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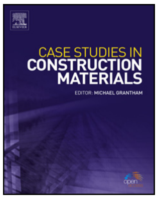

Short communication

The probability distribution of pitting for accelerated corrosion reinforcement

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ABSTRACT

This study adopts three-dimensional scanning technology to obtain accurate pit corrosion data to research corroded reinforcement morphology. The pitting factors α and β are proposed to quantify the corrosion degree along the axial and transverse directions of corroded bars, and both factors' probability distributions are analysed. The experimental results show that the probability distribution of α and the majority of β conform to lognormal distribution. When the value of η (the mass loss ratio) increases, the value of pitting factor α decreases and tends to be stable, while the expectation of β decreases, indicating that the corrosion pits tend to be uniform when corrosion becomes severe. Comparing the trend of corrosion depth with pitting factor α along the bar length, reveals that α has more regularity.

1. Introduction

Reinforced concrete structures are widely used because of their low cost and good durability. Due to the randomness of external environment as well as the heterogeneity of the concrete cover, the steel bars in the concrete have different degrees of corrosion. The corrosion position and corrosion degree of each bar occur irregularly, so the corrosion situation cannot be reasonably evaluated by η specifically, local corrosion, occurs randomly even when the materials and the environment are known, causing different depths of the corrosion pits on the surface of the steel bars. While η can roughly describe the degree of corrosion, it cannot adequately explain the local corrosion condition, making it difficult to make a correct evaluation of the corrosion degree of a given steel bar [1]. Previous statistical analyses have shown that uncertainty factors such as the corrosion pit depth conform to a probability distribution [2]. These studies show that the corrosion pit depth along the length of the bar is irregular in most situations. Given the difficulty of describing these corrosion patterns, researchers should change direction from emphasizing corrosion pit depth to identifying other indicators which could better express corrosion conditions.

The corrosion characteristics of steel bars' surface have great influence on their mechanical performance, as well as durability evaluation and service reliability. Ma [3] described the effects of pitting morphologies on the static and fatigue behaviour of steel bars. Pitting corrosion is one of the most common forms of localized corrosion. A corrosion pit result in stress concentration and fatigue crack for these corrosion pits, usually through initiation and propagation. The study of corrosion pits is helpful for evaluating the fatigue life of reinforced concrete bridges. Therefore, the depth of the reinforcement pit is a key indicator in corrosion analysis [4]. Corrosion pit depth usually derives from the average corrosion

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depth or the maximum pit corrosion depth. But if we just take the average corrosion depth into consideration and ignore the maximum pit corrosion depth, the durability of the whole steel bar would be overestimated. Likewise, the whole corrosion situation of the steel bar is not precisely reflected when considering the maximum corrosion depth alone. Accordingly, utilizing the ratio of the two kinds of depth as an analysis indicator of the corrosion characteristics could provide a more balanced evaluation.

Some scholars have studied steel corrosion mainly by recording the corrosion morphology parameters of steel bars at different corrosion periods. The experiment data of the maximum pit depth is analysed, and a probability model of the pit depth is expressed. Alma Valor [5] got different η distributions by relying on different corrosion growth models. Ma [6] proposed a probabilistic prediction with a Bayesian updating framework of corrosion-induced strength degradation for flexural beams. Other scholars have shown that pit corrosion depth is a random variable that satisfies the probability distribution [7–11]. D. Rivas has studied the distribution of the pit corrosion depth of pipeline steel, which conforms to the distribution of GEV (generalized extreme value) [12]. In these studies, the pit depth on reinforcement could reveal the corrosion rule.

The scientific nature of collected data is greatly influenced by external elements [13]. The morphological data usually depended on weighing methods in the past, but these methods are time-consuming and can be inaccurate depending on the instruments, methods, or principles of their measurement. 3D (three-dimensional) scanning technology can be used to collect coordinate data on the surface of a steel bar at a high speed and accuracy; these data can then form a three-dimensional point data cloud. Nowadays, many scholars use 3D scanning technology to obtain accurate morphological parameters data for corroded steel bars [14–17]. Mohammad M. Kashan established three-dimensional models of 23 corroded steel bars by 3D optical surface measurement technology. Statistical analysis of the corrosion models showed that logarithm normal (lognormal) distribution can be used for representing the non-uniform corrosion conditions [18]. Weiping Zhang [19], in order to evaluate the service reliability of corroded reinforced concrete structures, proposed a probability model based on a cross-section area of the corroded steel bar. The concept of factor R was also put forward, which means the ratio between the average cross-section area and the minimum cross-section area. Statistical results revealed that factor R could be characterized by the Gumbel distribution. Nevertheless, while factor R could be useful as an indicator to explain the whole corrosion conditions along the length of the bars, it is insufficient to explain the expression of local corrosion. Hence, more detailed concepts are required to explain the morphology of corroded steel bars in statistically.

In this study, 3D scanning technology is adopted to get accurate corroded reinforcement pitting corrosion data. First, after defining the pitting factors α and β, the probability distribution of α and β were analysed. α and β are used to indicate the corrosion changes of steel bars in the transverse and axial directions, respectively. Furthermore, the relationship between α and η as well as the probability distribution histogram of α are obtained. Finally, figures of corrosion depth and β along the length of the steel bar are compared, to emphasize the validity of β. This paper breaks through the constraint of traditional data acquisition methods. It combines high quality technology with a beneficial and more detailed study of reinforcing the surface of corroded steel.

2. Experiment and simulation process

Five concrete specimens with steel bars were prefabricated. There were six steel bars to be corroded in each specimen. 30 steel bars in the reinforced concrete specimens were electrified to accelerate corrosion after a maintenance period in the concrete curing room. The corroded steel bars from the destructive specimens were taken out, and the morphology parameters of the corroded steel bars were extracted by using 3D scanning technology (*HL-3DX*). The average corrosion depth and the maximum pit corrosion depth were obtained through VG Studio Max software. Finally, two pitting factors were calculated and analysed.

2.1. Corrosion process

A power supply with a constant current electricity can be used to accelerate steel corrosion for the sake of obtaining specimens rapidly. The length of each steel bar is 350 mm while each concrete cover is 250 mm; the 50 mm overlap on each side of the bar needs special protection so as not to be overly corroded. After 28 days of specimen maintenance, the full immersion method was used to accelerate corrosion in this experiment. The whole specimen was immersed in a 5% density NaCl solution, which was renewed regularly during the corrosion process to ensure the consistency of the solution concentration. Ultimately, the steel bar is connected with the anode, so the stainless-steel bar was placed in the solution to act as the cathode. The corrosion reinforcement process is controlled by Faraday's electric law and the current density was stabilized at 2 mA/cm^2 [20–22].

After the electricity accelerated corrosion procedure, the steel bars were taken out and the residual concrete which ended up on the surface of the steel bar was scraped. The steel bar was then cleaned in a 9% HCL solution. The next step was rinsing the steel bar with water after cleaning it up from the HCL solution. The corroded steel bar was put into a lime solution to neutralize the residual hydrochloric acid on the surface. Meanwhile, a steel wire brush was used to brush the surface remnants. Finally, washing with water and ensuring a cleaning time control of 3–5 min achieved the goal. The rinsed steel bar was put in a dryer for 4 h; after the bar was completely dry, antirust oil was painted on it. The seal protection of the preservation film was kept for 3D scanning.