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Experimental comparison of corrosion unevenness and expansive cracking between accelerated corrosion methods used in laboratory research

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HIGHLIGHTS

- Precise geometric measurement by 3D laser scanning and virtual modelling.
- Quantitatively described the non-uniform corrosion distribution.
- Compared corrosion unevenness & expansion effect between 3 corrosion methods.
- Direction on accelerated corrosion method design for future research.

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ABSTRACT

Eight reinforced concrete (RC) slabs were prepared and corroded using different accelerated corrosion setups including full-immersion, half-immersion, and wet-dry cycling, aiming to investigate their differences in terms of non-uniform corrosion distribution and expansive crack opening. Embedded steel bars were retrieved and cleaned before scanning into 3D models using a laser instrument to facilitate precise geometric measurement. Non-uniform corrosion is quantitatively characterized by a parameter R_n, whose asymptotic distributions belong to the domain of attraction of general extreme value (GEV) distribution. The results show that full-immersion method is less promising, because it generated the slightest non-uniform corrosion and expansive crack opening. The half-immersion method could be used in the research focusing merely on corroded steel bars as it led to serious non-uniform corrosion but less severe expansive cracking. Wet-dry cycling seems to be the best, whereas the impressed current density is recommended to be kept below 50 $\mu A/cm^2$.

1. Introduction

Galvanostatic methods are commonly used in the laboratory to prepare corroded reinforced concrete specimens, from which abundant achievements have been made from deterioration of material properties to residual service life of corroded RC members [1–5]. However, some pilot studies have revealed that great differences exist between accelerated corrosion and natural corrosion on corrosion products, distribution of corrosion penetration and developing of expansive cracks. Different accelerated corrosion setups and magnitude of impressed current both could introduce in a major influence on test results [6,7]. Fully understanding this effect would be helpful in explaining the discrepancies between structural degradation models built by different researchers, and more importantly in providing a direction for future research on accelerated corrosion method design.

The corrosion induced structural degradation can be reduced to two effects on material level, from which practical parameters can be proposed to carry out a feasible experimental comparison between the different corrosion methods. The first one is cross-sectional area loss and mechanical performance degradation of steel reinforcement, which highly depend on a geometric change of the corroded steel [8]. Corrosion penetration is far from uniform circumferentially and longitudinally under natural condition, especially in the case of serious pit corrosion [1,2]. Since impressed current tends to generate uniform corrosion penetration and less severe deterioration as a consequence, an accelerated corrosion method could be considered better when high non-uniform corrosion distribution is generated.

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The second deterioration effect is expansive cracking of concrete cover and deterioration of bond between reinforcing steel and concrete, which are mainly influenced by ingredients of the corrosion products and the consequent volume expansion. This effect, from the perspective of corrosion methods comparison, can be easily inspected through the correlation between steel mass loss and consequent expansive crack opening. A corrosion method can be seen as the best when it engenders the widest crack opening on same corrosion level, since non-uniform corrosion and long-time oxidization in a natural environment would reasonably lead to more severe cracking [9].

In this work, RC slabs were corroded using different accelerated corrosion methods aiming to explore the differences between them and finally to discover the most promising one, which was accomplished through comparison of the non-uniform corrosion distribution and expansive cracking described above.

2. Specimen preparation

A total of eight concrete slabs (150 × 300 × 400 mm) were constructed in which 24 steel bars were embedded, as shown in Fig. 1. The steel bars have diameters of 12 mm and 16 mm, extruding out of slab concrete for 50 mm at one end to be connected to direct current (DC) supply. Eight stainless steel rods with a diameter of 10 mm were embedded in four slabs which were designed for wet-dry cycling corrosion. The concrete was mixed with Portland cement, coarse aggregates with a maximum diameter of 25 mm, sand and tap water. The adopted water-to-cement ratio was 0.55, and the ratio of cement: sand: coarse aggregate equaled 1:1.47:3.29. Additionally, sodium chloride (NaCl), 4% by weight of cement, was premixed in the 4 wet-dry cycling specimens.

The eight specimens constitute four groups: F stands for the full-immersion method; S stands for the half-immersion method; W and M stand for wet-dry cycling method with large and small current, respectively. It has been proved that smaller impressed current in accelerated corrosion is preferable at a cost of prolonged time, herein a critical value as small as 200 μA/cm^2 was adopted as suggested by Tamer [10]. An even smaller current density of 50 μA/cm^2 was adopted for Group M specimens to make a comparison (see Table 1).

The concrete slabs were cured at room temperature for 28 days before corrosion process started. The test setups of the three methods are illustrated in Figs. 2–4, respectively. Full-immersion specimens were placed vertically in a glass tank so that the slabs were immersed in 5% sodium chloride solution except for the top part of about 30 mm–50 mm, as shown in Fig. 2. Half-immersion specimens were placed horizontally, and the steel bars to be corroded were kept above liquid level at a range of 30 mm–50 mm, as shown in Fig. 3. In these two cases, additional stainless steel rods were dipped into the solution acting as cathodes. Wet-dry cycling specimens were placed wholly above chloride solution, as shown in Fig. 4, and the embedded stainless steel rods were used as cathodes. All the reinforcing bars to be corroded were connected to anodes of DC supplies. The anode/cathode area ratios are 1.8 and 2.4, respectively for specimens with 12 mm diameter bars and 16 mm diameter bars.

The applied current density was kept constant as designed for each individual specimen during accelerated corrosion. The predefined mass loss ratios of the three steel bars in each slab were 10%, 20%, and 30%, respectively. Hence, the required time duration can be calculated using Faraday's law [10]:

$$t = \frac{ZF \cdot r \cdot \rho \eta_s}{2A \cdot i} \quad (1)$$

where t is the required time duration (seconds); Z is the valency of the reacting anode, which is 2 in this case (iron); F is Faraday's constant (F = 96,500 A s); r is the radius of the corroded bar (cm); ρ is the density of iron (ρ = 7.87 g/cm^3); A is the atomic mass of iron (A = 56 g); and, i is the current density (A/cm^2). In addition, a timer

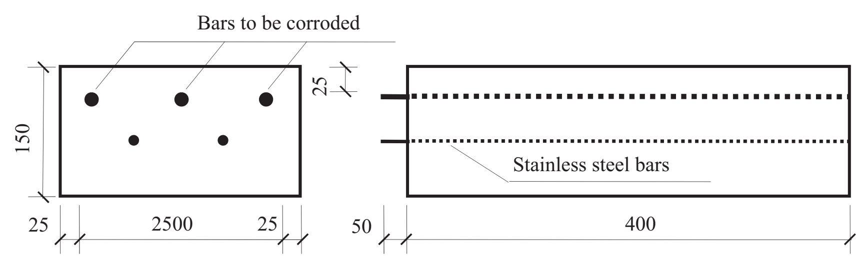

Fig. 1. Geometry of concrete slabs (unit: mm).

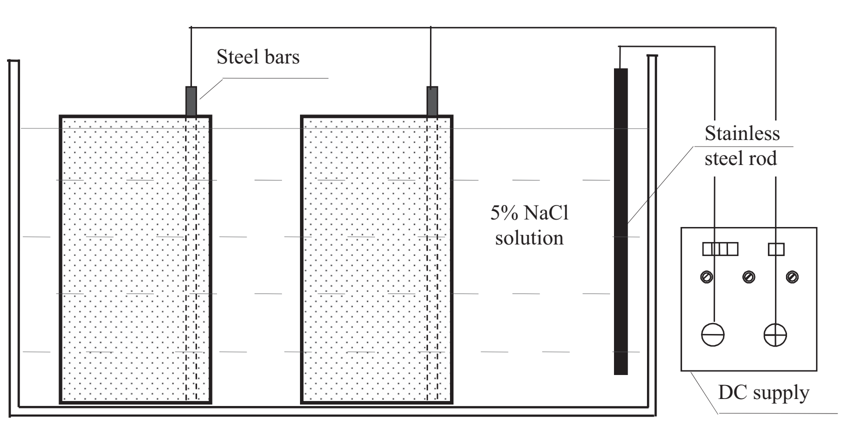

Fig. 2. Full-immersion accelerated corrosion method.