A Novel Anode Material for Cathodic Prevention of Steel Reinforced Concrete Structures with Hybrid Functions

(article starts on next page)

A Novel Anode Material for Cathodic Prevention of Steel Reinforced Concrete Structures with Hybrid Functions

Emma Qingnan Zhang
PhD candidate
Division of Building Technology
Chalmers University of Technology
SE-412 96, Gothenburg
emma.zhang@chalmers.se

Tang Luping
Ph.D., Prof
Division of Building Technology
Chalmers University of Technology
SE-412 96, Gothenburg
tang.luping@chalmers.se

Abstract
Carbon fiber mesh anode is used as an alternative of traditional anode material for cathodic protection system. Theoretical analysis of feasibility and preliminary experimental work of the new material is presented in this paper. Long-term exposure in marine environment has been simulated using an electrochemical acceleration method to shorten the experimental time. Treated specimens are examined by scanning electron microscope (SEM) and laser-ablation inductive-coupled-plasma mass spectroscopy (LA-ICP-MS) for microstructure study and chemical analysis. Preliminary results show a ring-pattern zone at anode adjacent area but no sign of damage at anode and anode adjacent area.

Key words: cathodic prevention, cathodic protection, corrosion, concrete, carbon fiber mesh anode, SEM, LA-ICP-MS, electrochemical acceleration, durability, modelling.

1. Introduction

Cathodic protection (CP) is en electrochemical technique applied on steel reinforced concrete structures which is achieved by polarizing steels to a more negative potential by means of an external electrical power source and an anode system. This technique has been proved to be a successful application in providing cost-effective long-term corrosion control for steel in concrete [1]. Cathodic protection (CP) is applied to structures already affected by corrosion, mainly induced by chlorides. Cathodic prevention (CPre) is applied to new structures that will presumably be contaminated by chlorides. The current density imposed varies from 1-2mA/m^2 for CPre, to 5-20mA/m^2 for CP [2]. The conventional means to protect the steel reinforcement from corrosion is to increase the thickness of concrete cover and/or to use low water/cement (w/c) ratio concrete. It will obviously consume more cement and other raw materials which it is at the sacrifice of more CO_2 emission and natural resources. Therefore, new and more sustainable approaches are needed for corrosion prevention or protection of reinforcement steel in concrete.

This paper presents a novel approach for protecting steel reinforcement in concrete by utilizing the principle of electrochemical migration in order to lower the cement consumption and decrease the thickness of concrete cover. The innovation from the traditional system and preliminary results are presented.

2. Difference from conventional CP/CPre

2.1 Intermittent power supply (solar cells)

Conventional cathodic protection needs a careful regulation of current density with continuous power supply and a complex monitoring system for maintenance, which are energy consuming, financially costly and high level of technical difficulties. Glass et al. has proved the laboratory evidence that intermittent current can still provide protection effect on reinforcement [3]. This provides possibility of using natural solar, wind, or wave energy instead of traditional power supply. Because of the rate of ionic diffusion under the current intermittent period is much lower than the rate of ionic migration under the external electrical field, it is possible to prolong the service life of the system and reduce the intensiveness of maintenance compared with conventional CP system.

2.2 Anode material

Activated titanium electrodes are most commonly used anode materials nowadays which are commercially available in several forms. The most widely used form is expanded mesh. Service life of this type of anode is predicted in a range of 20 years to in excess of 100 years from laboratory tests as well as practice [4]. However the main service life of CP system applied in Europe is about 25 years [5]. One of the reasons that can cause system failure is due to anode degradation caused by acid formation at anode zone which the cell resistance will increase and may lead to bond loss [6]. If low intermittent current is applied, the current intensity will be much lowered (average current density ≤5mA/m^2 through proper design). Therefore, anode materials with lower conductivity than titanium can be alternatives for CPre system, such as carbon fiber and glass fiber with conductive coatings which is relatively affordable price. In addition, carbon fiber and glass fiber have approved history as reinforcement material for concrete such strength reinforcement and preventing cracks.

3. Preliminary results

According to the theoretical feasibility analysis [7] of this approach, an electrochemical acceleration method can be used to investigate the effect of applied electrical field on cement matrix and anode material. The specimen was partially emerged in 10% NaCl solution and connected to continuous power supply. The accumulated power applied is equivalent to 130-year intermittent power supply. The specimen was prepared using the form shown in Figure 1 and the dimension is 40mm×40mm×250mm. the mould contained a plain steel reinforcement bar and a strip of carbon fiber mesh (SIGRATEX Grid 300 supplied by SGL Group) at certain distance.

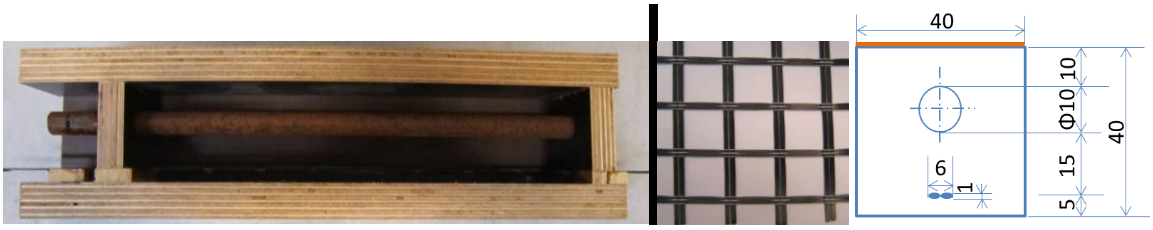

Figure 1 Image of the casting mould (left), the carbon fiber mesh anode (middle) and the dimension of specimen (right).

After one-month period of connecting to external electrical field, the specimen was taken out, sawed into slice and the dimension of the ring-patter around carbon fiber anode was investigated by SEM shown in Figure 2. The back-scattered SEM image also confirmed that the ring-pattern area has different phases as it is layered, as shown in Figure 3. LA-ICP-MS provided a semi-quantified analysis of chemical changes around the anode area as shown in Figure 4. Due to the nature of C-S-H gel, the distribution of silicon (Si) in the cement paste matrix is assumed unchanged because the Si–O bonding is very stable and hardly to be broken or reformed even under strong electrical currents [8]. Therefore the changes of Ca/Si ratio can be considered the changes of calcium in the cement paste matrix. On the other hand, positive ions sodium and potassium did not show the same movement as calcium. The signal intensity ratio shows that at the junction of ring 1 and ring 2, the signal intensities of sodium and potassium reached a peak and then gradually decreased to a base level.

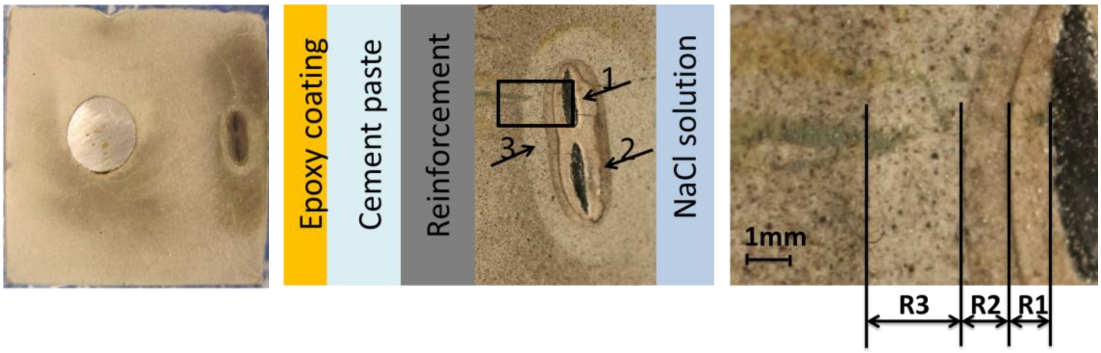

Figure 2 Sawed samples (left), ring-pattern (middle) and the dimension of the ring-pattern (right).

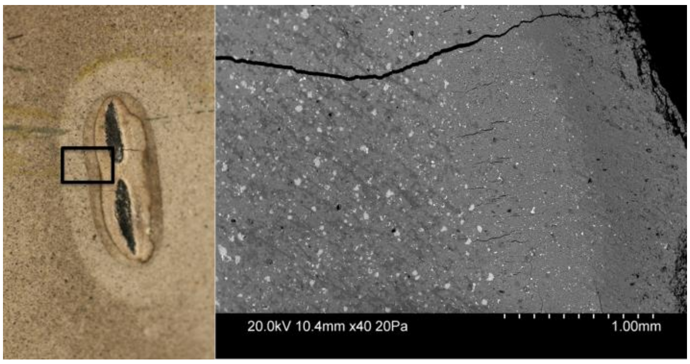

Figure 3 Back-scattered SEM image of the ring-pattern area. The crack through the ring area was formed after experiment possibly caused by drying.

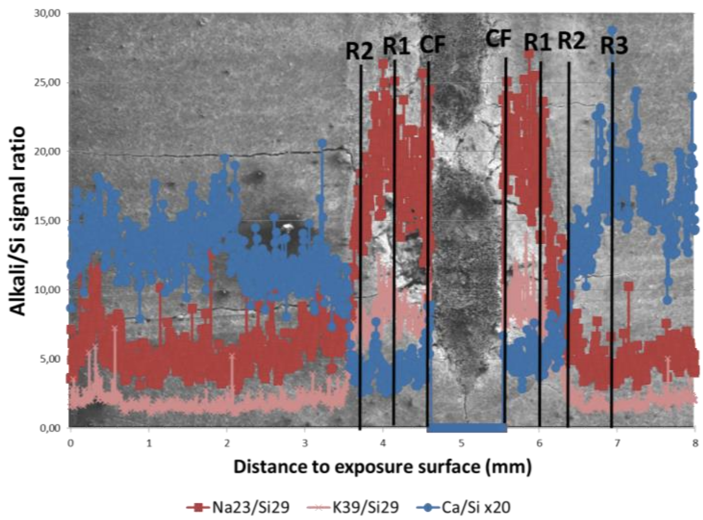

Figure 4 ICP-LA-MS analysis on the ring-pattern area. The exposure surface is on the left side. Signal intensities are normalized to Si and are proportional to the concentration of elements. However, there is no

intensity-concentration correlation between different elements. CF, R1, R2 and R3 stand for carbon fiber, ring 1, ring 2 and ring 3 respectively.

The carbon fiber anode showed a sign of loss of matrix material at the area of anode-paste interface, as shown in Figure 5. This can be caused by acidification that the polymer matrix degrades or decomposes, or by the process of sawing, polishing during the preparation stage which cannot be ruled out. Except for a certain loss of matrix material at the area of anode-paste interface, there is no obvious crack or delamination around the carbon fiber mesh, implying that it is suitable to be used as anode for corrosion prevention at a low current density for over 100 years.

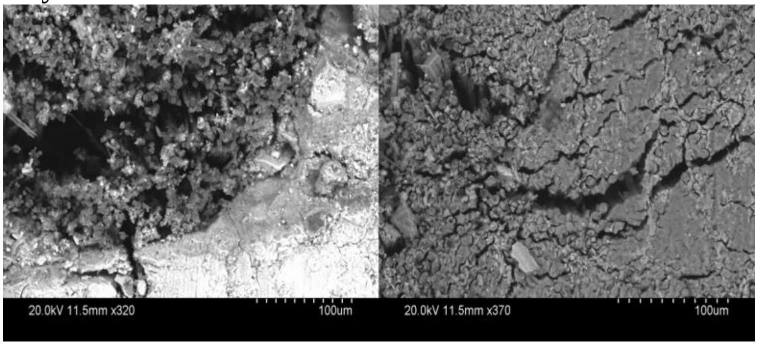

Figure 5 Back-scattered SEM images of carbon fiber anodes at the anode-paste interface (left) and in the middle of the grid (right).

4. Concluding remarks

With the development of solar cells and conductive fiber meshes, this novel approach of anode material with hybrid functions can be built up to cathodically prevent reinforcement steel in concrete from corrosion and mechanically prevent concrete surface from cracking. With this low current density the service life of the cathodic prevention system should be significantly longer than the conventional cathodic protection system. Thus the troubles due to the imposed current can be reduced or even eliminated. With this new type of anode material and intermittent power supply, the properties of concrete with high w/c can be better utilized and the cover thickness can be reduced. As a consequence, cement and raw materials will be less consumed in the reinforced concrete structures.

Reference

1. ISO, B., *12696 (2012).* Cathodic Protection of Steel in Concrete.
2. Bertolini, L., et al., *Corrosion of steel in concrete: prevention, diagnosis, repair*. 2013: Wiley. com.
3. Glass, G., A. Hassanein, and N. Buenfeld, *Cathodic protection afforded by an intermittent current applied to reinforced concrete.* Corrosion Science, 2001. **43**(6): p. 1111-1131.
4. Pedeferri, P., *Cathodic protection and cathodic prevention.* Construction and Building Materials, 1996. **10**(5): p. 391-402.
5. Polder, R.B., et al., *Service life and life cycle cost modelling of cathodic protection systems for concrete structures.* Cement and Concrete Composites, 2013.
6. Mietz, J., J. Fischer, and B. Isecke, *Cathodic protection of steel-reinforced concrete: structures-results from 15 years' experience.* Materials performance, 2001. **40**(12): p. 22-26.
7. Tang, L., et al., *Covercrete with hybrid functions–A novel approach to durable reinforced concrete structures.* Materials and Corrosion, 2012. **63**(12): p. 1119-1126.
8. Ryu, J.-S., N. Otsuki, and H. Minagawa, *Long-term forecast of Ca leaching from mortar and associated degeneration.* Cement and concrete research, 2002. **32**(10): p. 1539-1544.