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Corrosion Performance and Hydrogen Evolution in Galvanized Steel Fiber Reinforced Concrete

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1: Introduction

A new method was applied to protect corrosion of reinforced steel bars by using galvanized steel fiber. The galvanized steel fibers in contact with the steel bars act as a sacrificial anode and cathodically protect embedded steel bars exposed under an accelerated artificial aggressive environment (1,2). Due to using galvanized steel fibers it was needed to study durability, strength and hydrogen gas evolution in fibrous concrete. Results of experiments showed that galvanized steel fibers had good performance resistance corrosion and depth of corrosion was limited to 5-7 mm from exposed surfaces. Although, corrosion was occurred for fibers which were on the exposed surfaces but any spalling or crack phenomenon were not observed. The corrosion phenomenon in the fibers at the surfaces or inside of specimens did not show any decrease in ultimate compressive strength of galvanized steel fiber reinforced concrete compressive strength. On the other hand, the ultimate compressive strengths not only did not decrease but also an increase of min. 12% and max. 49% compared to strength of 28-day was obtained, even 2 and 5 months after exposure and existence of hydrogen gas evolution in the fibrous concrete matrix.

The study of hydrogen gas evolution due to zinc coating of fibers and results of experiments showed that hydrogen evolution is either a time-variable or a function of pH-value. Starting time of hydrogen evolution in a solution with a higher pH-value was earlier than a low pH-value. Also, it was concluded that, for the pH-value of 12.65, hydrogen evolution started 8 hours after ending final set of cement.

2: Experimental Program

The study to examine the effects of deicing salts on the corrosion of galvanized steel fiber reinforced concrete and hydrogen evolution were carried out by three series of experimental specimens. The main difference in the series of specimens was due to initial rate of additional salt. On the other hand, for the first series of specimens, to accelerate electrolytic corrosion, 3 kg/m^3 NaCl by weight of concrete was added to concrete during mixing. Mixture proportions of the second and the third series were as same as the first series, but with initial salt addition of 1.0 kg/m^3 and 0.3 kg/m^3, respectively. To evaluate ultimate compressive strength of such a fibrous concrete due to corrosion phenomena and hydrogen evolution ϕ10x20 cm compressive specimens were used and tested at 28 days, 2, and 5 months after exposure under an artificial aggressive of wet-dry acceleration test. The wet-dry cycles consisted of 12 hours wet and 12 hours dry every operational day. The wet portion used an artificial salt solution made by adding 5.0 percent sodium chloride by weight to tap water was then continuously sprayed over the each specimen with some specimens being withdrawn for evaluation at 60, and 150 days after exposure. The solution had an average temperature of 35°C temperature and initial pH of 6.8. The dry cycle consisted of a 35°C air temperature which circulated over the specimens.

The applied fibers were sheared steel fibers which were prepared from hot-dip zinc-coated steel sheets. The amount of fibers in the concrete mixture was 1.5 percent by volume of fibers or 120 kg/m^3. In accordance with the high rate of cement effect on mitigation of corrosion, the experimental data were obtained by using a moderate mixture with 280 kg/m^3 ordinary portland cement, 20 mm gravel, sand percentage of 45%, and W/C ratio of 0.55.

The study of hydrogen gas evolution due to zinc coating of fibers was carried out with 130 gm. of galvanized steel fibers in two types of saturated calcium hydroxide solution with initial sodium chloride (NaCl) addition of 0.3 gm./L. The first type of solution had pH-value 12.65 and the second type was 12.9. While the steel is cathodically protected by zinc coating, the hydrogen gas so liberated. However, such evolution of hydrogen can be eliminated by passivation of zinc with chromate ions. The passivation was carried out with either 10 ppm chromium trioxide (CrO_3) or 30 ppm sodium chromate ($Na_2Cr_2O_7$).

3: Results And Discussion

Mechanical properties of the galvanized steel fiber reinforced concrete were determined from ϕ10x20 cm cylinders after 28, 60, and 150 days exposure. Ultimate compressive strength at 28-day, for the first, the second, and the third series of galvanized steel fiber specimens, an average 3 specimens, f'_{sf}, of 32.9 MPa, 20 MPa, and 16.7 MPa were obtained, respectively. After 2, and 5 months of exposure, the ultimate compressive strength of the first series of specimens, showed an increase of 12.1%, and 36%, respectively. For the second series, variations in the 2, and 5 months of exposure were an increase of 31 %, and 41 %, respectively. Finally, an increase of 26%, and 49% in the ultimate compressive strength of the third series were obtained after 2, and 5 months of exposure, respectively, as shown in Fig. 1.

Keywords: Galvanized steel fiber, accelerated test, corrosion, hydrogen evolution, chromate passivation.
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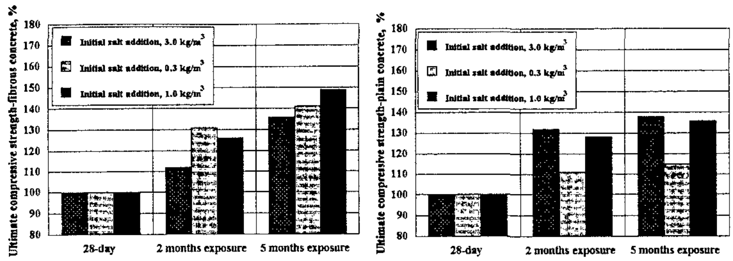

Fig. 1 Comparison of ultimate compressive strength of galvanized steel fiber reinforced concrete and no-fiber concrete specimens

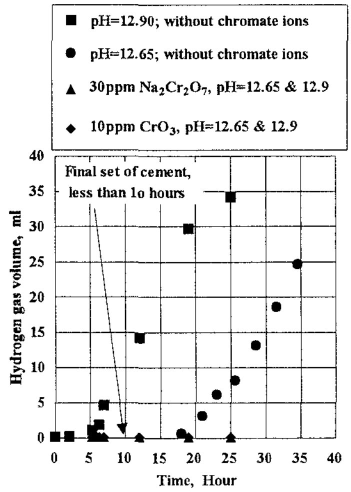

Fig. 2 Hydrogen evolution in saturated calcium hydroxide solution

Results of the chloride analysis showed that, in all the three series of specimens, the galvanized steel fibers were in concrete with chloride concentrations well above a threshold level of 0.025 percent by concrete weight. The analysis of chloride in the fibrous concrete confirmed that the fibers in the general, and galvanized steel fibers in particular, absorb more chloride ions from concrete matrix. According to the results, 5 months after exposure the amount of the chlorides were 7 times of threshold level in the depth of 17 mm from the directly exposed surfaces. It means, the chloride values for 5 mm depth below the directly exposed surfaces were about 20 times of a threshold level to initiate corrosion.

According to 6 months totally exposure in an artificial aggressive environment, superficial corrosion of galvanized steel fibers was occurred and limited to the maximum 7 mm depth from the exposed surfaces. It means, in the three series, although the rate of cement in the mixtures was not high and the chloride amounts exceed threshold, but corrosion of galvanized steel fibers was not extensive and serious. However, corroded fibers were easily observed on the direct and indirect exposed surfaces. Scattered corrosion phenomenon of galvanized steel fibers occurred under depth of exposure surfaces, but this state was not propagated to other fibers. The superficial corrosion of galvanized steel fibers, even, under 0.5 mm beneath the directly exposed surfaces was also observed. It seems, the galvanized steel fibers have enough potential to inhibit corrosion and its propagation under aggressive conditions. Volume expansion force due to corrosion products of a galvanized steel fiber compared to the common steel fibers was negligible and thus, any spalling phenomena of concrete was not observed, even around the corroded fibers.

According to the results, hydrogen evolution started to occur after 5.3 hours in the solution with a pH-value 12.9. However, in the solution with pH-value 12.65 after 18 hours the evolution started, Fig. 2. On the other hand, hydrogen evolution in a low pH-value occurred at least 8 hours later final setting time of cement. In the solutions with chromium ions passivation conditions of fibers was occurred and hydrogen evolution absolutely eliminated. When chlorides are present, however, the levels of chromate used to provide inhibition for hydrogen evolution from galvanized steel fibers may not be sufficient, however, in this study the level of chromate ions with 10 ppm CrO_3 and 30 ppm $Na_2Cr_2O_7$ were sufficient.

4: Conclusions

1: Corrosion of galvanized steel fibers have not any mechanism for propagation, and thus, entire matrix of concrete was in a durable conditions at the end of 6 months of severe environment.
2: Although galvanized steel fibers were corroded on the exposed surfaces and intrusion of corrosion products of fibers into concrete caused and also hydrogen evolution was occurred, however, there was not observed any abnormal phenomenon in the mechanical properties of galvanized steel fiber reinforced concrete after 6 months of severe environment.
3: Hydrogen evolution in saturated calcium hydroxide solution with initial salt addition showed that the gas evolution occurs after final set of cement with pH of 12.65. Volume of hydrogen gas evolution for low pH-value solution during 25 hours was about 80% less than for a high pH-value solution.
4: Chromate was used to provide inhibition for hydrogen evolution with the level of 10 ppm CrO_3 and 30 ppm of $Na_2Cr_2O_7$. This level of chromate was sufficient to inhibit hydrogen gas evolution.

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