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Effect of metakaolin on the corrosion resistance of structural lightweight concrete

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HIGHLIGHTS

- We investigated the corrosion resistance of SLC specimens with MK at various ratios.
- MK addition improved the physical properties of the SLC specimens.
- Addition of MK in ratios up to 15% w/w improved the mechanical strength of the SLC.
- Use of MK in ratios up to 15% w/w improved the corrosion resistance of the SLC.
- MK higher than 15% w/w reduced the mechanical strength and corrosion resistance.

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ABSTRACT

In this study, the mechanical and physical properties of structural lightweight concrete (SLC) specimens produced by substituting cement with metakaolin (MK) at ratios of 5%, 10%, 15% and 20% w/w were examined, and the corrosion behavior of the reinforcing steel bars embedded in these specimens was investigated. Corrosion rates of the bars were determined by using galvanic current measurement method. Furthermore, the corrosion potential of the steel bars in these specimens was measured daily for a period of 90 d based on ASTM C876 standard test method. As a result of this study, it was found that the MK improved the mechanical and physical properties of the SLC and the 15% w/w MK addition showed the optimum contribution to the strength development. Furthermore, the use of MK in SLC specimens, as a cement replacement up to 15% w/w, improved the corrosion resistance of the specimens, while there was no positive effect when MK was added in greater ratios. The conclusions were also supported with scanning electron microscope (SEM) studies.

1. Introduction

During the past decade, metakaolin (MK), a thermally activated amorphous alumina-silicate material acquired by calcining kaolin clay at the temperature range of 750–850 °C, has been objective of several studies, mainly due to its capacity to react vividly with $Ca(OH)_2$ by-products occurred during cement hydration [1,2]. Due to its high pozzolanic activity, the addition of MK greatly enhances the mechanical and durability properties of cement based materials [3–8]. Recent works have shown that MK is a very effective pozzolan, altering the pore structure of the lime and cement paste and greatly improving its resistance to the entrance of water and diffusion of harmful ions through the cement matrix, supporting the idea of its beneficial addition in cement based materials [9–15]. The reaction between the MK and calcium hydroxide (CH) produces tobermorite gel and alumina phases including C_4AH_{13}, C_2ASH_8 and C_3AH_6 at ambient temperature [16]. These phase's stability may lead to dense interfacial transition zone, producing a decrease in porosity and gain of microstructural compactness, i.e., more mechanical and physical strength.

The corrosion resistance of the concrete affects its durability and finally its performance. The durability of reinforced concrete structures is provided by both chemical and physical protection of the reinforcing steel bar against corrosion. Reinforcing steel embedded in good quality concrete normally displays good long-term durability due to the pore solution phase being sufficiently alkaline to lead to passivation of the bar. But, concrete is a porous composite material and thus reinforcing bar protection resulting from the penetration of aggressive ions may not remain excellent long term. This protection depends mainly on the environmental conditions, microstructure and the chemistry of the mixture.

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The two latter factors are strongly affected by the mix design and quality of its constituents. It is apparent that the existence of MK affects the corrosion resistance of concrete [17,18].

Various studies have been performed on the determining the corrosion behavior of concretes produced with MK. But, not a single study has been encountered on corrosion resistance of SLC obtained by substituting cement with MK in the open literature. Therefore, the aim of this study was to investigate the corrosion behavior of SLC specimens containing MK at proportions of 5%, 10%, 15% and 20% by weight. Furthermore, the mechanical and physical performances of the SLC specimens were also determined.

2. Materials and methods

A total five series of adjacent SLC specimens, including the control specimen, were prepared to determine the effect of MK addition on the corrosion behavior of reinforcing steel embedded in SLC specimens. A total of twenty-five pieces of 100 × 100 × 200 mm concrete specimens consisting of cube specimens in adjacent position were produced, with five specimens being taken from each series. Corrosion rate of the steel bars embedded in these specimens was determined based upon the galvanic current measurement method (GCM).

GCM is based on the principle of determining the galvanic current between electrodes immersed in electrolytes with various contents by using a sensitive ammeter. GCM was applied in two different methods by Jang and Iwasaki [19]. In the first method, out of two electrodes, one was submerged in a solution with broken concrete particles and chloride, the other was submerged in a solution without chloride. These solutions in two different containers were made to come into contact with each other by a saturated ammonium nitrate salt bridge. Electrodes were connected to each other by a cable, and the ratio of current passing through the corrosion cells was measured by means of a sensitive ammeter. The same test was also carried out by using two concrete specimens in lieu of solution containing concrete particles. In this instance, a thin film was placed between the concrete specimens. The specimens were connected to each other by a salt bridge, and galvanic current between the electrodes was measured through the agency of a sensitive ammeter. Keleştemur [20] investigated the corrosion resistance of concrete specimens produced by substituting coarse aggregate with waste vehicle rubber tires at various proportions by using GCM. Asan and Yalçın [21] determined the effects of chloride and acetate ions on the corrosion resistance of concrete containing fly ash by using GCM.

In this study, 5% w/w NaCl was added into the mixing water on one side of the adjacent SLC specimens. In this way, it was considered that galvanic current would occur between the reinforcing steels in the SLC specimens containing MK and with or without NaCl. The galvanic current values were measured daily for a period of 90 days by using a high impedance ammeter. Relative corrosion rates of the electrodes embedded in SLC specimens were determined by dividing galvanic current passing through the galvanic cell to the surface area of the steel.

The corrosion potentials of the electrodes embedded in SLC specimens were determined daily for a period of 90 days based on the ASTM C876 standard test method. The corrosion potentials of the reinforcing steels were measured versus time using a saturated copper/copper sulfate electrode (CSE) as a reference electrode. Corrosion potential measurements were carried out by using a high impedance voltmeter as measurement device. The corrosion potential changes of the steels versus time were showed as graphic to determine whether the electrodes were in active or passive situation.

2.1. Preparing electrodes

The rounded bar of SAE1010 steel produced by Ereğli Iron and Steel Factory in Turkey, which is main material of the construction sector, was chosen for this study as an electrode. The as-received material was in the form of 14 mm in diameter hot-rolled bar. The chemical analysis of the electrode is given in Table 1.

50 pieces of electrodes 120 mm in length were cut out from the as-received material and surfaces of the electrodes were mechanically cleaned with the aid of lathe machine. Then, electrode surfaces were polished with 1200 mesh sandpaper and cleaned with ethyl alcohol. 10 cm^2 surface areas were left open in the tips of steels which would be embedded in the SLC specimens. Screw thread was machined in the other ends of the steels and cables were connected to these ends for make easier measurements in the course of the test. Remaining regions of the steels were covered from exterior effects by coating them with epoxy resin at first and then with polyethylene. The steel bars were kept in a desiccator to protect them against corrosion up to test time.

Table 1
Chemical analysis of the electrode (% wt.).

C	Mn	Si	P	S	Fe
0.17	0.250	0.050	0.005	0.050	Balance

2.2. Preparing SLC specimens for the corrosion tests

100 × 100 × 200 mm SLC specimens consisting of cube blocks in adjacent position were prepared for corrosion tests. Rebars prepared in advance were embedded in these specimens as shown in Fig. 1(a). While one of the blocks contained 5% w/w NaCl, the other one was normal composition. A total of 25 specimens were prepared to determine the corrosion resistance of SLC specimens containing at various proportions of MK. The compositions of the concrete blocks in adjacent position are given in Table 2.

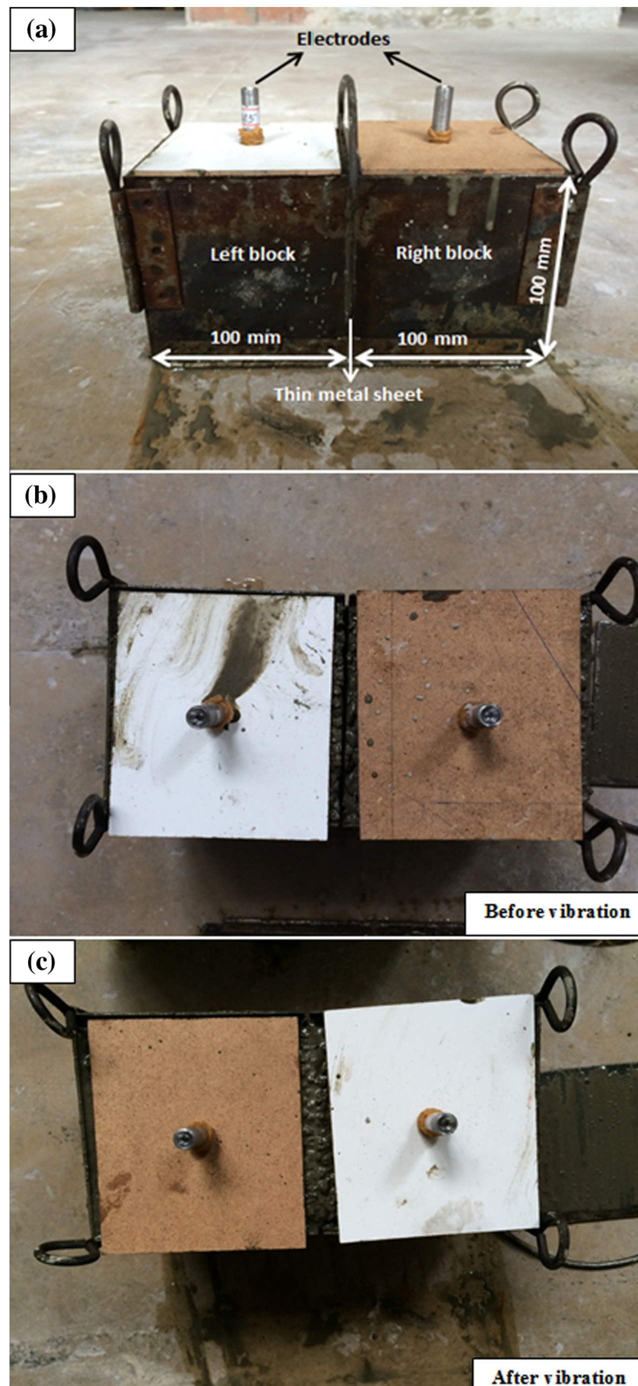

Fig. 1. SLC blocks in adjacent position.