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RAPID CORROSION TEST ON CARBON FIBER FABRIC STRENGTHENED CONCRETE

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ABSTRACT

Corrosion is a big problem to cause structure deterioration for reinforced concrete. During the use of existing low-strength structural elements, there is a need to strengthen over time. Saltwater, deicing chemicals, and freeze-thaw cycles can cause structural deterioration over a longer period. Most older buildings and bridges were constructed according to older design codes. These structures are vulnerable during extreme events and need to be retrofitted to meet the current codes and standards. The use of composite materials for strengthening and repairing engineering structures has been increasing rapidly in recent years. Existing studies have shown that the use of carbon fiber reinforced polymer (CFRP) materials restore or improve the column original design strength for possible axial, shear, or flexure and in some cases allow the structure to carry more load than it was designed for. Carbon fiber fabrics have a wide application area with their easy and fast application, light weight and high strength. In this study, concrete elements produced with low, medium and high strength are wrapped with carbon fiber fabric. The concretes were subjected to rapid corrosion test. According to the findings, Corrosion starting time was considerably increased by increment of plain concretes. Also, no corrosion was obtained on CFRP wrapped reinforced concrete samples.

Keywords: Corrosion, concrete, strengthening, carbon fiber.

1. Introduction

Fibre Reinforced Polymers (FRP) composites have been effectively used as passive jacket of concrete columns in the last three decades. It is known that concrete in compression expands radially leading to internal cracking (Pellegrino and Sena-Cruz, 2016). The confinement, first, delays cracking and, then, prevents the relative displacement of disaggregated concrete pieces, thus allowing concrete to reach higher compressive strength and higher ultimate axial and lateral strains (Bank, 2006). Fibre Reinforced Polymer (FRP) fabrics are composite materials containing an epoxy matrix reinforced with fibers. Common types of FRP fabrics used are Carbon FRP (CFRP), Glass FRP (GFRP), and Aramid FRP (AFRP). Due to its high strength-to-weight ratio and cost effectiveness, the use of FRP fabrics has been useful and is gaining popularity in the rehabilitation of structures (Liu et al., 2001; Sim et al., 2005). FRP fabrics may be slightly more expensive than steel plates. However, since welding or bolting is not required, the cost of labour is much lower.

Studies found that significant increase in the ultimate strength can be achieved through using CFRP fabric (Sen et al., 2001; Tavakkolizadeh and Saadatmanesh, 2003). Selvaraj and Madhavan (2017) found an improvement in the flexural moment capacity of steel structures strengthened with CFRP. El Damatty et al. (2003) found that steel beams strengthened using GFRP fabric resulted in increased elastic stiffness and yield and ultimate moment capacities. However, previous studies found that the ductility of beams rehabilitated using CFRP or GFRP fabrics decreased and this occurs due to the brittle failure mode of FRPs (Tomlinson and Fam, 2014).

For reinforced concrete and steel bridges and parking garages, corrosion is one of the main causes of deterioration, and the rate of corrosion is accelerated due to the widespread use of de-icing salts in the world. Various methods are available for rehabilitating corroded steel beams or reinforced structures. One of the most common method of corrosion repair includes wrapping of structure members with CFRP (Galal et al., 2012). Although the performance of CFRP-confined concrete is well studied, performance of CFRP wrapped concretes under corrosion was not investigated extensively.

A concerning issue with the use of CFRP for reinforcement rehabilitation, in this study, rapid corrosion effect on the plain and wrapped reinforced concrete samples were investigated.

2. Experimental program

2.1. Materials used

A ready-mix concrete was used in the present work. The maximum aggregate size was 22.5 mm. The experimental campaign of the confined concrete specimens herein described (see details in Section 3.2) was conducted in 15 consecutives working days. During test time, the concrete age was 28 days. Until the testing date, all specimens were kept in standard laboratory conditions (temperature around 20 ºC, relative humidity around 50%). In the end of the experimental campaign, 3 plain cylindrical concrete specimens, with a diameter of 100 mm and a height of 200 mm, were tested.

Commercially available epoxy resin, along with a hardener, was used as matrix material in the fabrication of different samples. Epoxy resin has a modulus of 3.42 GPa, and a density of 1100 kg/m^3. A mix ratio (by weight) of epoxy resin (4 parts) and hardener (1 part) was used for processing, as specified.

SPN U 300 carbon fabric was used as reinforcement element. SPN U 300 FRP (Fibrous Polymer) is a woven fabric made with E Glass thermoplastic glass fibers (90°) which is placed perpendicular to the axis of unidirectional carbon fibers (0°). Technical properties of carbon fabric are presented in Table 1.

Table 1. Technical properties of carbon fiber fabric

Property	Value
Tensile strength, MPa	4200
Modulus of elasticity, MPa	240000
Elongation at break, %	1.8
Unit weight, g/cm^2	300
Section thickness, mm	0.18

2.2. Preparing of test samples

The CFRP jacket was manufactured by wet lay-up method, following the best practices according to the following process: (i) application of a layer of epoxy resin over the dry concrete surface with a brush; (ii) saturation of the fabric layer with epoxy resin; (iii) application of an CFRP layer over the epoxy resin wetted concrete surface, adjusting it manually; (iv) pressure application by means of a ribbed rigid roller, in order to expel both the epoxy resin excess and air in the composite, and also stretching the latter. All the specimens were then cured at room laboratory for at least 7 days after wrapped (Fig. 1).



Figure 1. Wrapping and CFRP layered reinforced concrete samples

2.3. Corrosion test

Concrete specimens were produced by using the cylindrical mould of size ø100x200 mm. A reinforcement rebar was held in mid-position and concrete was poured into the mold. After 24 h, the reinforced concrete specimens were demolded and cured in a water pool until the time of test was reached. The specimen could cure for 28 days. The specimens were cast in various strength classes such as C10, C25 and C40 for corrosion test.

The test setup consists of a constant DC supply providing constant voltage of 50 V. The test was carried out in a 4% NaCl solution with an embedded reinforcement bar as a working electrode and a copper bar as a counter electrode. The variable parameter current was recorded at every 20 min interval in constant voltage study. The set up was kept for until cracking of concrete samples without disrupting the power supply. After cracking of concrete, the solution turned to reddish brown in color due to the formation of rust. Then the specimens were removed from the setup, dried in air, visually inspected and carefully split open to access the corroded steel bar. Simultaneously, the temperature of the solution was recorded together with the voltage value. The amount of corrosion in terms of mass loss of the reinforcing bar due to corrosion can be determined by the following equation:

$$\%W_c = [(W_0\text{-}W)/W_0]\times 100 \quad (1)$$

Where, W_c is weight loss after corrosion test; W_o is the initial weight of rebar and W is weight of rebar after corrosion test.

3. Results and discussions

Ordinary concrete contains pores changed from capillary to macro size. These voids allow water to reach rebar through concrete structure. If there is enough oxygen and moisture in the concrete, the corrosion process starts immediately (Sim et al., 2005). Rapid corrosion tests are widely by electrical stress method. When there is a difference in electrical potential along the steel reinforcement in concrete, electrochemical cell is setup. In the steel one part becomes anode and other part becomes cathode. They connected by electrolyte in the form of pore water in the hardened cement paste. It is well known that steel rebars exposed to corrosion when ambient conditions are appropriate (Hao et al., 2006; Manalo et al., 2016). Figure 2, Figure 3 and Figure 4 shows the current values versus time during rapid corrosion test for C10, C25 and C40 concretes, respectively. No current passing was recorded on all the CFRP wrapped reinforced concretes during rapid corrosion test. This is because the CFRP construction are made of completely insulating polymeric glue (epoxy). Therefore, corrosion event was not observed on the CFRP covered concrete. On the other hand, plain concretes in all the classes were exposed to corrosion under the 50V electrical voltage. When the voltage is applied firstly to the samples, the current values begin to decrease. After a while the current values reach the minimum value and become stable. It is understood that the corrosion process started when the current started to increase again. The current values start to decrease again after taking the maximum value. Here, corrosion time for the maximum current value is an indicator of cracking of concrete samples (Gillespie and Mertz, 1996; Pour-Ali et al., 2015).

Corrosion start time plays an important role in the service life and rehabilitation of reinforced concrete structures (Jamila et al., 2005; Tang et al., 2012). The corrosion starting time is about 120 min for C10 concrete. However, it is 1400 min and 2460 min for C25 and C40 concretes, respectively. If the traditional reinforced structures with C10 concrete class exposed to corrosion after 5 years depending on environmental conditions, same structures will be corroded after 55 years when C25 concrete class are used, and it will be 100 years when C40 class of concrete are used. Corrosion time increases with the increment of compressive strength.

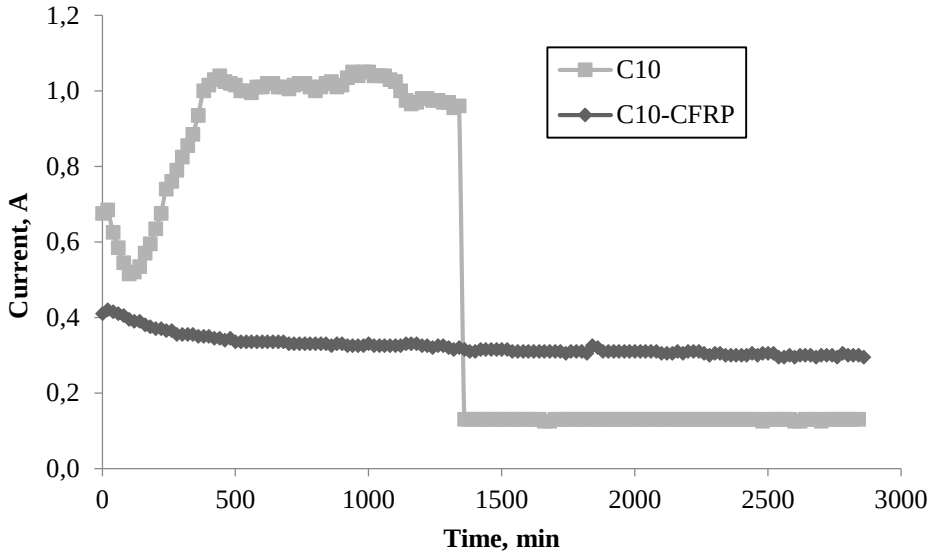


Figure 2. Current values versus time for C10 concrete in rapid corrosion test

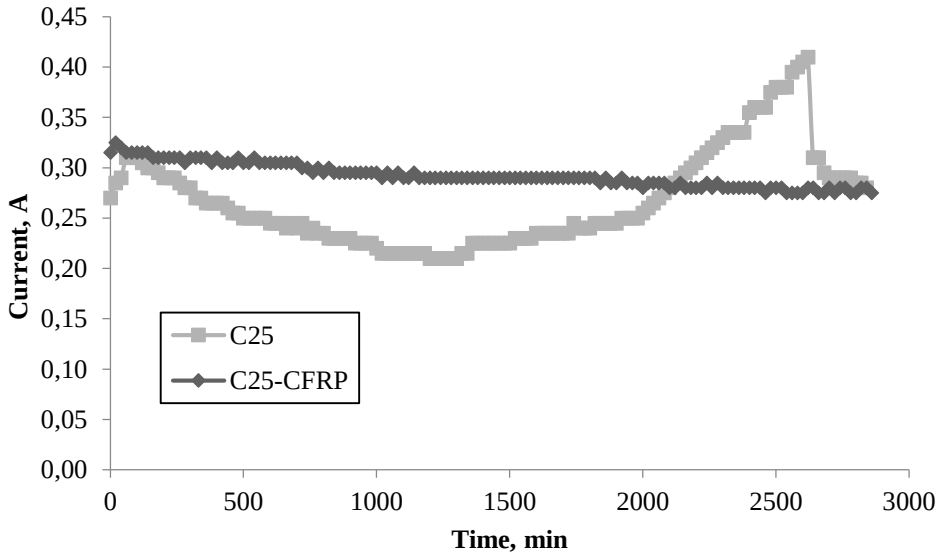


Figure 3. Current values versus time for C25 concrete in rapid corrosion test

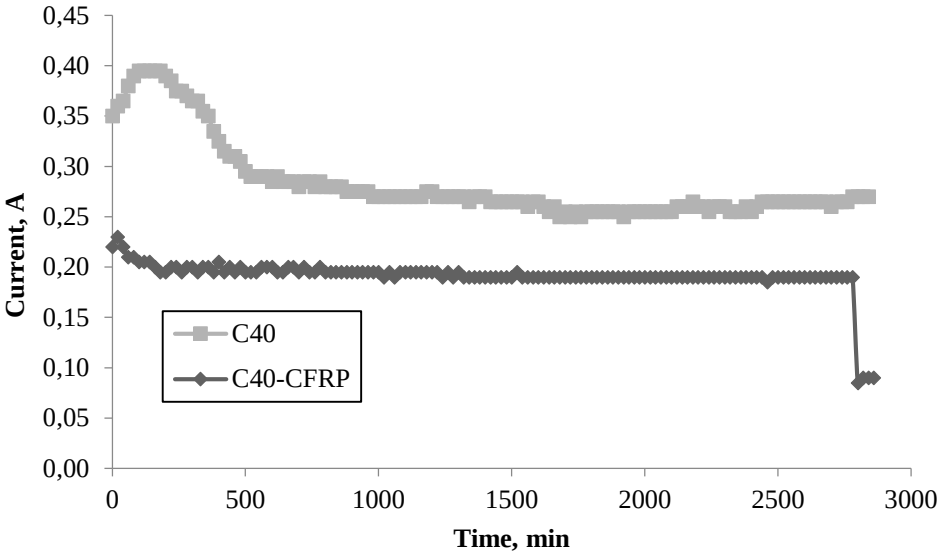


Figure 4. Current values versus time for C40 concrete in rapid corrosion test

Figure 18 shows weight loss of rebars after corrosion experiment. The loss of weight of steel rebar in C10, C25 and C40 class of concrete is determined as 9.1%, 8.7% and 8.2%, respectively. The migration of electrons underneath the coating takes place through the defects, whereas moisture and oxygen can penetrate through the intact coating (Yoemans, 1994; Varalakshmi and Ramaswamy, 2016). Thus, corrosion proceeds on the steel rebar. However, there was no weight loss on CFRP wrapped reinforcement samples due to non-corroded rod. Depending on coating type on steel rebars, a view from corroded samples was presented in Fig. 6 for the same class of plain and wrapped concretes.

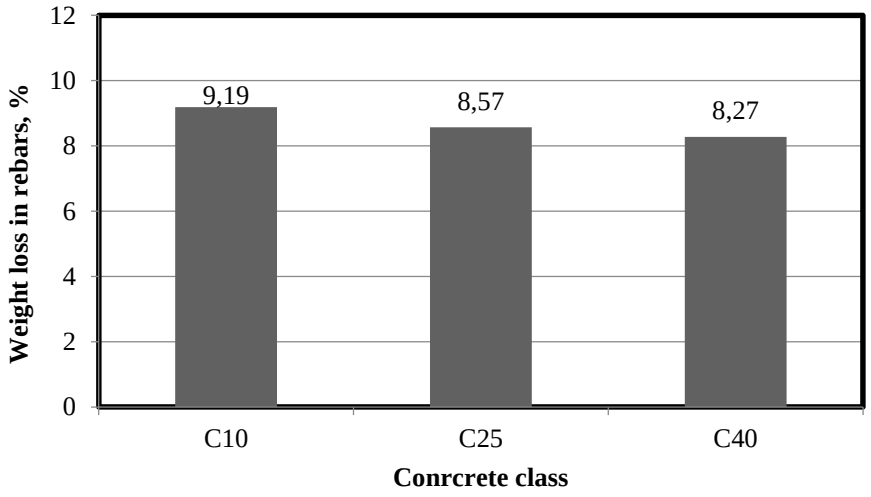


Figure 5. Weight loss of steel rebars after rapid corrosion test of plain concretes



Figure 6. View of plain and CFRP wrapped concretes after corrosion test

4. Conclusion

In this study, rapid corrosion test was carried out on plain and CFRP wrapped reinforced concrete samples in different strength classes. Concrete surface is blocked due to the CFRP coating with epoxy. Thus, it prevents the corrosion of reinforced concrete under excessive conditions. For plain C25 and C40 classes of concretes, the corrosion time is about 10 and 20 times higher than non-wrapped C10 class of reinforced samples. The high strength classes of concrete reduce the loss of weight in the embedded bar depending on the corrosion. Consequently, the CFRP coated concrete will permit the construction of concrete structures against the corrosion in aggressive media.

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