A Study on the Bond Strength Between Rebar and Concrete After Electrochemical Realkalisation Treatment for Carbonated Concrete

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Abstract: During the electrochemical realkalisation treatment for carbonated concrete, the bond strength between rebar and concrete was changed duo to the physical and chemical action. The pull-out test was used to study the effect of current density on the bond strength between rebar and concrete. The realkalisated products of the concrete were studied using X-ray diffraction (XRD). Test results show that after electrochemical realkalisation treatment (ERT), the bond strength of reinforced concrete increases; The current density has the significant effect on the bond strength; The amount of sodium silicate of the concrete is changed after ERT, Due to the increment of the sodium silicate that can increase the bond strength between the concrete and the rebar, it makes for the increase of the bond strength.

Keywords: Electrochemical realkalisation treatment, carbonated concrete, the bond strength

Introduction

The degradation of steel-reinforced concrete structures due to carbonation is increasing at a rate that out of the strips current rehabilitation efforts. Electrochemical realkalisation treatment is well known to be as a less expensive and less time-consuming rehabilitation technology than cathodic protection.

During the realkalisation experiment, the concentration of every species in the aqueous phase of pores of the cement paste is continuously changing. This is due to its own movement under the action of the electrical field, to the dissolution or precipitation of solid phases, to the electro-osmotic flux and also to the electrodic reactions. All these phenomena imply a change in the microstructure and phases of the paste (Castellote 2006), so it means that the bond strength between the concrete and the rebar may be changed. And the bond strength has a good effect on the durability of the reinforced concrete (FRANCOIS 1993).

Experimental Procedure

The design of the specimen referred to Standard Methods for Testing of Concrete Structures (GB 5015292, China Standard).The reinforcing steels used for both smooth and deformed bars were hot-rolled Grade I. The mechanical properties of the reinforcement are shown in Table 1. The reinforcement had a diameter of 8 mm and a length of 390 mm. The length of the main reinforcement bar was kept to 390 mm to facilitate loading of the specimen in a hydraulic universal testing machine. For those specimens with stirrups, the circular closed stirrup whose height was 5 mm was made from the steel tube with a diameter of 30 mm and a thickness of 5mm with a spacing of 40 mm, as shown in Fig. 1. To avoid corrosion of the stirrups, they were isolated from the main bar. To debond the remaining 80-mm length of reinforcement, 40-mm-long PVC conduits that were about the same in diameter as the main reinforcement were used on both ends of the specimen. This arrangement ensured a bar embedment length of 40 mm in contact with the concrete. These debonded zones were also used to protect the reinforcement from the confining pressure of concrete at the supports.

Table 1: Mechanical properties of reinforcement

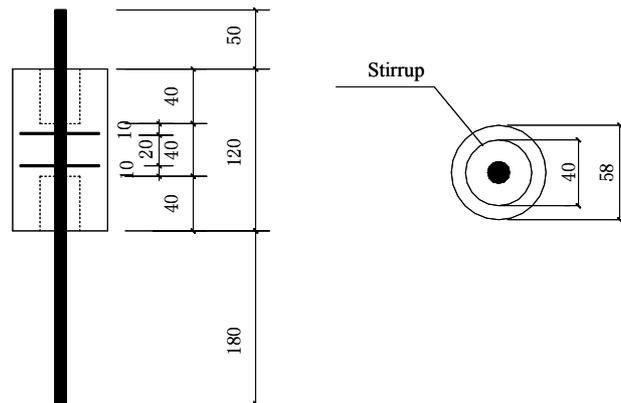| Material	Yield stress (N/mm^2)	Tensile Strength (N/mm^2)	Elastic Modulus (N/mm^2)
Smooth bar (Grade I)	290	440	210,000

Figure 1: Geometry of the specimens used in the study (mm)

Normal Portland cement was used and the crushed stone and river sand from local sources were used as aggregate. The concrete specimens were manufactured with a cement /water /sand/ aggregate ratio of 1: 0.65: 2.25:3.68.

All specimens were demoulded after 24 h and cured for 28 days at approximately $20 \pm 3 \,^{\circ}C$ and 100% relative humidity. Then, the specimens were carbonated at 65% RH, $20 \pm 3 \,^{\circ}C$ and $20 \pm 3\%$ concentration. The carbonation progress was assessed using an alcoholic phenolphthalein solution as colour indicator. This method gives rough information about local pH-value by changing its colour from colourless to red-violet when the pH exceeds values of about 9. Realkalisation experimental condition is the complete carbonation and realkalisation, the current densities are 3 and 5 A/m^2, the concentration of sodium carbonate solution is 1 mol/L and the realkalisation time is 14 day. The pullout test would to be done after three monthes when the realkalisation experiment was finished.

Fig. 2 shows schematically the electrochemical realkalisation treatment system used. The concentric pullout test is widely used due to its simplicity. In this test, a steel bar is embedded in a circular concrete specimen. The bond tests were carried out on a hydraulic universal testing machine that had a capacity of 1000 kN, as shown in Fig. 3. The loading speed was 0.004 mm/s when slip was not greater than 2 mm, and 0.02 mm/s when slip was greater than 2 mm. For all the tests, the strain in the steel bars was very low and yielding of the steel bars was not observed.
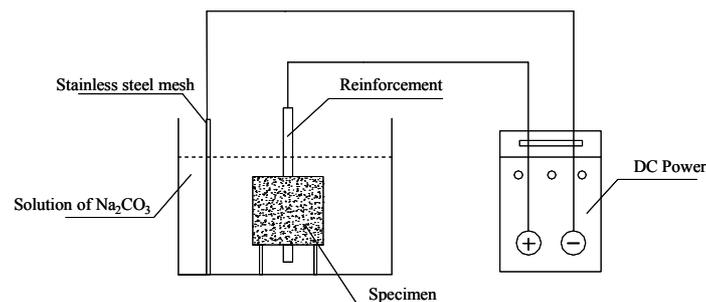

Figure 2: Schematic representation of the electrochemical system

Figure 3: Pullout test system

Result and Discussion

During electrochemical realkalisation treatment from steel reinforced concrete, cathodic action is characterized by the generation of hydroxyl ions, and the migration of alkali ions (mainly K+ and Na+ ions), released from cement hydrates as well as from the pore solution and the electrolyte, to the rebar region. The concentration of these alkali ions depend on factors such as the cement type and the electrolyte. Application of the polarizing electric field gradient necessary for electro-migration ensures ionic redistribution mainly because concrete is an ionic conductor and applied current flows as a result of the movement of dissolved ions in the cement paste pore solution. The process results in the electrochemical formation of alkali hydroxides as the K+ and Na+ ions react with OH^- ions, the reaction being supported by electron supply of the DC power source.

In Fig.4, the alkali content expressed as equivalent Na2O around the cathodic steel rebars were somewhat in proportion to the applied current density. From electrochemical considerations, an increased cation accumulation around the cathode region enhances damage to cement paste phase since alkali ions such as K+ and Na+ ions tend to electromigrate heavily solvated with a sheath of water molecules because of their small ionic radii. Figs. 5 and 6 show the variation of the bond strength increment both impressed current densities and the increment of the equivalent Na2O of the concrete-steel interface. Bond strength increment calculations are based on differential bond stress values of both the realkalisated concrete groups with their carbonated specimens.
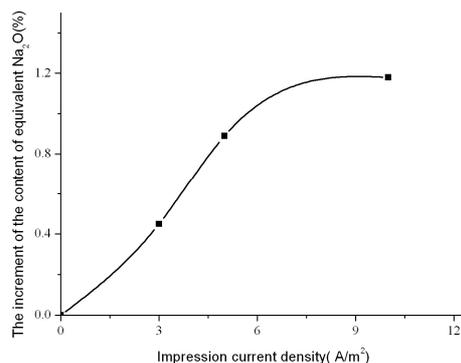

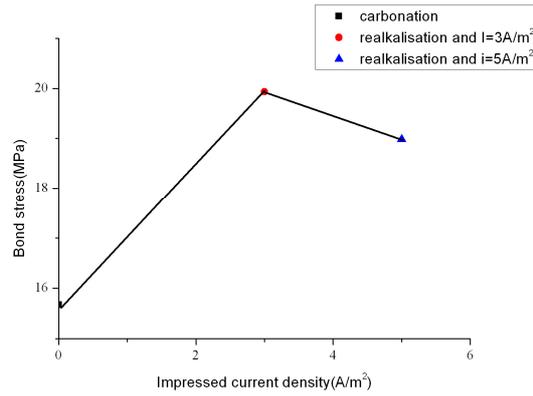*Figure 4: The increment content of equivalent Na2O near rebars*

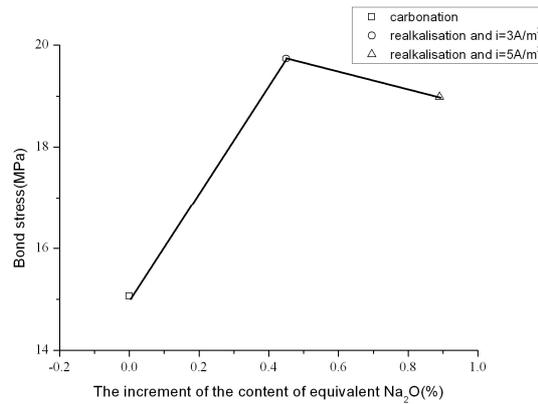*Figure 5: Bond stress vs Impressed current density*

Figure 6: Bond stress vs The increment of the content of equivalent Na2O

In some previous study, the formation of alkali hydroxides during electrochemical extraction was also known to initially soften concrete by substantially increasing the solubility of the cement silicate hydrates (Chang 2002, M.G. and Rasheeduzzafar 1993,), a principal cement binder of the hydrate form; Due to the high concentration of these alkali metals around the concrete-steel interface and coupled with the wetness associated with their electro-migration, it becomes more easily for the resulting cement paste deterioration around the steel rebars to cause disbondment. But in this investigation, after the realkalisation, the bond strength increases. The following mechanism is proposed as an explanation. As a consequence of the ion exchange reaction (eq. (1)) between dissolved calcium silicate and penetrated sodium carbonate takes place and leads to the precipitation of calcium carbonate and the formation of sodium silicate. And the sodium silicate may increase the bond strength between the concrete and the bar. The sodium silicate initially is soft after realkalisation and over time to be hardened. In Figure 7, the content of the sodium silicate after the realkalisation is more than of carbonated concrete.

$$Na_2CO_3 + CaSiO_3 \rightarrow CaCO_3 \downarrow + Na_2SiO_3 \tag{1}$$

Due to this reaction the concentration of sodium or potassium in the pore solution remains stable, because both sodium carbonate and sodium sulfate are water soluble salts.
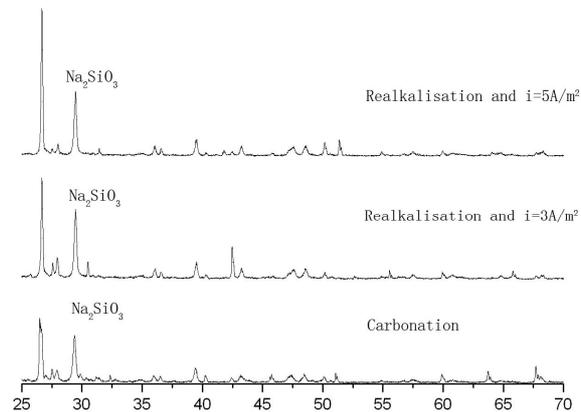
Figure7: The content of Na₂SiO₃ before and after realkalisation

Conclusion

In some previous studies, the bond strength was found to reduce to some degree after the electrochemical rehabilitation. But in this investigation, the bond strength increases after the electrochemical realkalsation treatment. The realkalisated product of the concrete is studied by XRD and the amount of sodium silicate increase. Due to the sodium silicate that can enhance the bond strength, the change of the bond strength between the concrete and the steel after the realalisation attributes to the increment of the determination of the sodium silicate.

Acknowledgements

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