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A Review on The Effect of Corroded Steel Fibre in Fibre Reinforced Concrete

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Abstract: Concrete has a very low tensile strength that contributes to concrete failure. The addition of steel fibers to concrete in a particular percentage has been found to enhance the mechanical properties, durability and serviceability of the structure. Therefore, the objective of this study was to study the effect of corroded steel fibre in fibre reinforced concrete and to determine the capacity between corroded and un-corroded steel fibre in fibre reinforced concrete (FRC). Accelerated corrosion test, compressive strength and corrosion assessment were reviewed in this study based on research conducted by previous researchers. It was found that wetting-drying is the most used method to accelerate corrosion and impressed current can considered good technique as it consume the shortest time among the other methods. The review confirms that the capacity of corroded steel fibre lower than un-corroded steel fibre yet the decrement is very small and can negligible. Nevertheless, the corroded fibre give a negative appearance to SFRC specimens which is the brown spot on the surface of specimens and rust appearance.Through this study, it was revealed that the compressive strength of corroded fibre was slightly reduced compared to un-corroded steel fibre and negligible. However, the corroded steel fibre gave a negative appearance to SFRC specimens.

Keywords: Corroded Steel Fibre, SFRC, Corrosion

1. Introduction

Concrete is a construction material composed of hydraulic cement, water, coarse aggregate and fine aggregate. and a brittle material which is strong in compression but has some deficiencies such as

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low tensile strength and low post cracking capacity [1]. Therefore, a technique for integrating fibers into concrete is being used to improve the tensile strength of concrete. These fibers keep the cracks from propagating. These fibers are distributed randomly and arranged at random [2]. This concrete is named as Fiber Reinforced Concrete (FRC). Enhancing the post-cracking potential is the key justification for incorporating fibers to the concrete matrix. Cement, water, fine aggregate, coarse aggregate, and discontinuous discrete steel fibers are called Steel Fibre Reinforced Concrete (SFRC).

At present, the usage of steel fiber reinforced concrete (SFRC) is widely used in various type of engineering construction since it has good crack resistance. Steel fiber reinforced concrete mostly used in pavements or as slabs that may be exposed to deicing salts and chemical, in repair work and in marine structures. This can lead to SFRC exposure in a corrosive environment that appears to cause passive film localized breakdown, a phenomenon called pitting corrosion. This form of corrosion is particularly insidious since it produces little material loss with little impact on its surface while destroying the metal's deep structures [3]. Sometimes, corrosion materials mask the pits on the surface. Sometimes, due to bad cover concrete materials, the corrosion process occurs that can act as an entry point of corrosion and thus the corrosion process is intensified in a short time. Although fibres have smaller diameter than steel bar, it could lead to a serious damage in steel fibre.

Therefore, the objectives of this study are to study the effect of corroded steel fibre in fibre reinforced concrete and to determine the capacity between corroded and un-corroded fibre in fibre reinforced concrete.

2. Literature Review

2.1 Steel Fibre Reinforced Concrete

The SFRC is a composite material made of cement, fine and coarse aggregates and discontinuous discrete steel fibres. In tension, SFRC fails only after the steel fibre is broken or separated from the cement matrix.. SFRC's composite nature is responsible for its freshly mixed and hardened state properties. In contrast to conventional concrete, the SFRC has many outstanding dynamic results, such as high explosion and penetration resistance. One of SFRC's most significant characteristics is its ability to pass stresses through a cracked section that increases concrete strength in a hardened state.

2.2 Corrosion

Corrosion is the mechanism by which oxidation reactions and steel cross-sectional reactions are reduced in the steel due to their contact with the environment. El Hassan et al. [4] reported that it is normally to divide corrosion into two stages: initiation and propagation.

The initiation stage considers the time necessary for external agents to penetrate into the concrete and cause steel depassivation, such as chloride ions, sulphate and carbonation. The stage of propagation is marked by violent corrosion, characterized by the loss of the cross-sectional reinforcement area and the gradual accumulation of rust, causing cracking and fracturing of the concrete matrix, reducing structural protection.

2.3 Corrosion in SFRC

As for Steel Fiber Reinforced Concrete, it has been commonly documented that corrosion in concrete structures less severe than corrosion in traditional reinforcing steel bars [5, 6]. By monitoring cracking at an early age by shrinkage or temperature gradients and cracking by external loads, steel fibers can minimize the entry of violent agents and concrete degradation. According to Masmoudi and Bouaziz [7], If steel fibers are rust-corroded, the comparatively low fiber volume is not sufficient to generate corrosion-related rupture stresses of larger diameter reinforcing bars and, thus, fiber corrosion is confined solely to the surface of the SFRC for well-compacted concrete. In the case of chloride-induced corrosion, local steel depassivation occurs when chlorides reach a certain limit known as the critical content of chloride or threshold of chloride, which causes a localized break of the reinforcement passive layer, a phenomenon called pitting corrosion [8]. However, the chloride threshold, which is particularly ideal for traditional reinforced concrete structures in the range of 0.4-1.0 percent, has shown itself to be considerably higher for the SFRC, with orders of up to 4.5 percent cementitious content by weight. According to Angst et al. [8], this enhanced corrosion strength of steel fibres embedded in concrete is due to the combination of

i. Short steel fibres, which avoid broad differences in electrical potential along the fibre and restrict the development of various anode and cathode regions,
ii. Manufacturing conditions (floating of fibres in the concrete matrix) enabling the creation of a very thin and well-defined $Ca(OH)_2$-rich interfacial layer, between concrete and steel, without interface voids as in the ordinary bar reinforcement,

While Steel Fibre Reinforced Concrete (SFRC) is less susceptible than conventional reinforced concrete to the effects of corrosion, its properties are inevitably changed during exposure to harsh environments. According to Granju and Balouch [9], if steel fibers are rust-corroded, corrosive environments may affect the SFRC's flexural efficiency, leading to decreases in the maximum load peak, along with a fragile and brittle post-peak behavior.

3. Data Analysis and Discussion

3.1 Accelerated corrosion test

Hammood and Mohsin [10] , G.Graeff et al. [11], Anandan et al. [12], and Marcos-Meson et al. [13] used the wetting drying cycling method as a method to accelerate the corrosion induced damage of SFRC. The process started by immersing specimens in a container with chloride solution for a certain period then followed a period of drying at ambient temperature. Table 1 shows the details of the the wetting drying cycling method used by the previous researchers.

Table 1: Details of wetting-drying cycles

Researchers	NaCI Concentration	Period for the cycles	Duration of exposure
Hammood and Mohsin [10]	3.5 %	3 days wetting 3 days drying	6 months
G.Graeff et al. [11]	3%	4 days of wetting 3 days of drying	5 months
Anandan et al. [12]	3%	1 days of wetting 1 days of drying	6 months
Marcos-Meson et al. [14]	7%	2 days of wetting 2 days of drying	2 months

As for Balouch et al. [15] and Granju and Balouch [9]. these researchers used salt spray chamber as a method to accelerate the time of corrosion induced damage of SFRC. The procedure are the same as wetting drying cycles method, where the cycles started with wetting the specimens using salt-fog spraying and then followed by dryness. Table 2 shows the details of salt-spray chamber methods.

Table 2: Details of salt spray chamber

Researchers	NaCI Content in salted fog	Period for the cycles	Duration of exposure
Balouch et al. [15]	35g/l	1 week of salted fog 1 week of dryness	7 months

Granju & Balouch [9]	35 g/l	1 week of salted fog 1 week of dryness	12 months

Lastly, Sadeghi-Pouya et al.[6] and Vidya et al. [16] used impressed current as a method of the accelerated corrosion test. This method starts by putting all the specimens in a container containing salt solution and using copper core cables linked to the positive end of the power at the titanium rod. After that, using a piece of bare steel electrode partially submerged in the solution, the negative circuit connection was given.. Figure 2 shows the setup of this method and table 3 shows the detail of the method. A specific current was set as constant to pass through the NaCI solution and specimens for specific period and table 3 shows the details of the method.

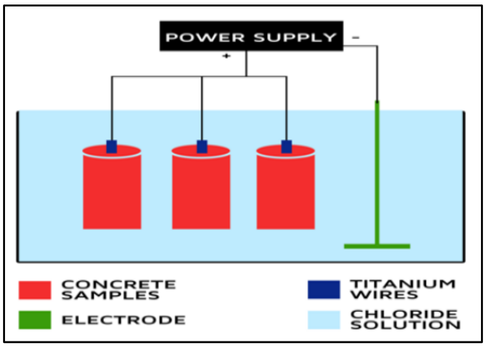


Figure 1: Setup for Impressed Current [6]

Table 3:Details of Impressed Current

Researchers	Current used	Duration
Sadeghi-Pouya et al. [6]	3A	1 month
Vidya et al. [16]	15A	24 hours

Table 4: Summary of accelerated corrosion test method used by previous researchers

Researchers	Method	Duration
Hammood and Mohsin [10]	Wetting drying cycling	6 months
G.Graeff et al. [11]	Wetting drying cycling	5 months
Anandan et al. [12]	Wetting drying cycling	6 months
Marcos-Meson et al. [14]	Wetting drying cycling	2 months
Balouch et al. [15]	Salt spray chamber	7 months
Granju and Balouch [9]	Salt spray chamber	12 months
Sadeghi-Pouya et al. [6]	Impressed current	1 months
Vidya et al. [16]	Impressed current	24 hours

Referring to Table 4, it can be seen that wetting-drying cycle is the most used method to accelerated corrosion. It even has been proven by Meson et al., [13] that it is an effective way to accelerate the corrosion-induced damage of SFRC [13]. Other than that, the impressed current method used to accelerate corrosion of steel fibre in fibre reinforced concrete can considered a good technique as the time used is short depend on the current used. Meanwhile, the use of the salt-spray chamber has been less prevalent among researchers because the time necessary for exposure is very long [13].

3.2 Compression Strength Test

The experimental work by Vidya et al. [16] on the effect of corrosion on steel fibre reinforced concrete indicates that by adding steel fibre, the compressive strength increases. After conducting the accelerated corrosion test, the compressive strength of steel fibre reinforeced concrete slightly decrease. Figure 3 shows the comparison of compressive strength before and after conducting corrosion accelerated test. It also shows clearly that there is a decrement of compressive strength after conducting the accelerated corrosion test.

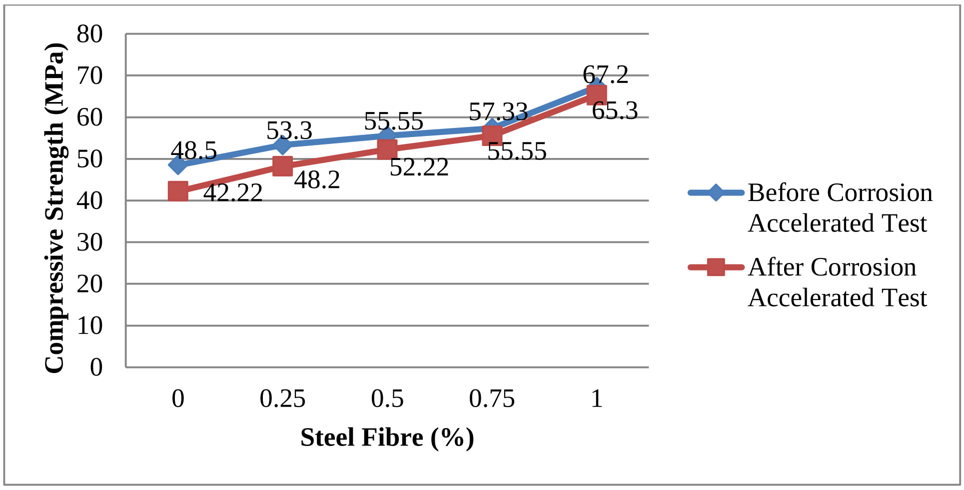


Figure 2: Comparison of compressive strength before and after conducting accelerated corrosion test [16]

The compressive strength tested by Anandan et al. [12] shows that the compressive strength of specimens increase after adding 1.5% of steel fibre. However, referring to figure 4, after conducting the accelerated test, it observed that there is a decrement for compressive strength of SFRC specimens after accelerated corrosion test being conducted.

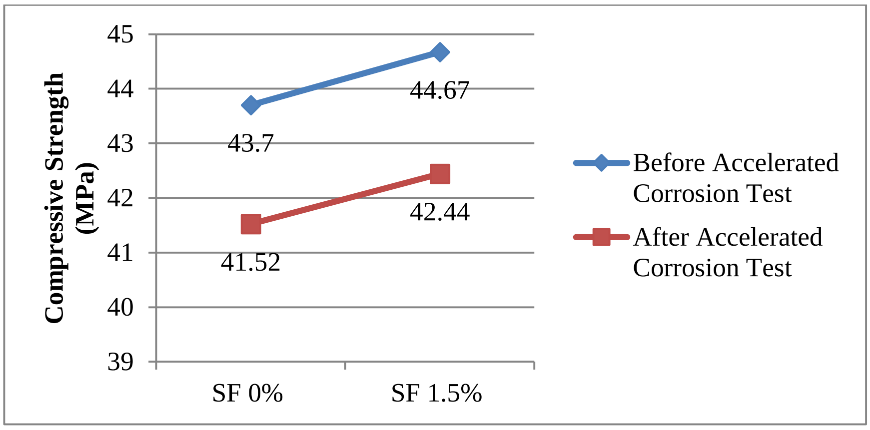


Figure 3: Comparison of compressive strength before and after conductiong accelerated corrosion test [12]

A study on corrosion durability of high performance steel fibre reinforced concrete conducted by Sadeghi-Pouya et al. [6] found that there is a decrement of compressive strength for steel fibre reinforced concrete after conducting the accelerated corrosion test meanwhile there is no difference for the ordinary portland cement (OPC) as shown in Figure 5.

Figure 4: Comparison of compressive strength before and after corrosion test [6]

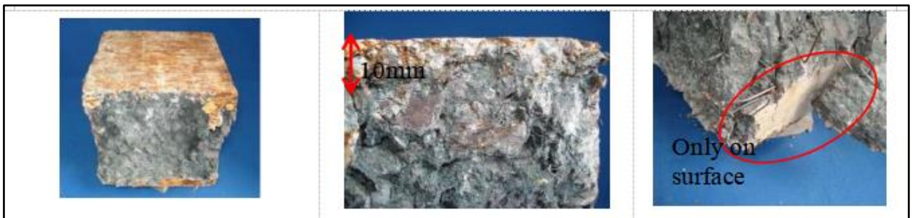
These researchers [6, 12, 16] found that the steel fibre reinforced concrete only has a very slight decrease in compressive strength after conducting the accelerated corrosion test. In general, the results showed that, with the exception of small surface rust spots, the compressive strength of steel fiber reinforced concrete does not affect by corrosion.

3.3 Corrosion Assessment

An experimental were conducted with industrial and recycled steel fibres by accelerating corrosion using wet-dry cycles in salt solution (NaCI) [11]. Recycle steel fibres are manufactured from post-consumer tires which might become alternative reinforcement due to their lower cost ant associated environmental benefits.

During the curing phase, specimens with recycled fibres it was visually observed that some fibres at the surface already presented signs of corrosion (brown spots on the specimen’s surface). Other specimens did not present any sign of corrosion. At 2 months and half, it was noticed that the specimens with recycled fibres had more superficial corrosion effects than specimens with industrial fibres. After 5 months of corrosion accelerating test, both specimens of industrial and recycled fibres are the same conditions as at 2 months and half of accelerating corrosion test, except that the corrosion spots were bigger. It was verified that specimens with industrial fibres had less corrosion spots than recycled fibres.

After a compressive strength test, internal examination was carried out by inspecting the surface samples of the fractures, it was checked that the signs of corrosion were limited to a concrete cover of a thickness not exceeding 10 mm in the case of recycled fibre specimens, while the signs of corrosion for commercial fibre specimens were limited to surface fibres only.. Figure 6 shows the internal analysis of specimens after the accelerated corrosion test conducted on it.



a) Fractures of specimens after compressive strength | b) SFRC with Recycled Fibres | c) SFRC with Industrial Fibres

Figure 5: Internal analysis of specimens after 5 months of accelerated corrosion test [11]

In the study of corrosion durability of high performance steel fibre reinforced concrete, it is observed that after one month concrete exposed to accelerated corrosion test using impressed current method, there are corrosion signs with some red and brown spots on the surface of concrete [6].

Balouch et al. [15] observed that, in surface corrosion of steel fibre reinforced concrete for high-porosity concrete matrix (W/C=0.60) case, the chloride penetrated several millimeters inside the concrete after subjected to wetting and drying cycles, spots of corrosion start appear after the first month, until the end of seventh month only the fibres with a concrete cover thinner than 1mm were corroded which cause the corrosion spot at the surface. The fibres embedded more than 1mm were not affected

Abbas et al. [17] examined the embedded steel fibre visually for signs of corrosion by cutting slices from cylindrical steel fibre reinforced concrete specimens. It is found that there was no evidence of corrosion steel fibre found beyond a depth of 5mm from the ponding surface.

Table 5 shows the summary of corrosion assessment more to corrosion at the surface. Referring to the table 5, mostly the appearance of rust spots at the surface of specimens and just a few signs of corrosion can be visualised internally.

Table 5: Summary of corrosion assessment

Authors	Subject	Method of accelerated corrosion test used	Duration of corrosion	Depth of fibres embedded in concrete corroded
Graeff et al. [11]	Corrosion durability of industrial steel fibre reinforced concrete	Wetting-drying cycle	5 months	Only on the surface
	Corrosion durability of recycled steel fibre reinforced concrete	Wetting-drying cycle	5 months	10mm
Sadeghi-Pouya et al. [6]	Corrosion durability of high performance steel fibre reinforced concrete	Impressed current	1 months	Only on the surface
Balouch et al. [15]	Surface corrosion of steel fibre reinforced concrete	Salt spray chamber	7 months	Less than 1mm (considered as only on surface)
Abbas et al. [17]	Chloride Ion Penetration in Reinforced Concrete and Steel Fibre-Reinforced Concrete Precast Tunnel Lining Segments	Wetting-drying cycle	6 months	Less than 5mm

4. Conclusion

As conclusion, the aim of this study was achieve by understanding the effect of corroded steel fibre in fibre reinforced concrete. It was found that, the corroded steel fibre leave a negative effect on specimens' surface as there are brown spot on it. These can give an uncomfortable feeling for users if these spots are beig notice in real life structures.

Next, after reviewing the previous studies, it was found that the capacity of corroded steel fibre lower than the un-corroded steel fibre. However, the amount of decline is very small and can be neglected. The strength of corroded steel fibre reinforced concrete still higher than concrete without steel fibre before accelerated corrosion test.

From reviewing the method used by previous studies, it observed that, the most use method for accelerated corrosion test was wetting-drying cycle method and the least used was salt spray chamber. The impressed current can consider as a good technique as it consumes a little time.

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