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# Multifunctionality of cement based composite with electrostatic self-assembled CNT/NCB composite filler

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ABSTRACT

In this paper, electrostatic self-assembled carbon nanotube (CNT)/nanocarbon black (NCB) composite is employed as filler for developing multifunctional cement-based composites. The performances of the composites with different content of filler are investigated. The electrochemical impedance spectroscopy and equivalent circuit are used to explore the conductive and mechanical mechanisms of the composites. Experimental results indicate that the compressive strength and elasticity modulus of the composites sharply decrease when the filler content exceeds 0.77 vol.%. The percolation threshold zone of the electrical conductivity of the composites ranges from 0.39 vol.% to 1.52 vol.%. The piezoresistive properties of the composites with 2.40 vol.% filler are stable and sensitive, and the maximum fractional change of electrical resistivity is 25.4% when the stress amplitude is 10 MPa. The composites feature sensitive and linear thermal resistance effect when the filler content is 0.77 vol.%. Electromagnetic shielding effectiveness of the composites with 2.40 vol.% filler at 18 GHz is 5.0 dB, which is 2.2 times of that of the control samples. The composites exhibit high absorbing electromagnetic wave performances in the frequency range of 2–18 GHz, and the minimum reflectivity reaches −23.08 dB with 0.77 vol.% filler.



## 1. Introduction

Cement-based composites are the most used construction materials. Many infrastructures, such as buildings, road and bridges, are made of cement-based composites in various shapes and sizes. Therefore, the performances of cement-based composites have a close relationship with the safety, longevity and function of infrastructures. With the rapid development of society, cement-based composites are

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undergoing a development from high strength and performance to multifunctionality.

Multifunctionality of cement-based composites means that the cement-based composites not only possess the acceptable mechanical properties and durability, but also feature function/smartness such as self-sensing, self-healing, self-adjusting, self-heating, self-cleaning, electromagnetic (EM) shielding/absorbing, energy harvesting, and light transmitting [1]. The multifunctionality of cement-based composites is usually achieved by adding functional fillers, changing component materials, or modifying the micro-structure. Adding functional fillers is an effective approach to endow cement-based composites with different functions. For example, adding carbon nanotube (CNT) [2–6], nanocarbon black (NCB) [7,8], carbon fiber [9–11], or nickel powder [12] into cement-based composites can attach self-sensing ability to them, which can sense the conditions and environmental parameters such as stress, strain, crack, damage, temperature, and humidity. Cement-based composites with $TiO_2$ [13–16] or $LiNbO_3$ [17] can improve the quality of air and bring clean environment by decomposing organic materials, biological materials, and pollutants. Cement-based composites with zeolite can self-adjust humidity of indoor at an appropriate level, which is important for patients, specific instrument and museum [18]. Adding polypropylene and nylon fibers can endow spalling protection property to cement-based composites [19]. Self-heating cement-based composites can be obtained by adding conductive fillers (carbon materials or metal materials), and they have a wide range of applications for deicing and snow-melting of parking garages, sidewalks, driveways, highway bridges, and airport runways [20–23]. Moreover, adding proper conductive fillers to cement-based composites also can enhance their electromagnetic shielding/absorbing properties [24–26].

Among the functional fillers, CNT and NCB show tremendous potential to make multifunctional cement-based composites due to their excellent electrical conductivity, low density, large specific surface area, and stable chemical properties. A lot of researchers have used CNT or NCB to develop multifunctional cement-based composites. For example, Materazzi et al. explored the electrical response of cement-based composites with CNT subjected to sinusoidal stress–strains in the typical frequency range of large civil structures. The results showed that the composites' output retains all dynamic features of the input thus it can provide useful information for structural health monitoring [27]. Han et al. developed sensing cement-based composites with CNT and investigated its feasibility for traffic monitoring. The developed composites showed great potential for traffic monitoring including traffic flow detection, weigh-in-motion measurement and vehicle speed detection [28]. Xiao fabricated cement-based composites with NCB, and they observed a linear relationship between the fractional change in resistivity and compressive strain in cement paste with 8.79 vol.%, 11.39 vol.% and 13.85 vol.% of NCB [8]. Han et al. studied the piezoresistivity of cement-based composites with carbon fiber and NCB under single compressive loading and repeated compressive loads at different stress amplitudes. They stated that the sensing property was reversible and stable within the elastic stage [29]. Dai et al. tested EM wave absorbing effectiveness of cement-based composites with NCB. They observed that the concrete exhibits good performance of absorbing EM waves in the frequency range of 8–26.5 GHz. The minimum reflectivity reaches −20.30 dB when the cement-based composites contain 2.5 wt.% of NCB [24].

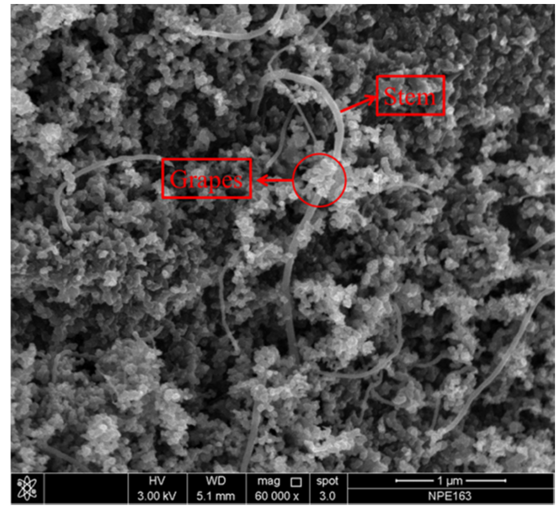


**Fig. 1 – Scanning electron microscope (SEM) image of CNT/NCB composite filler.**

CNT as a fibrous material that can form long-range conductive path in the cement-based composites, while NCB particles can be responsible for the short-range conduction inside the composites. As a result, the combination of CNT and NCB is beneficial for forming rich conductive paths inside the cement-based composites. CNT/NCB composite filler, made with electrostatic self-assembled technology, has a structure like a bunch of grapes where CNT is the stem and NCB is the grapes (as shown in Fig. 1). Besides cooperative improvement effect to electrical conductivity, CNT/NCB composite filler may be easier to be dispersed in the cement-based composites compared with CNT or NCB alone because its size is larger than that of CNT or NCB alone. Therefore, CNT/NCB composite filler possesses excellent electrical conductivity, electromagnetic property, thermal properties and dispersibility. The use of CNT/NCB composite filler may provide a new bottom-up design and fabrication approach for nano-engineering multifunctional cement-based composites.

Therefore, this paper is to investigate a series of functional properties of cement mortar with different contents of CNT/NCB composite filler including piezoresistivity, thermal-resistance effect, electromagnetic shielding/absorbing properties, compressive strengths, elasticity modulus, and electrical resistivity.

## 2. Experiments

### 2.1. *Raw materials*

The raw materials mainly include CNT/NCB composite filler, cement, silica fume, water, sand and water reducing agent.