

## International Journal of Innovative Research in Science, Engineering and Technology

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# A Study on Durability Characteristics and Corrosion Resistance of Stainless Steel Fibre Reinforced Concrete

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**ABSTRACT:** Corrosion resistance of concrete in chemical environment affects the durability thereby reducing the life span of buildings. Concrete with several limitations such as low ductility, poor crack resistance, permeability to liquids, poor resistance to chemical attack results in corrosion of reinforcement. These limitations were overcome by developing special concretes like fibre reinforced concrete, high performance concrete etc. One such type of fibrous concrete is the steel fibre reinforced concrete, but steel fibre when exposed to chemical environment corrodes. In the present study stainless steel fibres were used instead of steel fibres and subjected to aggressive chemicals like sulphates, chlorides, acids. Stainless steel fibres contain a passive film of chromium oxide which prevents from corrosion of fibres inside concrete. Also the impact of stainless steel fibre under electro chemical or galvanic corrosion was studied. The results of the experimental investigation were analysed and important conclusions on the influence of stainless steel fibres in durability of concrete were arrived.

**KEYWORDS:** Stainless Steel fibre, Durability, Half Cell potential, Corrosion, compressive strength

### I. INTRODUCTION

Reinforced concrete is a composite material in which concrete's low elasticity and durability are balanced by incorporation of reinforcement. The most powerful chemical environments that influence the durability of concrete structures are the chlorides and the sulphates. Sulphate salts which are highly soluble, if present above 1000 ppm react with hydrated cement paste leads to deterioration of concrete. In acid environment, hydrated and unhydrated compounds of cement gets dissolved exposing the calcareous aggregate inside the concrete. The aggregate too gets affected by acid attacks. The water-soluble compounds calcium which is formed by chemical reaction is then leached away. Corrosion in general is defined as "the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties". Corrosion induced by chlorides present is one of the major reasons for deterioration of steel reinforcement [5]. At the point when chloride moves into the concrete, it disturbs the passive layer covering the steel, making it rust and pit. Fibre reinforced concrete, self compacting concrete and high performance concrete are a few among the wide range of special concretes developed to overcome these disadvantages of reinforced concrete.

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. Recent advancements in metal fibres have introduced a

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Vol. 9, Issue 3, March 2020

promising new type of stainless steel fibres with high stiffness, high failure strain, can be utilized in fibre reinforced composites [1]. 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% [2].

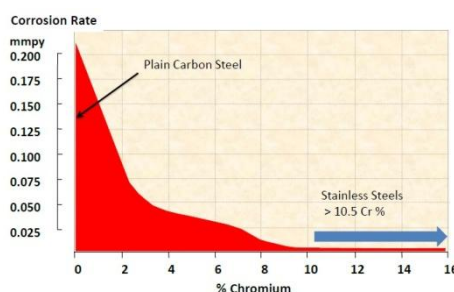


Figure 1: Corrosion rate vs chromium composition [22]

The fibre chosen for the present study is stainless steel fibre as steel fibre is highly vulnerable to corrosion. Stainless steel is an alloy of iron with a minimum 10.5% of chromium content and other alloying elements like nickel, titanium, molybdenum and copper to improve strength, formability and toughness. The most important requirement of stainless steel is that it should be corrosion resistant to aggressive environment [4-9]. The main theme of this research is to evaluate the feasibility of using stainless steel fibre in concrete because carbon steel rusts when exposed to aggressive environments.

## II. MATERIALS USED AND METHODOLOGY

### Cement:

Cement used for the experimental investigation is ordinary Portland cement. The specific gravity of cement was determined as per IS 576- 1964 and found to be 3.15.

### Fine aggregate:

Locally available river sand conforming to IS 383:1970 whose specific gravity was found to be 2.65 was used fine aggregate and sieved through IS 4.75 mm sieve.

### Coarse aggregate:

Hard blue granite stones from quarries with an average size of 12mm were used as coarse aggregate and stored in separate dust proof containers. The specific gravity of aggregate was determined and found to be 2.71.

### Steel fibre:

Hooked end steel fibres as shown in fig 4.1 were used to provide sufficient end anchorages and bond strength in the concrete matrix.

### Stainless Steel Fibre:

Stainless steel fibre as shown in fig 4.2 with 0.5 mm diameter, aspect ratio of 55 and tensile strength of 690 MPa were used for the present study

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Vol. 9, Issue 3, March 2020

**Table 1 : Properties of steel fibre**

S.No	Parameter	Steel Fibre	Stainless Steel Fibre
1.	Length	38mm	25mm
2.	Diameter	.5mm	.5mm
3.	Aspect ratio	60	50
4.	Modulus of elasticity	210 Gpa	190 Gpa
5.	Tensile strength	1100Mpa	690Mpa



**Fig 3 Steel Fibre**



**Fig 3 Stainless Steel Fibre**

### III. EXPERIMENTAL SETUP

#### **CORROSION TEST**

To study the corrosion resistance of stainless steel Half-cell potential test (HCP) generally considered a non-destructive and rapid indicator to check the probability of steel corrosion in concrete. HCP test was carried out on all the faces of cylinder specimens after completion of accelerated corrosion test as per the guidelines specified in ASTM C876. Cu/CuSO<sub>4</sub> electrode was used as the reference electrode. The corrosion process was accelerated by impressing a constant DC voltage between the steel bar (as anode) and stainless steel plate (as cathode) and the variation of current with time was recorded. The cylinder specimen with a centrally embedded steel bar was partly immersed in a 3% NaCl solution. A potential of 12V (DC power supply) was applied across the specimens, the reinforcement steel bar being connected to the positive terminal and stainless steel sheet being connected to the negative terminal of the DC power supply. The current response was measured at 1 minute interval by digital data acquisition system till the cracking of

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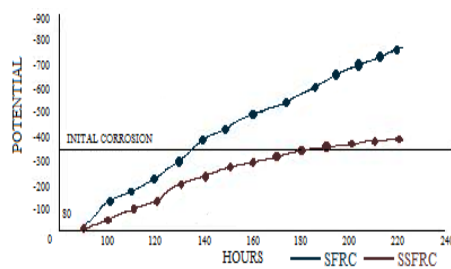
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Vol. 9, Issue 3, March 2020

the specimens. The specimens were inspected visually 4-5 times a day to check the appearance of corrosion on the surface.

**Table1. Electro - Chemical Corrosion Test Results**

Duration	Type of Concrete		Duration	Type of Concrete	
	SFRC	SSFRC		SFRC	SSFRC
Hours (From 29 <sup>th</sup> day)	Δ	Δ	Hours	Δ	Δ
0	245	266	120	-228	-126
10	232	245	130	-301	-193
20	209	235	140	-387	-226
30	186	186	150	-438	-268
40	157	157	160	-493	-292
50	119	129	170	-532	-312
60	98	98	180	-580	-339
70	35	45	190	-643	-357
80	-11	21	200	-693	-371
90	-43	-9	210	-732	-380
100	-116	-43	220	-785	-392
110	-169	-97	230	-792	-398



**Figure 4: Variation of Potential values with Control Concrete & SSFRC Specimens**

### 3.1 Sulphate Attack Test

To study the impact of sulphate exposure on concrete, concrete cubes of size 150 x 150 x 150 mm were cast, cured, weighed and then immersed in Na<sub>2</sub>SO<sub>4</sub> solution with 5% concentration up to 28 days. After 28 days of immersion, the specimens were taken out and visually observed for the deterioration of the concrete due to sulphate attack and weighed again. The compressive strength of concrete cubes after sulphate attack was found.

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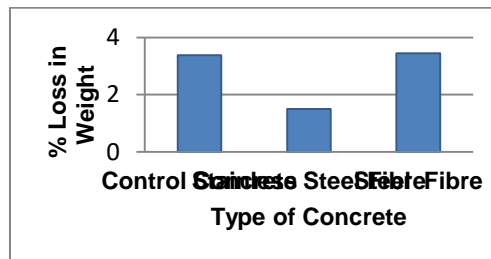
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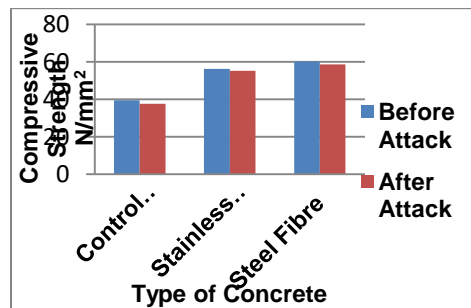
Vol. 9, Issue 3, March 2020

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

S.No	Mix	Average % Loss in Weight (%)	Strength (N/mm <sup>2</sup> )		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

A non-porous container is selected and chloride solution has been prepared by adding sodium chloride to distilled water with a concentration of 3.5%. This solution is stirred well so that all the sodium chloride salts get dissolved in the solution. Concrete cubes of size 150 x 150 x 150 mm were cast, cured for 28 days and their initial weights were found. They were then immersed in sodium chloride solution for 28 days, weighed again. The changes in weight were found and also the compressive strength of concrete cubes after chloride attack was found. In the case of chloride attack too stainless steel fibre reinforced concrete

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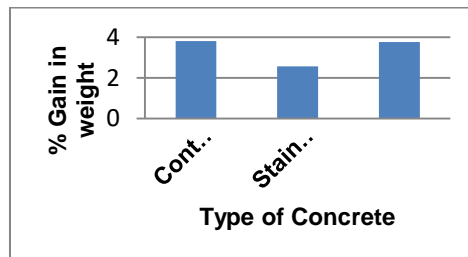
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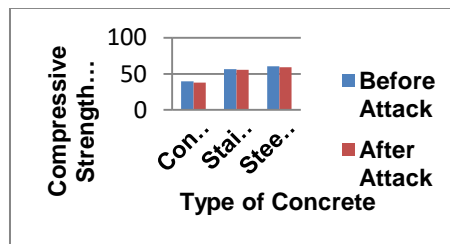
Vol. 9, Issue 3, March 2020

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

S.No	Mix	Average % gain in weight (%)	Strength (N/mm <sup>2</sup> )		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 acid attack test, concrete cubes were cast and immersed in water for 28 days of curing. After 28 days all specimens were weighed and immersed in sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) and hydrochloric acid (HCl) solution (3% concentration) for 28 days. After 28 days of immersing in acid solution, the specimens were taken out and weighed again. After drying the cubes, the changes in weight were found and also the changes in compressive strength due to acid attack were calculated.

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 9, Issue 3, March 2020

**Table 3. % Loss in Weight & Strength due to H<sub>2</sub>SO<sub>4</sub> attack**

S.No	Mix	Average % Loss in Weight (%)	Strength (N/mm <sup>2</sup> )		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

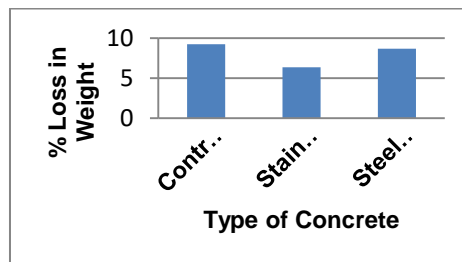


Figure 8: % Loss in weight vs concrete type (H<sub>2</sub>SO<sub>4</sub>)

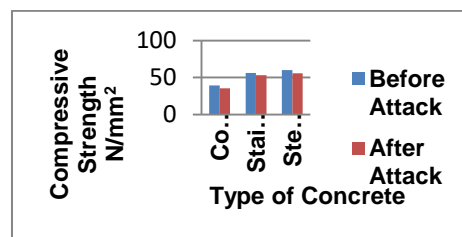


Figure 9: % Loss in Strength before & After Acid attack vs Concrete type (H<sub>2</sub>SO<sub>4</sub>)

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

S.No	Mix	Average % Loss in Weight (%)	Strength (N/mm <sup>2</sup> )		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

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Vol. 9, Issue 3, March 2020

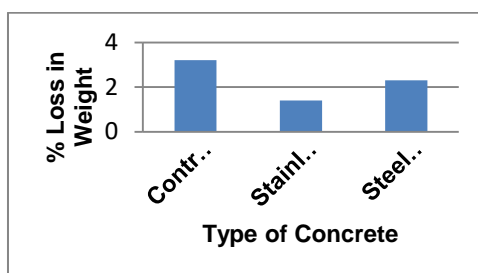


Figure10: % Loss in weight vs concrete type (Hydrochloric Acid)

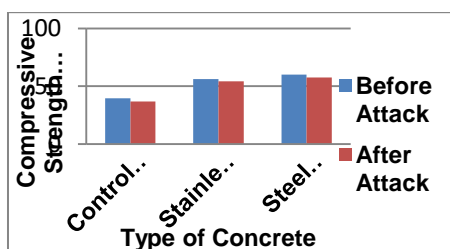


Figure 11: % Loss in Strength before & After Acid attack vs Concrete type(HCL)



Fig 12: cube specimen before acid attack



Fig 13: cube specimen after acid attack

### 3.4 CORROSION RESISTANCE TEST

To study the corrosion resistance of stainless steel Half-cell potential test (HCP) generally considered a non-destructive and rapid indicator to check the probability of steel corrosion in concrete. HCP test was carried out on all the faces of cylinder specimens after completion of accelerated corrosion test as per the guidelines specified in ASTM C876. Cu/CuSO<sub>4</sub> electrode was used as the reference electrode. The corrosion process was accelerated by impressing a constant DC voltage between the steel bar (as anode) and stainless steel plate (as cathode) and the variation of current with time was recorded. The cylinder specimen with a centrally embedded steel bar was partly immersed in a 3% NaCl solution. A potential of 12V (DC power supply) was applied across the specimens, the reinforcement steel bar being connected to the positive terminal and stainless steel sheet being connected to the negative terminal of the DC power supply. The current response was measured at 1 minute interval by digital data acquisition system till the cracking of



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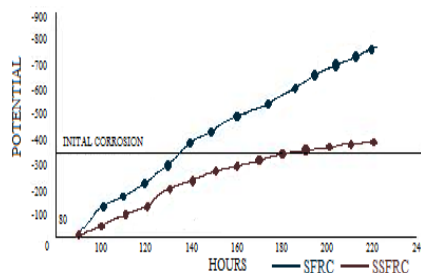
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Vol. 9, Issue 3, March 2020

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	VALUES		Duration	AGE	VALUES	
		SFRC	SSFRC			SFRC	SSFRC
Hours	days	$\Delta$	$\Delta$	Hours	days	$\Delta$	$\Delta$
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
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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 Control Concrete & SSFRC Specimens**

### IV. 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 be 1.86% 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

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Vol. 9, Issue 3, March 2020

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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