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Modification of properties of reinforced concrete through nanoalumina electrokinetic treatment

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HIGHLIGHTS

- Nanoalumina particles were drifted into reinforced concrete through electrokinetic treatment.
- Transport of nanoalumina was evidenced up to rebar-concrete interface by microstructural observations.
- Nanoalumina transport into reinforced concrete reduced total porosity at rebar-concrete interface.
- Nanoalumina transport increased bond strength between rebar and concrete.

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ABSTRACT

An attempt was made to drift nanoalumina particles into concrete pores through electrokinetic treatment. An external electric current (current density = 3 A/m^2) was applied for 3 and 15 days in reinforced concrete blocks toward steel reinforcement and microstructural characterizations (i.e. morphology observation and porosity analysis) were performed on concrete fragments of different depth from exposure surface. The morphology observation evidenced transport of nanoalumina from the exposure surface even reaching the rebar-concrete interface (up to 25–30 mm, in 15 days treatment). The porosity analysis of treated samples revealed that reduction of porosity of rebar interface was more pronounced as compared to the exposure surface and the treatment for 15 days was more beneficial for porosity refinement than treatment for 3 days. Effects of the electrokinetic NA treatment on strength of rebar-concrete interface were evaluated through pull-out test. The results showed that by increasing current density, bond strength of rebar-concrete interface increased.

1. Introduction

Application of external electric current for prevention, protection and mitigation of corrosion of the reinforcement in reinforced concrete (RC) structures is getting more demanded, discussing durability of RC structures. Several techniques have been developed as electrochemical repair methods applying external electric current such as cathodic prevention [1] and protection [2,3], electrochemical chloride extraction (ECE) [4,5], electrochemical realkalization [6] and electroosmotic transport [7]. Other techniques such as electrokinetic nanoparticle treatment [8–10] and crack closure by electrodeposition [11,12] also have been developed but have received less attention in the literature.

Electrochemical repair methods are based on the accelerated transport of charged particles (ions, inhibitors, etc.) inside pore structure by migration mechanism, under the influence of an electric field [8]. The electric field, which is established through RC structure, can extract chloride ions toward the surface or generate alkalinity close to the cathode (rebar). Simultaneously, the electric field can cause ions or cationic corrosion inhibitors or other positively surface charged particles to drift towards reinforcement through migration mechanism during an electrochemical repair method. Cathodic inhibitors (positively charged) have been reported to be transported utilizing the conventional setup of electrochemical repair methods [13,14].

Suspended nanoalumina (NA) can be considered as formed by surface charged particles depending on pH value of the suspension and on surfactant by which the particles are modified. For instance, considering suspension of bare NA, for pH lower than 8 NA particles had positive surface charge and for pH higher than 8 the NA particles had negative surface charge [15]. Thus, transport of NA particles into concrete pores by means of external electric field could be theoretically possible through a so-called electrokinetic treatment.

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Electrical transport phenomena, which are based on the charge separation inside the electric double layer, are called in general electrokinetic [16]. Electrophoresis is a type of electrokinetic treatment and is defined as the movement of dielectric particles relative to a stationary liquid through application of an electric field. Surface charged particles induce charge separation inside the liquid phase, see Fig. 1. Electric field may propel the particles with positive zeta-potential through the liquid towards the cathode. The transport of the particles is in direct relation with zeta-potential of the particles, electric field and in inverse relation with viscosity of the fluid [17]:

$$v_\infty = -\frac{E_\infty \xi}{\mu} \tag{1}$$

where v_∞, E_∞, ϵ, ξ and μ are velocity of the fluid far from the particle with respect to the particle, component of electric field far from the particle along with the velocity, permittivity (F/cm), zeta-potential (V) and viscosity of the fluid (g/cm.s), respectively. As a consequence, a particle with positive zeta-potential moves in the direction of electric field.

Cardenas et al. [18] made the first attempt to drift NA coated nanosilica (NS) particle into the concrete through electrokinetic treatments. In another study, Sanchez et al. [8] modified a setup in order to conduct migration treatment of negatively charged NS into hardened mortar. One of the differences between these two studies is that Cardenas et al. [18] used nanoparticle suspension as anolyte, while Sanchez et al. [8] used nanoparticle suspension as catholyte. This transport of nanoparticles may influence porosity of hardened cement composites and as a result, may modify durability properties.

Several durability properties of cement composites have been claimed to be affected by electrokinetic transport of nanoparticles. Permeability of cement paste was reduced by 1–3 orders of magnitude by electrokinetic treatment of NA coated NS [18]. Capillary porosity of concrete was found to be reduced with electrokinetic treatment of NS [8,9]. Cylindrical samples were treated by electrokinetic NS transport for 8 days [8] and for 4 h [9]. The samples were immersed in water after treatment and after approximately 28 days immersion, the electrical resistivity increased with respect to that of before the treatment. Moreover, resistance to carbonation after a treatment with NS for 4 h increased with respect to untreated sample [9]. Beneficial effects of transport of nanoparticles by electric current were also reported with respect to reinforcement corrosion. A significantly lower corrosion current density was measured for electrokinetic treated (EN) concrete compared to untreated, when the concrete was re-exposed to chloride solution after ECE treatment followed by EN treatment [10]. Kupwade-Patil et al. [10] claimed that nanoparticles appeared to form a physical barrier against chloride re-penetration.

Application of plain NA suspension as anolyte in electrokinetic treatment for reinforced concrete is an innovative rehabilitation method and is not studied in the literature. In this study, reinforced concrete blocks were subjected to electrokinetic treatment with NA suspension. The aim was to investigate the feasibility of transport of NA into concrete under the action of an external electric field and to study influences of the nanoparticle transport on microstructure of the concrete. Microstructural characterization such as morphology observation and porosity analysis were conducted on samples of different depth from exposure surface. Further information was provided concerning influence of NA electrokinetic treatment and effects of application of electric current on bond strength of rebar-concrete interface through pull-out test.

2. Material and experimental methods

2.1. Materials

Ordinary Portland cement was used for fabricating concrete blocks with w/c ratio 0.55. The concrete composition is presented in Table 1 and the aggregates were river siliceous particles with size in the range 0.15–9.5 mm. NA suspension was used with concentration of 20% by total mass. Density and pH values of the suspension were, respectively, 1.14 g/cm^3 and in the range of 5–7. Particle size distribution and cumulative volume fractions of the NA suspension, conducted by measurement of dynamic light scattering (DLS), are shown in Fig. 2. Based on the figure, 100% of the volume of tested NA suspension had particles finer than 10 nm.

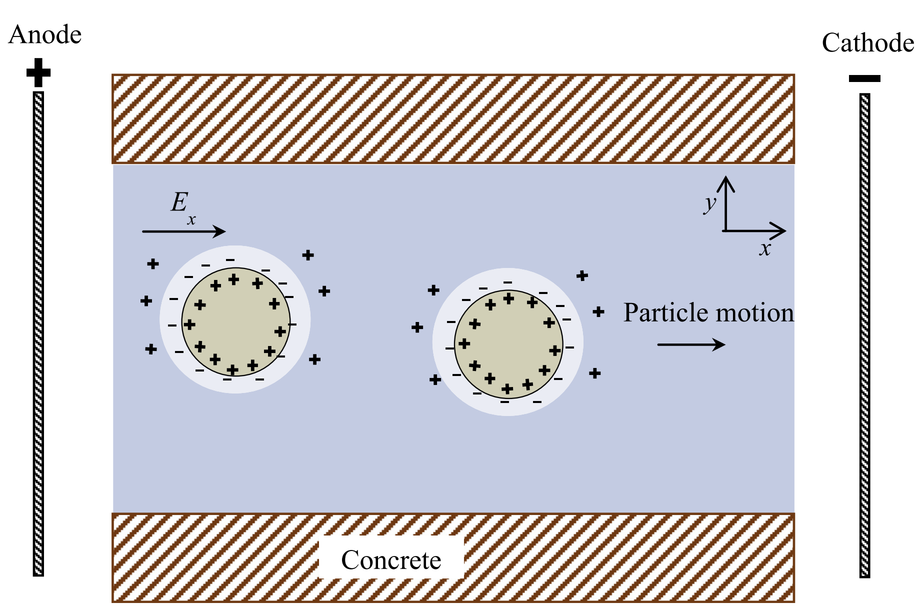

Fig. 1. Schematic of capillary porosity of concrete containing electrolyte (pore solution) and nanoalumina. Electrophoretic movement of particles with positive surface charge and charge separation around the particles is shown.