The Effect of Micro- Steel Fiber on the Corrosion Steel Reinforcement

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Abstract. There are many possible sources of ion chloride which can be open to concrete during service. Structure thesaurus to the sea may be sprayed with salt mist or seawater carried by the wind. In order to understand the behaviour of structures, different levels of corrosion must be studied. The current study has been taken up to investigate the behaviour of Reinforcement Concrete beams (RC) and bond strength of specimens exposed to 5% chloride solution, to cause corrosion of reinforcement. Two types of mixing by using Ordinary Portland Cement (OPC) type (I) concrete (with and without using micro steel fiber $V_f=1.2$) to cast eight reinforce concrete supported simply beam. Corrosion was accelerated using electrical current with different density to cause mass loss in steel bar with different levels of 6 %, 10 %, and 16 %. The results of the bond test and beams show a decrease in capacity with increasing the corrosion. The micro steel fiber causes an increase in bond strength of concrete ranged from (40-60%), and an increase in ultimate strength of beams ranged from (4 to 38 %) as compared with the beam without steel fiber.

Keywords: Corrosion, Corrosion level, current density, Micro steel fiber, OPC concrete, RC beam.

1. Introduction

Corrosion of reinforcement has been identified as the deterioration mechanism of reinforced concrete structures, which seriously affect the safety and integrity of structures, corrosion increases its volume from 2 to 6 times compared to the original steel; that cause internal expands the size of the tensile pressure development in the concrete [1]. Thus, the corrosion affects the mechanism of the bond between concrete and steel.

Berrocal et al. [2], indicated that, the effects of steel on concrete that were summed up that fibers interlock the cracks, increase the tensile strength and keep the member free of corrosion despite high chloride content and rely on the opinions of published experimental indications notice that the fibers had little influenced and affected the corrosion rate of the bar. Passive fibers are considered to be insulated as long as the passive layer is intact, but they will become conductive if corrosion initiates, resulting in a decreased concrete resistivity. As well as rust fiber is usually confined to fibers on the surface or cracks, the impact of low resistance has not been studied due to the existence of fibers connected to the rate of corrosion in reinforcing bars. In recent years, due to the simplicity of construction and diversity of reinforced concrete made of the steel fiber reinforced concrete (SFRC), their use has increased significantly SFRC is currently used in many fields of civil engineering such as airport pavements, hydraulic structures, supporting underground tunnels, coatings with shotcrete or sprayed concrete ([3]; [4]; [5]).
Corrosion of reinforcing by the ion of chloride is one of the major causes to deterioration of the structures by oxidation reinforcing steel [6]. That degradation is due to industrial growth in the coastal area around the world, where the salt is a major negative factor. A slight amount of chloride ion is found in the environment. It can be found in the mixtures material. By taking advantage of these products, small amounts of chloride ions add to the mix, especially when additives are used [7]. The chlorine concentration necessary to break the passive steel layer is related to specific parameters like tri-calcium aluminate (C3A), tetra calcium of aluminoferrite (C4AF), water-cement ratio and pH [8]. The medium resistance decreased because of the ion’s chloride, when the ionic concentration of the matrix pores increased, the electrical conductivity increases as well as velocity of the rust. One of the most important prerequisites of reinforced concrete construction is an adequate bond between the reinforcement and the concrete.

This work has been done to research the influence of corrosion on the performance of reinforced concrete beams, especially on the middle and with maximum crack. The following are the main points of the study:
1. OPC and FRPC were used for casting the specimens.
2. Bound strength; cubes with steel bar at its center have been cast and tested in Pullout test.
3. Accelerator corrosion using impressed current technique was taking on for achieving the chosen corrosion levels.
4. The specimens were cast and tested under four-point loading flexural strength.

2. Experimental Investigation

2.1 Materials
The materials used for the experimental works are as follows:

2.1.1 Cement
Ordinary Portland cement, Type I (OPC), used through this study. Tables 1 & 2 illustrates the chemical composition and the physical properties of the cement, which conformed to the provisions of Iraqi specification standards (No.45) 1984 [9].

| Table 1: Chemical composition and the main compound of the cement used. |
|--------------------------|--------------------------|--------------------------|
| Grains                  | OPC No.      | Limits of OPC No.45820     |
| SiO₂                    | 23.2%         | > 22%                     |
| Al₂O₃                   | 30.1%         | > 28%                     |
| Fe₂O₃                   | 5.0%          | > 4.5%                    |
| MgO                     | 4.0%          | < 5.5%                    |
| Loss on ignition        | 3.5%          | < 4.5%                    |
| Lime saturation degree  | 0.95%         | < 1.0%                    |
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| Moisture content        | 2.1%          | < 3.0%                    |
| C₃       | 43.1%         | > 45%                     |
| C₄AF    | 16.1%         | < 18%                     |
| L.cl.    | 2.0%          | < 2.5%                    |
| C₃       | 0.05          | < 0.6%                    |

| Table 2: Physical properties of cement used. |
|---------------------------------------------|
| Physical properties                       | Test result | Limits of IQS No.45820 |
|---------------------------------------------|
| Specific surface area cm²/gm               | 2.79         | > 2.50                   |
| Initial setting, hr.                       | 0.25         | > 45.00                  |
| Final setting, hr.                         | 0.04         | < 10.00                  |
| Compressive strength, N/mm² 3 - day        | 20.0          | > 15.00                  |
| Compressive strength, N/mm² 7 - day        | 29.0          | > 22.00                  |
| Soundness (Anticracks), %                 | 0.4           | < 0.8                    |

2.1.2 Coarse and fine aggregate
Natural sand with a maximum size of 4.75 mm and crush coarse aggregate with 19mm maximum size were used in this investigation. The test of the grad result are conform to Iraqi specification [10]. Table3 and 4 are shown the coarse aggregate and fine aggregate result.
2.1.3 Steel reinforcement
The deformed bars are used with two size Ø12, Ø6 mm (Medium carbon Ukrainian steel). The tension tests of all these bars gave the properties listed in Table 5. The result of testing bars met the ASTM A615-16[11] requirements for Grade 75.

2.1.4 Supperplaster(SP)
A light brown superplasticizer (SP) commercially named Betonae- BVS 2.2 was used. It acts as a dispersing agent, breaking down the agglomerate of cement particles and enables water in the mix to perform more efficiently. Betonac - BVS 2.2 delays the initial hydration of cement and complies with ASTM C494-13 type G [12]. The technical Properties are listed in Table 6.

2.1.5 Micro steel fiber
The short straight brass plated with gold color and aspect ratio (75%) were used as Fig.3 The source of import is china. The properties are listed in Table 7.

2.1.6 Water
Ordinary potable water was used for mixing and curing of all samples.
2.2 Test Program.

2.2.1 Mechanical properties

The mechanical properties of the mixes were investigated by casting control specimens as the following specimens were required:

1- Cubes with 150mm dimension for compression strength according to BS 1881 Part 116: Part 4:1983[13], and cylinder with the dimensions (150*300mm) tested according to ASTM C39-15[14].

2- Cylinder with 150*300mm for splitting tensile strength, performed according to ASTM C496-14[15].

3- Prism with 100*100*400mm for flexural strength (Modulus of rupture), according to the ASTM C78-10 [16].

2.2.2 Bond strength

Cubes with (150) mm and one bar of 12mm diameter, put at the center while casting and cured in the same salt solution as beams, used to measure the bond strength in pull-out test [17].

2.2.3 Beam specimens

Simply supported beam with dimension (100*150*1000mm) and reinforced with two bars $\Phi$ with 12mm in diameter as main tension reinforcement (the two bars were extended to a distance (50mm) to achieve the accelerated corrosion), as well as two $\Phi$ 6mm as compression reinforcement. Stirrups with $\Phi$ 6mm distributed at 60mm along the beam, as shown in Fig. 1.

2.3 Mixing, casting, and curing

The concrete mixture was designed in accordance with ACI211.191[18] to obtain a minimum compressive strength of 40MPa at 28days. The mix percentage was 1:1.5:3 (cement: sand: coarse aggregate) from the weight with a w/c ratio of 0.45 (casting at a temperature of 47 - 60°C). The mixing weight was as Cement: Sand: Corse aggregate 380: 570: 1140 kg/m$^3$, respectively, with 171 kg/m$^3$ water, with slump range 100±5 mm. Table 8 shows the detail of the mixes, the super-plasticizer percent was changed to keep a constant slump. The vertical pan mixer was used to mix the concrete; the interior surface of the mixer cleaned and moistened before placing the materials. All mixing works with vibrating took about 15-20 minutes then the mixture was ready to cast in molds and forms and the surface was level. Mechanic characteristics, compressive strength (150mm cubes), splitting strength (150*300mm cylinders), flexural strength (100*100*400mm) as well as to Pull out cubes, were studied by control specimens cast with the same mix for the beam. Beams and control specimens were covered for 24 hours; then demoded and cured in a water tank for 28 days. Fig. 3 shows the process of casting some beams [19]
2.4 Accelerated Corrosion Technique

Beam specimens and bond strength cubes (except reference beam) were subjected to an accelerated corrosion condition. Plastic containers with the external steel plate were prepared to expose the beams and pull out cubes to 5% NaCl solution in a tank, (prepared previously by adding 5gm salt to 20 liters of distilled water as drawn in Figs. 4, 5 and 6). After moist curing for 28 days, the beams were reverse upside down and left for 24 hours; then a container was fixed in the middle third of the beam and filled with 5% in NaCl solution. Figs 7 and 8 indicate the exposed method for beams and pull out cubes. The specimens were immersed in a cycle of 3-day to ensure the full saturation condition and then remove on the air one day, then; were connected in parallel to a DC power supply of 13 V and the current passing through each specimen was recorded. The concrete was acting as the electrolyte, the steel bars (Φ 12) became anodic, and the steel plate, attached at the beam and pull out, served as the cathode to connect the power supply, as indicated in Fig. 9. The percent reduction in mass (6%, 10%, and 16%) was calculated experimentally by weighting the steel bar before and after corrosion. The number of days was primarily determined to cause the corrosion percent mass loss required as listed in Table 9. The beams were cleaned after corrosion testing and the crack width and crack pattern was drown, as shown in Fig. 10 for the six beams of tests. It was noticeable that longitudinal cracks occurred mainly on the sides of the beams, with dark brown color in the surface extent of damage to concrete cover when the steel corrodes.
3. Test Results

3.1 Mechanical properties
The results of the control specimens were listed in Table 10; which indicate that using micro steel fiber gave a higher result and an improvement on all results.

| No. of groups | Corr. percent | Current (A) | Required time (days) | Crack width (mm) |
|---------------|---------------|-------------|----------------------|------------------|
| G1 | 5% | 0.24±0.22 | 18 | Top | 1.5 |
| | 10% | 0.24±0.20 | 24 | Side | - |
| | 15% | 0.24±0.17 | 30 | - | - |
| G2 | 5% | 0.46±0.35 | 26 | - | - |
| | 10% | 0.46±0.26 | 37 | - | - |
| | 15% | 0.46±0.19 | 45 | - | - |
3.2 Bond strength result.

The bond strengths developed in the steel bars depend on splitting tensile strength and concrete strength. For all groups, the failure load values were reduced with increasing the corrosion percent as indicated in Table 11. It was noticed that the specimens with micro steel fiber perform better than normal concrete specimens. The increase in bond strength was (60.7, 55.7, 45.8 and 39.7%) for corrosion percent (0, 6, 10, and 16%), respectively as compared with specimens with CC. This is due to the expansion of the corroded steel bar, corrosion products at early stage of corrosion increase radial stresses between bar and concrete and hence increase the frictional component of the bond. However, further corrosion develops longitudinal cracking and reduction in the resistance to the bursting forces generated around the steel bar. At late stages of corrosion may reduce in the rib height of the deformed bar, which causes a reduction in the contact area between the ribs and the concrete leading to a reduction in the bond strength. The failure mode of all the groups was splitting the cube along the steel bar and cause displacement of bar less than 5 cm approximately as shown in Fig. 11.

3.3 Flexural beam results

An eight simply supported reinforced concrete beams were divided in two groups G1 cast with CC and G2 cast with FRC concrete, tested up to failure under the action of two point’s symmetric loading. Table 12 shows that the results of the beam with steel fiber have higher values for first crack and ultimate loads with all corrosion percent, which need more energy to fail down and cause higher deflection results. The reduction in ultimate strength for beams in group G1 was 22.49%, 53.88% and 55.14% for corrosion percent of 6%, 10%, and 16% respectively [19]. However, the reduction in ultimate strength for G2 was 11.62%, 28.26%, and 41.09% for corrosion percent of 6%, 10%, and 16% respectively, which is more than beams with group G1. Fig. 12 and 13 indicate the load deflection relations for all beam specimens at mid-span. In fibrous beams, more energy was required for the cracks to propagate since the majority of these cracks crossed by the randomly oriented fibers, which cause the higher result of deflection and higher ductility. The concrete cover detracted due to steel fiber corrosion, and the crakes were small and distributed randomly. The test results showed that the presence of transverse cracks in the tension zone of the reinforced concrete beam does not affect the efficiency of steel fiber. The fibrous beams require higher absorbed energy to cause failure, as shown in Fig. 14. The absorbed energy was calculated as the area under the load-deflection curve for each beam.
In all tested beams, cracks have initiated due to steel corrosion in the tension face of the middle third of the beam. As the load increases, the cracks increase in the number and decrease in width. Figs. 15 and 16 show the crack pattern for beams under monotonic loading, which indicate flexural failure as well as to concrete crushing in some of them.

| Groups | Corr. (%) | First crack (cm) | Percent reduction in crack (load) (%) | Max. Load (kN) | Percent reduction in ultimate load (%) |
|--------|-----------|------------------|--------------------------------------|----------------|---------------------------------------|
| G1     | 0%        | 4.25             | -                                    | 155.6          | -                                     |
|        | 6%        | 2.50             | 11.70                                | 125.0          | 22.40                                 |
|        | 10%       | 2.00             | 14.51                                | 106.0          | 19.80                                 |
| G2     | 0%        | 4.75             | -                                    | 154.0          | -                                     |
|        | 6%        | 3.50             | 13.75                                | 108.0          | 11.45                                 |
|        | 10%       | 2.75             | 14.79                                | 114.0          | 24.28                                 |
| Fiber  | 0%        | 4.40             | -                                    | 147.0          | -                                     |
|        | 6%        | 3.20             | 11.73                                | 111.0          | 11.45                                 |
|        | 10%       | 2.40             | 14.73                                | 114.0          | 24.28                                 |

Fig. 15: Experimental ultimate results of beams G1 & G2

Fig. 13: Load-deflection relation of groups G1 and G2.

Fig. 14: Energy absorption with corrosion percent for beam specimens.

Fig. 16: Crack pattern for beams G1.
4. Conclusions

The following conclusion has been indicated in the investigation:
1. The results of the control specimens for group G1 gave a lower result than group G2.
2. In general, using micro steel fiber gave a higher result and less crack width.
3. Cracking and ultimate load capacity results of tested beams showed a reduction with increasing corrosion percent. With the addition of steel fibers, noticeable enhancement in both the ultimate capacity and ductility.
4. Beams with steel fiber required higher absorbed energy than normal concrete.

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