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Corrosion durability of high performance steel fibre reinforced concrete

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ABSTRACT

High performance concrete containing steel fibre has gained popularity in recent decades for use in aggressive environments such as coastal and marine structures. It is generally acknowledged that steel fibres are added to improve the toughness, abrasion resistance, flexural behaviour and impact strength of concrete. However, little information is available about the rate of corrosion of fibres in concrete with pozzolanic cementitious matrix and its effects on ductility and flexural capacity of reinforced concrete, which play an important role in long-term serviceability of concrete structures. This paper presents the results of an experimental study that was carried out by accelerating corrosion process to evaluate the effect of corrosion of steel fibres on residual compressive and flexural strength concrete. The mechanical properties of fibre reinforced concrete containing PFA and GGBS subjected to accelerated corrosion were measured and results were correlated to the estimated rate of corrosion.

INTRODUCTION

Corrosion of steel is an electrochemical process with different reactions occurring at the anodic and cathodic sites. A supply of water and oxygen is required to maintain the reaction. In new concrete the pores solution pH is about 12.5. In these conditions a stable oxide “passive” layer is formed on the surface of the steel which provides protection from corrosion. If the concrete carbonates to the depth of the steel and/or chlorides are present at above critical threshold the protection can be compromised. Products of corrosion generally occupy a larger volume than the uncorroded steel. Unhydrated ferric oxide is about twice the volume, once hydrated it may be up to 6 to 10 times the volume. (Broomfield, 1996).

Steel fibres have been used in external concrete slabs for some 30 years. The steel will be protected by the background alkalinity of the cement paste. It has been reported by researchers that corrosion is less active as compared to steel bar reinforcement (King and Adler, 2001; Bernard, 2004). A fibre, being electrically discontinuous, is not capable of giving rise to galvanic corrosion. If they do corrode, the small volume of the fibre is insufficient to create the bursting stresses associated with the corrosion of larger diameter reinforcement bars and therefore for well compacted concrete the corrosion of fibres is restricted to the surface of the concrete (Lambrechts, 2003).

Janotka et al. (1989) also studied the corrosion resistance of steel fibres and steel bar reinforcement in cement mortar incorporating various amounts of calcium chloride from 2 to 10%. The results showed that by addition of calcium chloride while the bar reinforcement displayed corrosion at 2% calcium chloride, the fibres did not indicate any harmful corrosion until the chloride content was 6%. The critical chloride threshold may thus be higher in fibre reinforced concrete than in conventional reinforced concrete.

Corrosion durability of recycled steel fibre reinforces concrete under accelerated corrosion (wet-dry condition) showed after 5 months of wet-dry process only the external part of the specimen corroded but the internal showed very less signs of corrosion. After the corrosion the strength in the concrete remained the same with only surface corrosion (Graeff et al., 2008).

EXPERIMENTAL METHOD AND MATERIALS

An experimental program was performed to evaluate the mechanical properties of the SFRC specimens containing silica fume, PFA or GGBS subjected to accelerated corrosion.

Cement

A single source CEM 52,5N Portland cement complying with BS EN197-1 made by Hanson Heidelberg UK was used in this study.

Fine Aggregate

Natural siliceous sand available in the laboratory with maximum particle size 4.75mm was used in this research. The density of sand used was 2670 kg/m^3.

Coarse Aggregate

Crushed lime stone coarse aggregate obtained from local supplier with a maximum aggregate size 10mm was used to make concrete specimens.

Super-plasticiser

A poly carboxylate based super-plasticiser Fosroc Auracast complying with EN 934-2200 was used in concrete mixes. The recommended dosage of use was 0.3 to 1.2 liters per 100 kg of concrete material.

Silica fume, Fly Ash and GGBS

Fly ash was a single source material conforming to BS EN 450-1 (2005). Fly ash was supplied and stored in air tight containers. Silica fume was a single source powder as supplied and stored in air tight containers. The material conformed to BS EN 12363-1 (2005). GGBS obtained from Hanson conforming to BS 42461 was used in this study.

Mixing, Casting and Curing

The final mix proportions of concrete specimens from trial mixes carried out are shown in Tables 1. 3% chloride (as sodium chloride salt) per weight of cement was added to all concrete mixes in order to accelerate the corrosion.

Mixing and casting of concrete was carried out in accordance with the current British Standard BS 1881-125 (1986). Fibres were the final material to be added to the fresh concrete and mixing continued for 4 minutes to ensure dispersion of the fibres throughout the concrete. A mixed metal oxide coated titanium rod was placed in each specimen as part of preparation for accelerated corrosion test. On demoulding at 24 hours, all concrete specimens were cured in hot water curing conditions for 7 days (50°C ± 2°C) and then transferred to corrosion tank containing 3% chloride salt solution.

Table 1. Concrete mix proportions

Materials	Cement	Cement replacement materials	Coarse Aggregate	Fine Aggregate	Water	Super Plastisicer	Fibre
UNIT	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3
SF	500	50	668	801	237	8	40
GGBS	208	312	1064	710	156	7.8	40
OPC	250	-	1116	655	190	4.8	40
PFA	375	175	1064	710	190.6	9	40

Figure 1. Hot curing of concrete specimens

Measurement of Compressive Strength
100mm cubes were tested in compression to BS EN 12390-3 (2009).

Measurement of Modulus of Elasticity (E-value)
Modulus of elasticity was measured in accordance with BS 1881-121 (1983). Prior to testing, demec studs were glued at 1/3 points on the generatrix of 150mm Ø x 300mm cylinders to allow measurement of deflection over a 100mm gauge length. A basic stress of 0.5N/mm² was applied and loading applied to 1/3 fc of measured compressive strength of the concrete.

Measurement of Split Cylinder Indirect Tensile Strength
Split cylinder indirect tensile strength was measured in accordance with BS EN 12390-6 (2009). The test was carried out on 150mm Ø x 300mm cylinders.

Measurement of Flexural Strength
Flexural strength was carried out in accordance with BS EN 12390-5 (2009) on prism specimens of 510 × 100 × 100mm.

Accelerated Corrosion Test
All specimens were placed in the tank containing salt solution and connected to the positive end of the power supply at titanium rods using cupper core cables. The negative connection of the circuit was provided using a piece of bare steel electrode partly submerged in the solution. Figures 2 and 3 show the accelerated corrosion test setup. A constant 3A current was passed through the solution and specimens for 1 month. This is equivalent to approximately 50-60 years life of a typical bridge exposed de-icing salts. In this arrangement steel fibres acted as a consuming anode to maintain the current flow through the concrete

specimens. Mechanical properties of specimens were measured before and after exposure to accelerated corrosion condition.

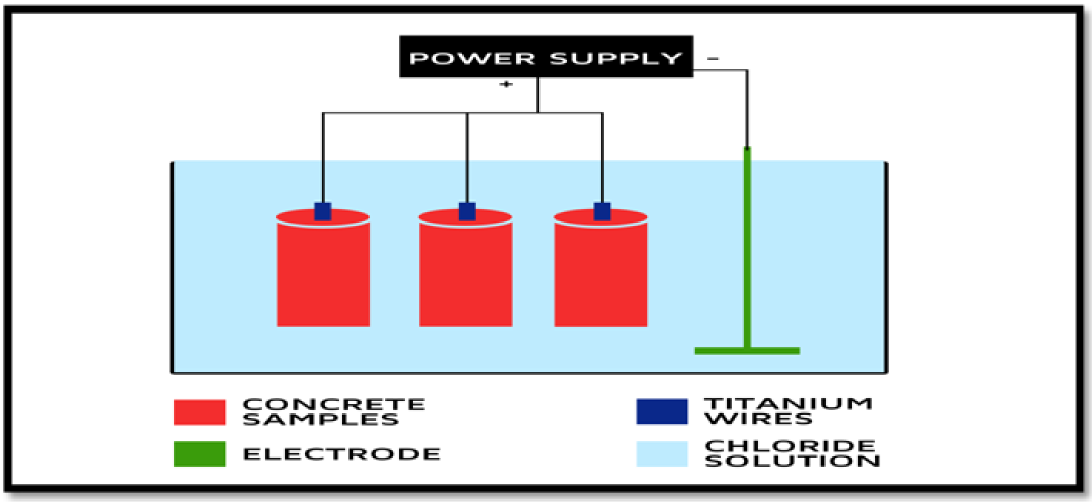

Figure 2. Schematic diagram of the accelerated corrosion test used

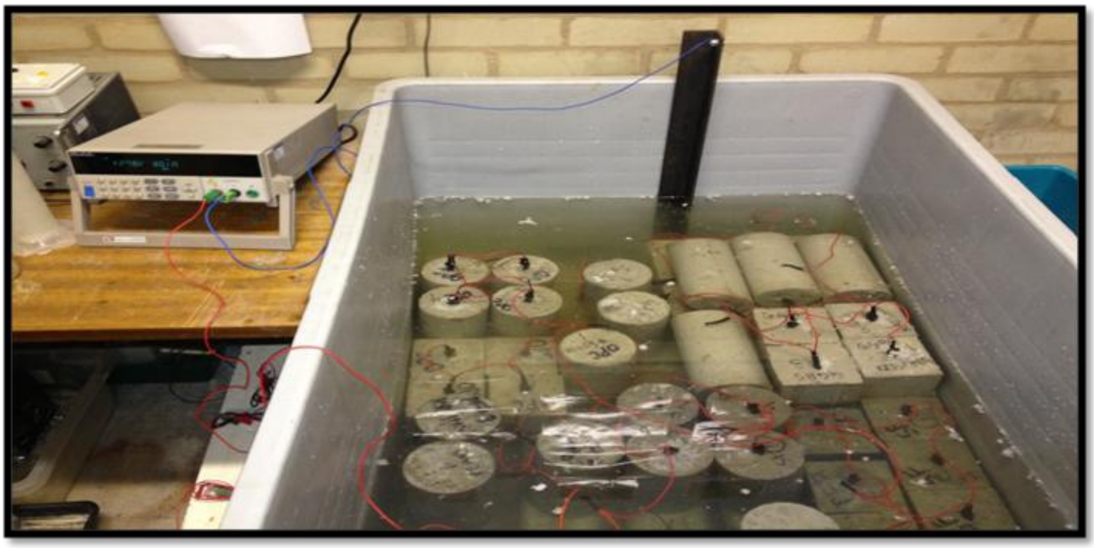

Figure 3. Corrosion tank used for accelerated corrosion test

RESULTS

Visual Inspection

Concrete specimen were examined after 1 month exposure to the accelerate corrosion condition. Expect surface corrosion and a few microcracks in the control OPC sample no sign of significant corrosion or spalling was observed. Figures 4 and 5 shows the state of specimens before and after accelerated corrosion test. It was found that steel fibres were less susceptible to corrosion. This is likely to be due to discontinuity of steel fibres in the mix or small surface of fibres.

Figure 4. Concrete specimens before accelerated corrosion test

Figure 5. Concrete specimens after accelerated corrosion test

Mechanical Properties

Figures 6-9 show mechanical properties of specimens before and after corrosion. It can be seen that specimens did not suffer from any significant strength or stiffness loss.

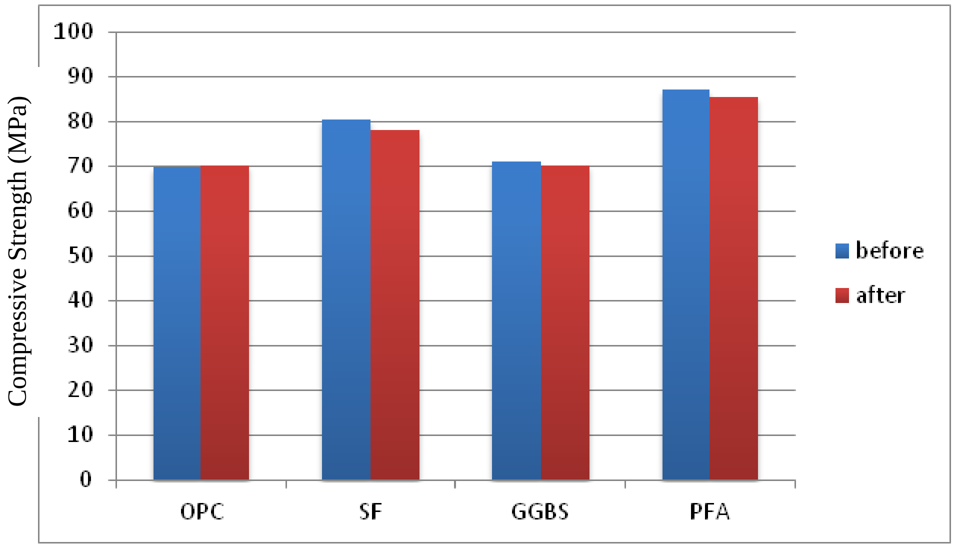

Figure 6. Comparison of compressive strength before and after accelerated corrosion

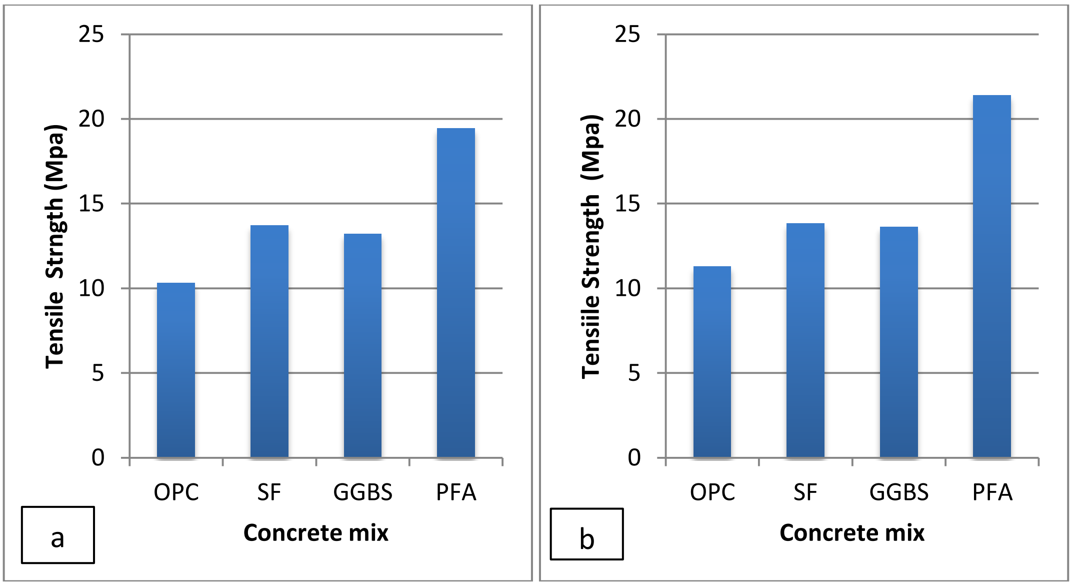

Figure 7. Comparison of indirect tensile strength a) before and b) after accelerated corrosion

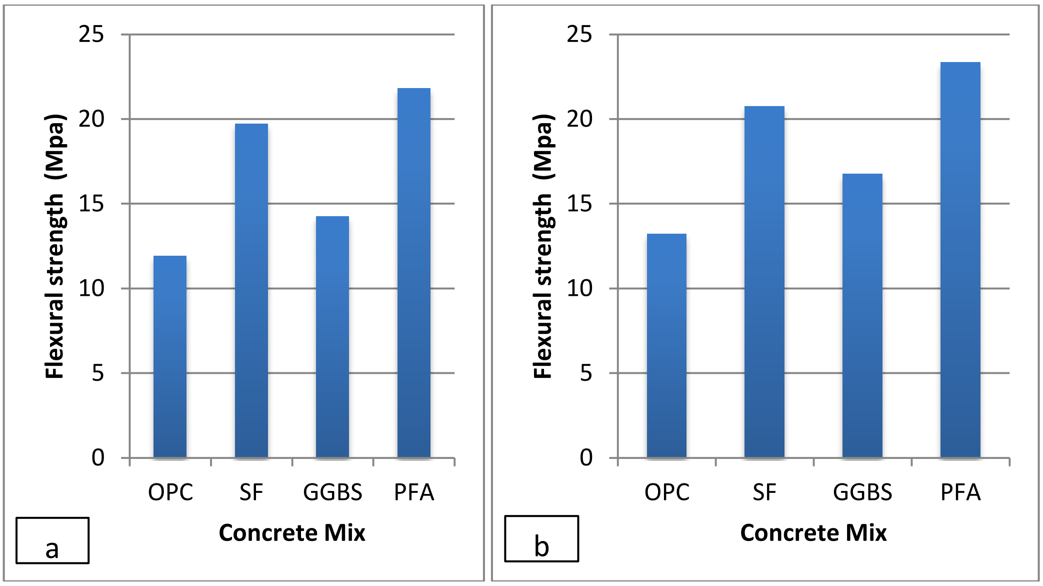

Figure 8. Comparison of flexural strength a) before and b) after accelerated corrosion

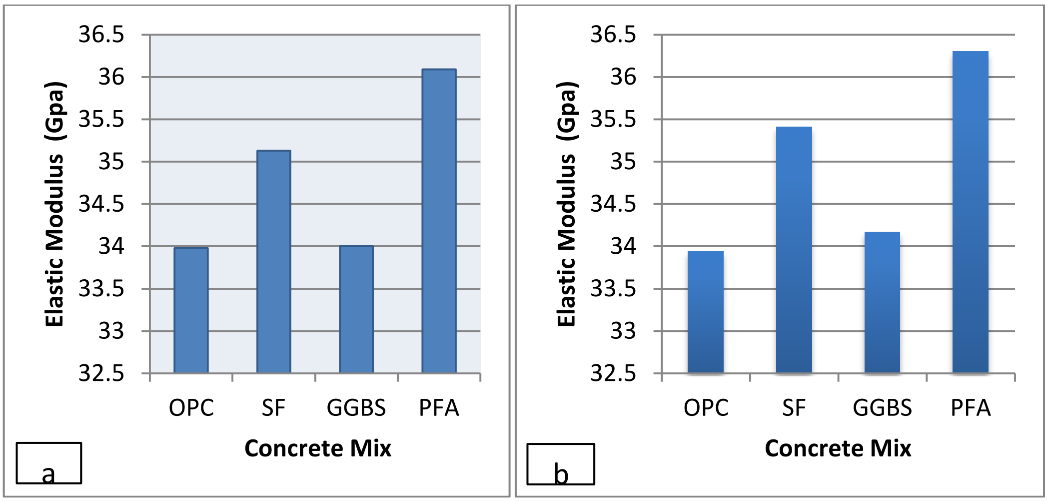

Figure 9. Comparison of elastic modulus a) before and b) after accelerated corrosion

The data show that indirect tensile strength of specimens containing cement replacement materials increased marginally during accelerated corrosion test. This is in line with expected high performance of these mixes. The flexural strength and stiffness of the concretes tested thus far was consistent and correlated with the compressive strength data. In general results indicated that steel fibre concrete specimens were not significantly affected by corrosion except minor surface rust stain.

CONCLUSION

Steel fibre reinforced concrete specimens containing SF, PFA and GGBS as cement replacement were exposed to accelerated corrosion test. Mechanical properties of specimens were measured before and after corrosion. The following conclusions can be drawn:

1) The impressed current procedures used to accelerate corrosion in steel fibre reinforced concrete can be considered as a good technique to imply corrosion in concrete specimens in a small period of time.
2) Steel fibres appear to present less damage than the normal steel bar used normally in corrosion tests. OPC specimens developed more external rust.

3) From flexural and tensile behaviour of corrosion steel fibre concrete it was observed that the performance of specimens was not reduced by corrosion attack. The same conclusion can be extended to compressive results, which showed that, even if specimens are externally corroded, this has no influence on the compressive strength of the specimens. Marginal increase in the strength of specimens after corrosion test is likely due to the age of the specimen.

4) The overall analysis of the results showed that corrosion of fibres can be noticed only externally. Less sign of corrosion was observed in specimens containing cement replacement materials i.e. SF, PFA and GGBS.

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