Construction and Building Materials 79 (2015) 311–317

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Improving steel fiber reinforced concrete pull-out strength with nanoscale iron oxide coating

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HIGHLIGHTS

- The paper studies the pull-out strength of nanorods coated steel fibers in concrete.
- The iron nanorods increase the fiber pull-out strength by over 80%.
- The electrodeposition process of iron nanorods is simple and easy to scale up.

ARTICLE INFO

Article history:
Received 3 September 2014
Received in revised form 8 January 2015
Accepted 10 January 2015
Available online 28 January 2015

Keywords:
FRC
Iron oxide
Electrodeposition
Pull-out test

ABSTRACT

Fiber-reinforced concrete (FRC) has been extensively used all over the world for over 40 years. Steel fiber, being the first and most commonly employed reinforcement fiber, is always favored as the uniformly dispersed reinforcement for concrete due to its improvement towards mechanical strength, failure mode and bonding toughness. This article depicts a nanoscale reinforcement of iron oxide coatings on steel fibers prepared by electrodeposition method. The results indicate that pristine Fe_2O_3 particles, Fe_2O_3 nanorods and nanosheets were synthesized under different depositing conditions. The nanorod and nanosheet coated steel fibers were embedded in cement mortar for fiber pull-out tests. Corresponding pull-out tests revealed that iron oxide coating showed a strength enhancement up to 82% compared to the conventional fiber reinforced cement mortar samples.

1. Introduction

Reinforced concrete (RC), a hardened mixture of cement and mineral aggregate and reinforced by different kind of fibers, is by far one of the most important construction materials and has been extensively used in construction projects such as road surfaces, load-bearing structure and airport pavements, etc. However, concrete is sensitive to even slight modification in composition comparing to other civil materials, and is brittle and has a low tensile strength and shear capacity [1–3]. Zube [4] published the study on the reinforcement of concrete mixtures in 1956, which revealed various types of wire mesh placed under concrete overlay in an attempt to prevent reflection cracking. It evaluated the effect different wire reinforcements prevented or greatly delayed the formation of longitudinal cracks, also showed that the utilization of wire reinforcement would allow the thickness of overlays decrease while maintaining the same level of performance.

Steel fiber, among all reinforcement materials, is the most accessible and extensively used one for most structural and mechanical purposes [5,6]. This largest consumption of steel fiber combines the concern on economics, location of manufacturing facilities, reinforcement efficiency, resistance to environmental aggressiveness and feasibility for further endeavor [7]. With improved pull-out strength, the steel fibers can enhance the compressive strength, tensile strength, shear strength of concrete. Report showed that by introducing steel fiber into concrete matrix at an amount of 1–1.5 wt% will increase the tensile strength up to 100%, flexural strength up to 150–200% and the compressive strength of 10–25% [6], because it has homogeneously distributes into the concrete matrix and lead to better exploitation of high strength matrix [8]. Furthermore, the presence of steel fiber improves the impact strength and toughness [9], and converts the pattern of concrete from brittle to more ductile [10,11]. The fracture energy in steel fiber reinforced concrete (SFRC) is higher per volume than plain concrete [12], and it is also reported that the introduction of steel fiber will strengthen both compressive strength and strain corresponding to peak stress [13]. In addition, SFRC is also superior in maximum compressive strain than plain

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http://dx.doi.org/10.1016/j.conbuildmat.2015.01.055
0950-0618/

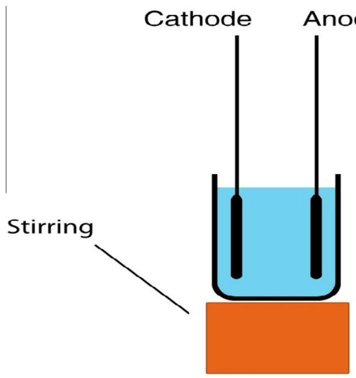

Fig. 1. Experiment setup of electrodeposion of nano-structure iron oxide onto steel fiber wire mesh.

Table 1
samples under different experiment conditions.

Sample	Current intensity (mA/cm^2)	Deposition time (min)
#0	Reference sample	N/A
#1	1	30
#2	1	60
#3	1	120
#4	3	10
#5	3	30
#6	3	60
#7	5	10
#8	5	20
#9	5	60

concrete. In case of tensile strength, it is also reported that with the addition of same type and volume of steel fiber, the improvement in performance is much more observable for lightweight aggregate concrete than normal weight concrete [14]. Concrete pull-out test is an important evaluation parameter indicates the bonding strength between reinforcement fiber and the concrete matrix as well as a crucial factor of the pullout strengths of hardened concrete, has been standardized by ASTM-C900 standard [15]. However, this standard involves a cast-in-place procedure that requires shape modification of fibers, which will introduce manufacture complexity. Filho et al. [16] have reported an alternated experiment layout for pull-out test, in which a rebar was penetrated into a cylindrical concrete matrix that was mounted on a load cell. Thus, mounting the specimen on a properly designed testing machine according to its shape and dimension would eliminate most of the complexity and will simplify the entire procedure.

Nevertheless, despite the advantages brought by steel fiber, there also exist drawbacks. Specifically, it reduced the fracture of fresh concrete due to its relatively high density. Furthermore, report also showed that the dead load of composite would subject to increase with the coexistence of steel fiber [17,18]. In order to remit the abovementioned disadvantages at most extent and improve the pull-out force between steel fiber and concrete matrix, this article describes an approach to synthesis ~~the~~ nanostructure iron oxide coatings on the steel fiber by electrodeposition technique. This technique provides a feasible and economic access to improve the pull-out force between steel fiber and concrete matrix in the following aspects, (1) unlike the work presented by Anwaw et al. [19], it does not require shape modification to the steel fiber; (2) the work presented in this study to be conducted with either non-toxic or minor toxic materials and a procedure occurs under ambient temperature at a mild experimental environment. The strategy and plot for this study is to provide a controllable, observable and quantifiable synthesis approach for the nanostructured ferrous oxide grown on the steel fiber. Therefore it demands sufficient concentration of precursor, a localized pH that is relatively lower than the neutral plus a high ionic strength, revealed by Vayssiers et al. [20]. Although some previous researchers provided a synthesis approach involving iron–water reaction [21,22], the lack of feasibility of being extensively and practically applied at workplaces like construction site and airports. This research introduced the method of electrodeposition under room temperature with easily accessed material and high reliability that can be applied to the surface of metallic foil or surface. Due to the minimized surface mismatch between ferrous ion and steel fiber substrate and the protection mechanism towards anode, the electrodeposition procedure will bring a firm coating on the surface with a minimized level of corrosion attack. The goal of this research is to extend a preliminary investigation on the performance of this new type of SFRC refined by iron oxide nanostructures. This innovated SFRC is expected to show improved mechanical performance and superior compressive strength as stated in other similar studies [23] while reducing the coarse aggregate quantity.

2. Experiment and characterization

2.1. Synthesis of nanostructured Fe_2O_3 on steel fiber

In this experiment, nanostructured Fe_2O_3 was prepared by electrodeposition using a conventional two-electrode configuration, of which the working electrode is the steel fiber mesh to be deposited (5 cm × 5 cm) and the counter electrode is a graphite slab electrode (Fig. 1) where the distance between the electrodes was kept at about 1.5 cm by using a non-conducting plastic holder. The experiment was performed in a small tank with electrolyte containing 0.2 mol^{-1} Sodium Acetate (Sodium Acetate Trihydrate, ACS Grade, AMRESCO), 0.01 mol^{-1} Sodium Sulfate (Sodium Sulfate Anhydrous, ACS Grade, AMRESCO) and 0.01 mol L^{-1} Ammonium Ferrous Sulfate (Ammonium Iron (II) Sulfate Hexahydrate, 99%, Alfa Aesar), with simultaneous magnetic stirring at an appropriate rate. The pH value was adjusted to ~8 by HNO_3 and NH_3H_2O.

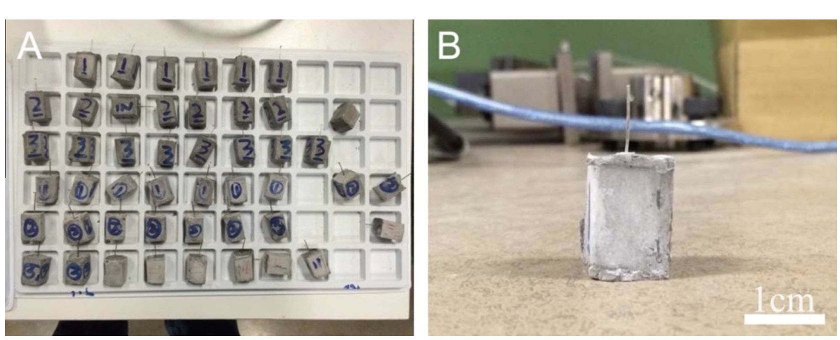

Fig. 2. As-prepared concrete samples.