing they were weighed and immersed in the NaCl solution again for 28 days. The specimens were taken out and weighed to calculate the difference in weight before and after attack. The cube compressive strength of the cubes after Sodium chloride immersion was determined for control concrete, steel fibre reinforced concrete and stainless steel fibre reinforced concrete was determined.

Table 2. % Gain in Weight & Loss in Strength due to Chloride Attack

S.No	Mix	Average % gain in weight (%)	Strength (N/mm^2)		Average % Loss in strength
			Before Attack	After Attack	
1	Control concrete	3.10	39.50	38.00	3.74
2	Stainless steel fibre	2.56	56.28	55.65	1.11
3	Steel fibre	3.75	60.20	59.00	1.98

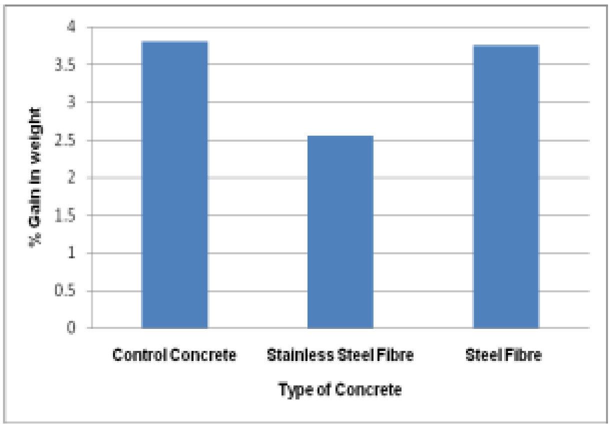

Figure 6: % Gain in weight vs concrete type

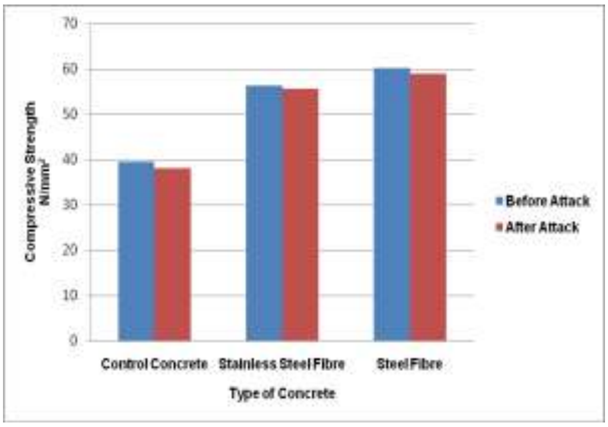

Figure 7: % Loss in Strength before & After Chloride attack vs Concrete type

3.3 Acid Attack Test

For the acid attack study on concrete, two acids namely sulphuric acid (H_2SO_4) and hydrochloric acid (HCl) both with a concentration of 3% were chosen. The concrete cubes of size 150 x 150 x 150 mm were cast and cured in water for 28 days. After curing, the specimens were weighed and immersed separately in respective acid solution for 28 days. The cube specimens were weighed to determine the percentage difference in weight. Compressive test was carried out and the loss in strength of the concrete specimens after attack was found.

Table 3. % Loss in Weight & Strength due to H_2SO_4 attack

S.No	Mix	Average % Loss in Weight (%)	Strength (N/mm^2)		Average % Loss in strength
			Before Attack	After Attack	
1	Control concrete	5.42	39.50	35.56	9.97
2	Stainless steel fibre	3.82	56.28	53.10	5.65
3	Steel fibre	4.37	60.20	55.74	7.42

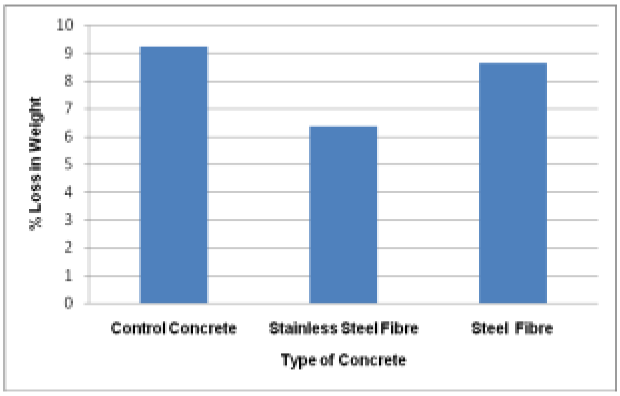

Figure 8: % Loss in weight vs concrete type (H_2s0_4)

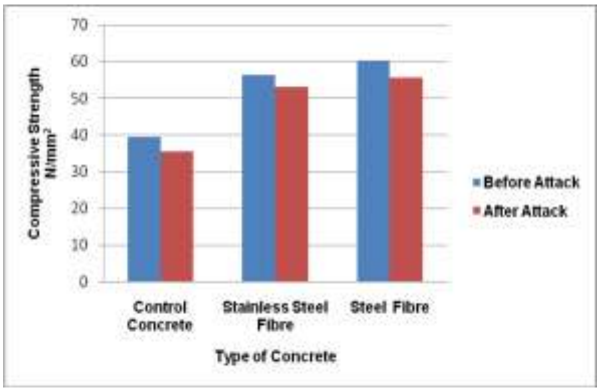

Figure 9: % Loss in Strength before & After Acid attack vs Concrete type(H_2s0_4)

Table 4. % Loss in Weight & Strength due to HCL attack

S.No	Mix	Average % Loss in Weight (%)	Strength (N/mm^2)		Average % Loss in strength
			Before Attack	After Attack	
1	Control concrete	3.2	39.50	36.82	6.83
2	Stainless steel fibre	1.4	56.28	54.30	3.51
3	Steel fibre	2.3	60.20	57.62	4.28

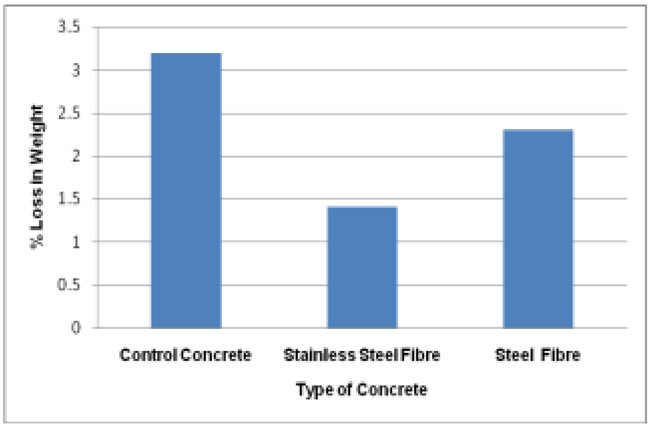

Figure10: % Loss in weight vs concrete type (Hydrochloric Acid)

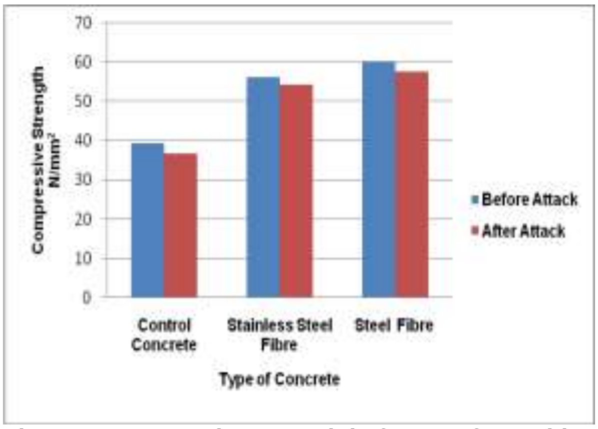

Figure 11: % Loss in Strength before & After Acid attack vs Concrete type(HCL)

Fig 12: cube specimen before acid attack

Fig 13: cube specimen after acid attack

3.4 CORROSION-HALF CELL POTENTIAL TEST

Half-cell potential test (HCP) is generally considered a non-destructive and rapid indicator to check the probability of steel corrosion in concrete. As per the specific guidelines in ASTM C876, the Half-Cell potential test on all cylinder specimens was carried out. The reference electrode was chosen as $Cu/CuSO_4$.This test was done after completing the test on accelerated corrosion. A constant DC voltage was impressed between steel bar and stainless steel plate. The steel bar acts as anode and the stainless steel as cathode and the corresponding current variation with respect to time was recorded. The cylindrical specimens containing centrally implanted steel rod was immersed partly in a 3% concentrated NaCl solution. The reinforcement steel rod of the cylinder was connected to positive terminal and stainless steel sheet to the negative terminal and a 12V power supply (DC) was applied to all the specimens. The current response was measured at 1 minute interval by digital data acquisition system till the cracking of the specimens. The specimens were inspected visually 4-5 times a day to check the appearance of corrosion on the surface.

Table 5. Half Cell Potential Test Results

Duration	AGE	POTENTIAL		Duration	AGE	POTENTIAL	
		SFRC	SSFRC			SFRC	SSFRC
Hours	days	Δ	Δ	Hours	days	Δ	Δ
0	29	245	266	120	34	-228	-126
10	29	232	245	130	35	-301	-193
20	29	209	235	140	35	-387	-226
30	30	186	186	150	36	-438	-268
40	30	157	157	160	36	-493	-292
50	31	119	129	170	37	-532	-312
60	31	98	98	180	37	-580	-339
70	32	35	45	190	38	-643	-357
80	32	-11	21	200	38	-693	-371
90	33	-43	-9	210	39	-732	-380
100	33	-116	-43	220	39	-785	-392
110	34	-169	-97	230	39	-792	-398

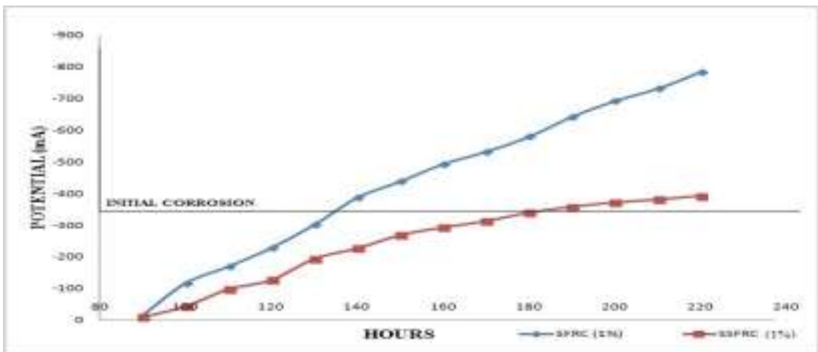

Figure 14: Variation of Potential values with SFRC & SSFRC Specimens

4. CONCLUSION

Based on the results of the experimental investigations carried out on fibre reinforced concrete, the mechanical properties of concrete have increased due to the presence of fibres. When exposed to chemical attack such as sulphate and chloride the average loss in strength of control concrete was 4.65% and 3.74% whereas for steel fibre reinforced concrete the loss in strength was 2.65% and 1.98%. Whereas in stainless steel fibre reinforced concrete the average loss in strength was found to be1.86% and 1.11%. The loss in strength due to the chemical attack is reduced to about 60% in stainless steel fibre reinforced concrete. For acid exposure in control concrete the loss in strength was 9.97% and 4.28% and in the case stainless fibre reinforced concrete the average loss in strength was 5.65% and 3.51% compared to 7.42% and 4.28% of steel fibre reinforced concrete. The results prove that the loss in strength due to acid attack reduced to about 50% in stainless steel fibre reinforced concrete. The time taken for corrosion initiation in stainless steel fibre reinforced concrete is about 180 hours whereas for the steel fibre reinforced concrete the initiation of corrosion starts at about 130 hours in half-cell potential test. This indicates the presence of steel fibre increases the corrosion resistance of the concrete substantially due to the chemical composition of stainless steel.

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Author biography with Photo

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