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Measurement methods of geometrical parameters and amount of corrosion of steel bar

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HIGHLIGHTS

- Five methods were used to measure bar geometrical parameters and amount of corrosion.
- The results using 3D scanning and XCT match well and more precise than other methods.
- 3D scanning is most suitable for measuring geometrical parameters of a corroded bar.
- Vernier caliper is the best option for measurement of a non-corroded bar.

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ABSTRACT

This paper aims to evaluate the applicability and suitability of the different methods, including weight loss, vernier caliper, drainage method, 3D scanning and XCT methods in the measurement of geometric parameters and amount of corrosion of a steel bar. A single 400 mm long and 14.11 mm diameter steel bar was measured first as non-corroded specimen before an accelerated corrosion of its 300 mm long middle part took place. This was followed by the measurement and evaluation of the geometrical parameters of the same bar specimen within its 300 mm long corroded part and 30 mm non-corroded part at its right end using different methods. The results show that the geometrical parameters of a corroded bar measured using 3D scanning and XCT methods well matched each other and much more precise than those using weight loss, vernier caliper and drainage methods. 3D scanning is the most suitable method to measure the geometrical parameter of a corroded bar. Vernier caliper is the best option for measuring the geometrical parameter of a non-corroded bar.

1. Introduction

Corrosion of steel bar is one of the major reasons for the deterioration of concrete structures that are widely used in our society. It not only causes cracks on concrete surface and even spalling of concrete cover, but also decreases the effective areas of a steel bar and, in particular, reduces its strengths and ductility significantly [1–3]. As a result, the load-bearing capacity and service reliability of a concrete structure deteriorate substantially, which has ever been a concern for the owners and users of the existing concrete structures [4–6].

It has been well recognized that the corrosion of a steel bar initiates on its circumferential surface and penetrates bar surface very irregularly afterwards. This results in the uneven residual sections along the length of a corroded bar, which in turn dominates the mechanical properties of a corroded bar and the safety of a deteriorated structure. Therefore, a precise measurement of the geometrical parameters and amount of corrosion of a corroded bar is crucial for the assessment of safety and reliability of a deteriorated structure.

Various methods, including weighing loss, vernier caliper, drainage method, 3D scanning and XCT methods, etc. have been attempted to measure the geometrical parameters and amount of corrosion of a corroded bar. Among these methods, weight loss method is one of the most popular method for the measurement of amount of corrosion of a steel bar [6–9]. However, weight loss method can only measure the average value of the residual section of a corroded bar [7–9].

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In fact the load-bearing resistance and deformation capacity of a corroded bar depends on its minimum residual section and the distribution of its residual section along the length of the bar, respectively [1]. Accordingly Zhu and Francois cut the whole length of a corroded bar into a number of 10 mm to 20 mm small segments before measured their weight loss for the purpose of reflecting the variation of the residual area along its length and approaching the called minimum residual section [10,11]. However, cutting of a corroded bar not only causes a loss of its mass and some section, but also potentially misses some minimum residual section. Therefore it still cannot evaluate the geometric feature of a corroded bar precisely. Zhu, Francois and Torres-Acosta used the vernier caliper to measure the diameter and the pitting depth of a corroded bar for estimation of its residual area and mechanical properties [10–12]. However, due to the irregular corrosion pitting and residual section, the deviation of the measured results is inevitable. On the basis of the Archimedes' principle that buoyant force on an object that is submerged in water is always equal to the weight of the water it displaces, Du et al. set up an apparatus and used drainage method to measure the variation of the residual section of a corroded bar along its length qualitatively [1]. However, in their apparatus, the movement of the steel bar was manually controlled and therefore it could not define the amount of corrosion qualitatively. Over the past few years, with the development of 3D scanning technology, the 3D scanning has been used to describe the surface morphology of a corroded bar, including the diameter, area, morphology, depth of pitting, centroid and inertia moment of a cross section [13–17]. However, the majority of publications have just focused on how to acquire the measured data from a steel bar specimen, few of them were devoted to the applicability and suitability of the different methods for measuring the characteristics of a steel bar in different conditions [18]. In fact, different measurement methods have their own test principles, accuracy and applicability. In particular, so far less significant comparison and validation have been made between different methods that have applied to the same specimen under the same corrosion condition.

Hence, this paper aims to evaluate the applicability and suitability of the different methods, including weight loss, vernier caliper, drainage method, 3D scanning and XCT methods in the measurement of geometric parameters and amount of corrosion of steel bar. A single 400 mm long and 14.11 mm diameter steel bar was taken as a non-corroded specimen and measured for its surface feature before an accelerated corrosion of its 300 mm long middle part took place. This was followed by the measurement and evaluation of the geometrical properties of the same bar specimen within its 300 mm long corroded part and 30 mm non-corroded part at its right end. The results measured using different methods show that the geometrical parameters of a corroded bar measured using 3D scanning and XCT methods well match each other and much more precise than those using weight loss, vernier caliper and drainage methods. 3D scanning is the most suitable method to measure the geometrical parameter of a corroded bar. Vernier caliper is the best option for measuring those of a non-corroded bar.

2. Experimental work

2.1. Specimen and corrosion tests

A 14.11 mm diameter plain bar in grade of Q235 was used for the test specimen. The steel bar is 400 mm long in total and has 300 mm length in its middle to be corroded, as shown in Fig. 1.

The steel bar in grade Q235 has a minimum yield strength of 235 MPa, ultimate strength of 370 and elongation of 20%, as specified in China's National Standard – GB/T11253-2007 [19]. The geometric parameters and self-weight of the steel bar before its corrosion were first measured along its length and taken as the benchmark of non-corroded bar specimen. Afterwards, the same steel bar was subjected to an accelerated corrosion test under an impression of 2.25 mA/cm^2 direct current and taken as the corroded bar specimen. Before corrosion, both 50 mm long ends of the steel bar specimen were covered using the electrical insulation tape and epoxy resin to protect them from corrosion. Namely only the 300 mm long middle part of the bar specimen was subjected to corrosion, as shown in Fig. 1. After the amount of corrosion of the steel bar reached the anticipated level of corrosion, as predicted using Faraday's law, it was cleaned using acid solution and tape water, before dried in air. The weight of the corroded steel bar was measured using a scale for its weight loss, before it was painted in white for the further measure at a spacing of 10 mm along the length of the corroded bar specimen as shown in Fig. 2.

2.2. Measurement methods

Five different methods were used to measure the geometric parameters and corrosion mount of above specimen, namely, weight loss method, vernier caliper, drainage method, 3D scanning and XCT methods for both non-corroded and corroded specimens, as detailed below.

2.2.1. Weight loss method

It is assumed that weight loss of the corroded bar took place only within its 300 mm long middle corroded part. Therefore, the amount of corrosion was determined by Eq. (1).

$$Q_{cor} = \frac{W_0 - W_1}{W_0} \times 100\% \tag{1}$$

where Q_{cor} is the amount of corrosion of a steel bar (%), W_0 is the weight of the non-corroded bar prior to its corrosion, W_1 is the weight of the same steel bar after it was corroded, cleaned in acid solution and dried in air.

Accordingly the average cross-sectional area and penetration depth of the corroded steel bar can be calculate by Eqs. (2) and (3),

$$A_{sc} = A_{s0}(1 - Q_{cor}) \tag{2}$$

$$x_{sc} = d_{s0}(1 - \sqrt{1 - Q_{corr}}) \tag{3}$$

where A_{sc} and x_{sc} are the average cross-sectional area and penetration depth of the corroded bar, A_{s0} and d_{s0} are the initial cross-sectional area and diameter of the same bar specimen prior to its corrosion.

2.2.2. Vernier caliper method

A digital vernier caliper was used to measure the original diameter of the non-corroded bar specimen and the residual diameter of the 300 mm long corroded bar. The vernier caliper has a maximum deviation of 0.01 mm. 31 sections of the bar specimens at a spacing of 10 mm along their length were marked, as showing in Figs. 1 and 2, and were measured for their residual diameters using the caliper. For each cross section of the bar specimen, four readings were taken at the angles of the 0°, 45°, 90° and 135° in circumferential direction of the bar section, as shown in the Fig. 3. Among the four readings, both maximum and minimum readings were picked up and averaged for nominal diameter of bar specimen, which, in turn, is used for the calculation of cross sectional area and other geometrical parameter of the bar specimens.

2.2.3. Drainage method

As shown in Fig. 4, a new apparatus was set up and used to measure the original area of the non-corroded bar and the residual area of the 300 mm long corroded bar [20]. This apparatus uses a