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Original Research Article

Comparison of compressive strength and electrical resistivity of cementitious composites with different nano- and micro-fillers

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ABSTRACT

Cementitious composites with 0–1.5 wt.% Nano-SiO_2 (NS), nano-TiO_2 (NT), carbon nanotubes (CNTs), carbon nanofibers (CNFs) and carbon microfibers (CFs) are fabricated and tested. The enhancing effects of different fillers on the compressive strength and electrical resistivity of composites are compared, and the underlying modification mechanisms of fillers to composites are investigated by analyzing the difference in the morphology of fillers and rheology of composites. The compressive strength of composites containing 0.1% NS, 0.5% NT, 0.1% CNTs and 0.5% CFs by weight of cement presents approximately 12.5%, 20.8%, 16.8% and 21.4% higher than that of control sample, respectively. It is revealed that CFs also have improving effect on the compressive strength of composites besides flexural strength. When the composites with nano-fillers cannot be processed to ideal state, the reinforcing effect of nano-fillers is no better but even worse than that of micro-fillers. Composites with CNTs, CNFs and CFs possess good electrical conductivity. Composites with CNFs and CFs have a percolation threshold of electrical resistivity below 0.5%, while the percolation threshold of electrical resistivity of composites with CNTs is about 1%. Although CNFs do not have significant effect on compressive strength of composites, they have the best improvement to electrical resistivity.

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1. Introduction

Cementitious materials (including cement paste, cement mortar and concrete) are widely used in construction industry for their high strength, low cost, simple construction and wide applicability. However, some disadvantages limit the use of cementitious materials such as poor durability and relatively low flexural strength. An effective method to mend these shortages is adding micro/nano fiber or nano particle fillers into cementitious materials [1–4], as the mechanical strength and service life of cementitious composites are determined by the micro-structure and by the mass transfer in nano-scale [5]. The extremely fine size makes nano and micro fillers exhibit unique physical and chemical properties [6]. In addition, the composites with nano- and micro-fillers will exhibit excellent electrical conductivity [7,8] and piezoresistivity [9–11]. They can be applied as anti-corrosion earth connectors for electrical-shock protection and electric-heating pavement materials for de-icing roads [12–14].

In recent years, many studies have been done about the mechanical and electrical properties of cementitious composites mixed with different types of fillers, and some of these studies have obtained considerable enhancements. For example, nano particles (e.g. nano-SiO_2 (NS) [15,16], nano-ZrO_2 [15], nano-TiO_2 (NT) [17–19]) can strengthen the composites by nucleus effect [15,18], filling effect [16] and hydration acceleration effect [15,18,19]. Nano and micro fibers (e.g. carbon nanotubes (CNTs) [20–24], carbon nanofibers (CNFs) [22], and carbon microfibers (CFs) [25]) mainly enhance the composites by forming an enhancing network [20,22,26] and improving bonding strength [22,23,25,27]. Especially the CFs which have good conductivity can also be used for developing electrically conductive cementitious composites [24,28]. In addition to the difference of enhancing effect between particle fillers and fiber fillers, fiber fillers with different aspect ratios and particle fillers with different specific surface areas may affect their enhancing effects. Moreover, although nano-fillers can take effect in lower content, their practicability is limited by high price and difficult fabrication processes [29,30]. The study on comparison of the enhancing effect of different fillers helps to choose the right filler under different conditions. However, little work has been done on comparison of the enhancing effect of different fillers based on their dimensions or size scales. The influences of different types of fillers, e.g. nano- and micro-fibers, particle and fiber fillers on the mechanical and electrical properties of cementitious composites have not been studied. The different enhancing mechanisms among them have not been explained by morphological characteristics of different fillers and rheology of composites.

In this paper, we choose five representative nano- and micro-fillers, which are NS, NT, CNTs, CNFs and CFs. Cementitious composites mixed with different fillers by 0–1.5 wt% are fabricated and tested for compressive strengths and electrical resistivity. The enhancing effect and the corresponding mechanisms are explained by analyzing the difference in the morphology of fillers and rheology of composites.

2. Experimental programs

2.1. *Materials*

The raw materials used to fabricate cementitious composites include cement, water, water reducer and fillers. The chemical composition of P.O 42.5 R cement is shown in Table 1. The water reducer is 3310E polycarboxylate superplasticizer. Its solid content is 45% and it can reduce water to an extent of 30%. In order to compare the enhancing effect of different fillers on cementitious materials, five types of representational fillers are chosen in this paper. 0D nano particle fillers include NS and NT. 1D nano carbon fiber fillers include CNTs and CNFs. 1D micro carbon fillers are CFs in lengths of 3 mm and 6 mm.

The NS is hydrophilic type and the physical parameters of NT and NS are shown in Table 2. The CNTs are multi-walled and the CNFs are PR-24-XT-HHT type. The Physical properties of CNT and CNF are shown in Table 3. Performance parameters of 3 mm and 6 mm PAN-based CFs are shown in Table 4.

Table 1 – Chemical composition of cement.

Chemical Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O
Wt.%	61.13	21.45	5.24	2.89	2.08	2.05	0.77

Table 2 – Physical properties of NS and NT.

Type	Diameter/nm	Specific surface area/$m^2\ g^{-1}$	Density/$g\ cm^{-3}$	pH	Purity/%
NS	12	200	60	4.5	≥99.8
NT	10	150	–	–	≥99

Table 3 – Physical properties of CNT and CNF.

Type	Diameter/nm	Length/μm	Specific surface area/$m^2\ g^{-1}$	Conductivity/$s\ cm^{-1}$	Purity/wt%
CNT	>50	10–20	>60	>100	>95
CNF	100	50–200	230	–	–