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Electrochemical study the corrosion behaviour of carbon steel in mortars under compressive and tensile stresses

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ABSTRACT

The influence of compressive and tensile stresses on the corrosion behaviour of the rebar in mortars was investigated. The corrosion of the rebar intensified with increasing magnitude of the stress. Results of electrochemical impedance spectroscopy and the observed corrosion state indicated that the stress-induced corrosion of the rebar resulted mainly from degradation of the concrete/rebar interface. For the same magnitude of stress, the rebar in the compressed sample was more severely corroded than that in the tensile sample. In addition, modes were proposed to illustrate the different failure patterns of the concrete/rebar interface, owing to the action of the stresses.

1. Introduction

The durability of concrete structures is reduced primarily by the corrosion of steel bars [1]. In practice, engineering structures are subjected to various types of loading or stress and as such, many researchers have evaluated the effect of loads on the durability of the concrete structure. Anhvu [2] studied the corrosion behaviour of steel wires under tensile stresses and found that pitting corrosion attacks evolved into stress corrosion cracking. Furthermore, the corrosion led to a severe decrease in the ultimate strain, thereby resulting in brittle failure of the corroded wire. Jaffer [3] examined the distribution of corrosion products of steel rebar and found that, compared to static loading, dynamic loading resulted in a greater detachment of bonds between the aggregate and the cement paste. Moreover, owing to the opening and closing of cracks under dynamic loading, corrosion products moved away from the concrete/rebar interface and into the crack of the concrete cover layer. Ahn [4] studied the corrosion behaviour of concrete beams under static and fatigue loading, respectively, in the simulation tidal zone. In that work, the beam subjected to fatigue loading deteriorated more rapidly than its statically loaded counterpart. The former also exhibited a lower ultimate strength bearing capacity than the latter at the end of the experiments. In other work, Hariche et al. [1] determined the effect of the corrosion of rebars on the serviceability of reinforced concrete beams under loading; this study revealed that the deflection of the beam increased with progressive corrosion of the reinforcement. In fact, the deflection increased significantly during the early stages of corrosion, owing to crack propagation on the tensile side of the beams. The authors attributed this increase to the flexural tension and the expansive stresses induced by the corrosion products. Valiente [5] found that the strength and ductility of the pre-stressed steel wire in a concrete line meant for water supply, decreased significantly when the concrete cover layer was not damaged. In addition, Fang et al. [6] evaluated the bond behaviour of the corroded reinforcement in a concrete structure and found that cyclic loading led to a significant reduction in the bond capacity. The results also indicated that severe corrosion will result in substantial reduction of the bond capacity under cyclic loading. Furthermore, Arteaga et al. [7] found that the coupled effect of corrosion and fatigue led to a substantial reduction in the expected lifetime of concrete structures subjected to corrosion and fatigue deterioration processes. Apostolopoulos [8] investigated the low-cycle fatigue behaviour of corroded reinforcing steel and found that the number of cycles to failure decreased significantly with increasing amount of corrosion. In addition, Blunt and Ostertag [9] compared the corrosion behaviour of rebar in control and hybrid-fiber-reinforced concrete beams under cyclic flexural loading; they found that the start of corrosion was delayed and the corrosion rate of the rebar in the latter was lower than that of its counterpart in the former. Previous stud-

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ies indicated that applied loading accelerates the degradation of concrete structures. This is especially true for structures subjected to dynamic loading [3,6] or fatigue loading [4,7,8].

The corrosion behaviour of concrete elements under compressive and tensile stresses has also been extensively investigated [10–12]. One study showed that, compared to tensile stresses of the same magnitude, compressive stresses led to more severe corrosion of the passive film on the rebar in a chloride-free cement extract (CE) solution [10]. Zhang [11] also studied the corrosion behaviour of carbon steel in a simulated concrete pore solution, under static tensile and compressive stresses; the corrosion current density of the former was found to be lower than that resulting from the action of a compressive stress in the chloride-free pore solution. However, the tensile carbon steel sample was more severely corroded than its compressed counterpart when chlorides were added to the pore solution. Aveldaño and Ortega [12] compared the degradation of tensile and compressed concrete beams; this study revealed that cracking of the cover was more extensive in the latter (but with less loss of the bars) than in the former. Previous studies [10–12] reported conflicting results about the effect of tensile or compressive stresses on the degradation of concrete structures. Therefore, the effect of these stresses on the corrosion performance of rebar in the concrete structure, is elucidated via open circuit potential (OCP), linear polarization resistance (LPR), and electrochemical impedance spectroscopy (EIS) measurements. The results indicate that, for the same magnitude of stress, the rebar in the compressed concrete samples is more severely corroded than that in the tensile samples. Moreover, modes are introduced to explain the difference in the degradation of the concrete/rebar interface under the action of tensile and compressive stresses.

2. Experimental methods

2.1. Materials

Carbon steel rods (diameter: 10 mm) were used in this study. The chemical composition of the steel was (wt.%): 0.37% C, 0.16% Si, 0.32% Mn, 0.053% S, and 0.026% P. Plain round bars were cut to a length of 190 mm and ground with emery paper up to No.600. The samples were then degreased with acetone, rinsed with alcohol, and dried in hot air. In preparation for electrochemical testing, copper wires were subsequently welded at one end of each sample. The rebar samples were then coated with epoxy resin, leaving a 50 mm × 5 mm exposed region in the middle.

After the coating solidified, each rebar was embedded in a mold and the mortar was poured into the mold. The mortar samples, having sizes as shown in Fig. 1, were mixed with ordinary Portland cement (P.O 42.5) and river sand. The granular distribution of the sand (Fig. 2) was obtained by sieving the sand through sieve sets with sizes of 1180 μm, 750 μm, 600 μm, 425 μm, 250 μm, 150 μm, and 75 μm, respectively. In addition, the sand-cementitious material ratio and water–cement ratio (W/C) of the mortar were maintained at 3 and 0.5, respectively. The samples

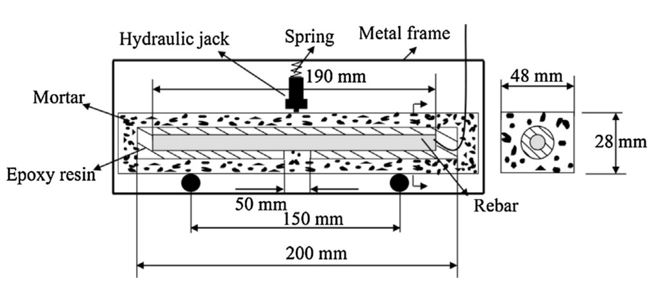

Fig. 1. Schematic of the mortar sample and loading mode.

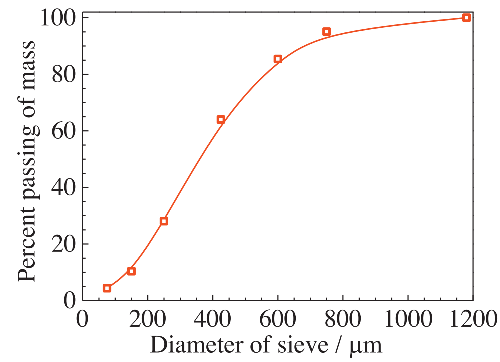

Fig. 2. The distribution of grains in the river sand.

were removed from the molds after 24 h and the surfaces of the mortar were coated with epoxy resin except for the side face of the exposed rebar. After the resin solidified, the mortars were subjected to three-point loading. The effect of stress on the corrosion behaviour of rebar in the concrete was determined by applying var-

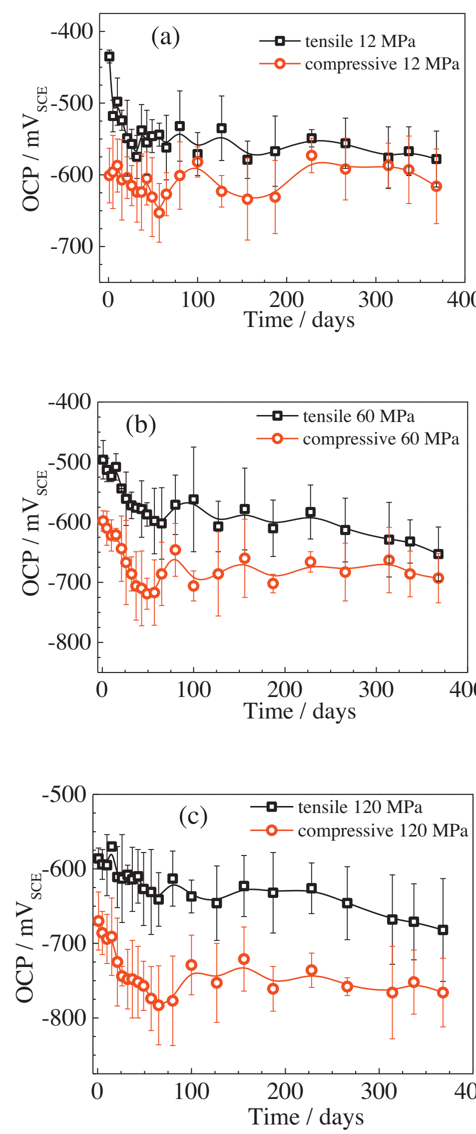

Fig. 3. OCP values of the rebar in the mortar subjected to compressive and tensile stresses of (a) 12 MPa, (b) 60 MPa, and (c) 120 MPa, while immersed in a 3% NaCl solution.