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Nano graphite platelets-enabled piezoresistive cementitious composites for structural health monitoring

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HIGHLIGHTS

- Nano graphite platelets are used to develop piezoresistive cementitious composites.
- Piezoresistive responses of composites are studied under different loading conditions.
- Composites with nano graphite platelets feature stable and sensitive piezoresistivity.

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ABSTRACT

This paper studied the piezoresistive effects of cementitious composites filled with nano graphite platelets (NGPs). Experiments are performed to investigate the electrical responses of cementitious composites filled with NGPs when subjected to cyclic compressive stress under different quasi static and dynamic loading conditions such as different loading amplitudes, different loading rates and constant loading within the elastic regime of these composites. Meanwhile, the cementitious composites filled with NGPs are explored for the application in measuring dynamical loading rate. The results demonstrated that cementitious composites filled with NGPs possess sensitive piezoresistive effect and stable repeatability to different loading conditions.

1. Introduction

Conductive cementitious composite is a kind of heterogeneous material, which consists of binder, conductive material, aggregate, water, etc. Due to the good electrical conductivity and multifunctionality (e.g. joule effect, thermo-electric effect, and piezoresistive effect), the conductive cementitious composites can be widely used in the fields of intelligent buildings, health monitoring, disaster and damage prevention, etc. Short carbon fiber [1] was firstly introduced into cementitious composites to function as a smart sensing device and allow non-destructive electrical probing of flaws. Recent researches on the conductive cementitious composites mainly focus on adding new types of conductive fillers [2–5] (e.g. nickel powder [6] and carbon nanotube/nanofiber [7–17]) into the cementitious materials to further modify the sensitivity and stability of the piezoresistive effect. They found that carbon nanotube/nanofiber filled cementitious composites presented obvious piezoresistive effect.

Nano graphite platelets (NGPs) are stack of monolayer carbon atom flat-structure graphene [18,19]. They are bidimensional carbon nanomaterials with nano scale thickness and several micrometers diameter, and have one more dimension than carbon nanotube/nanofiber. The extreme case of NGPs is single layer graphene. The electronic mobility of NGPs in ambient temperature exceeds 15,000 $cm^2/(V \cdot s)$ which is higher than that of carbon nanotube and silica crystals. As a result, the electrical resistivity of NGPs is only about 10^{-6} Ω cm, which is lower than that of copper and silver. The connections among carbon atoms in each single layer of NGPs are very pliable and tough. When NGPs are under exterior mechanical force, the carbon atoms will bend and deform without realigning to adapt to the force. This makes their structure remain stable. This steady lattice structure endows carbon atoms

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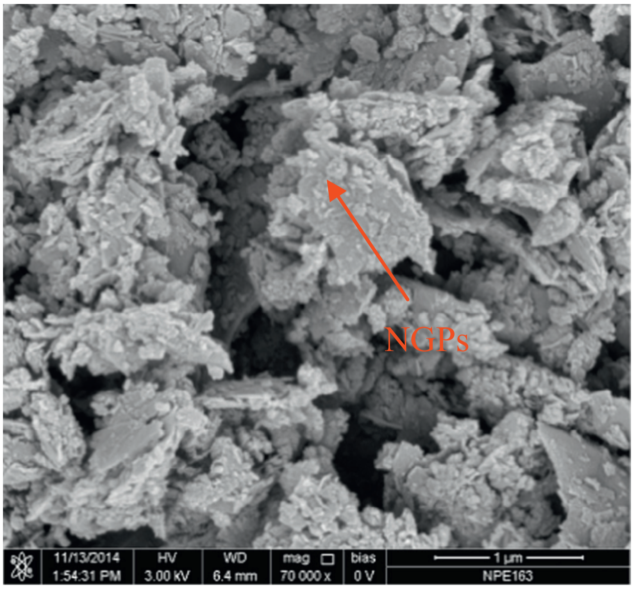

Fig. 1. Field emission scanning electron microscope (FESEM) images of NGPs.

Table 1
Properties of NGPs.

Parameters	Diameter	Thickness	Specific surface area
Description/value	< 2 µm	1-5 nm	$500 m^2/g$

Table 2
Mix proportions of cementitious composites filled with NGPs.

Sample	NGP content (vol%)	Water to cement ratio	Superplasticizer content (vol%)
NGP-1	1	0.3	1
NGP-2	2	0.3	1
NGP-3	3	0.3	1
NGP-4	4	0.3	1
NGP-5	5	0.3	1
NGP-6	6	0.4	1
NGP-8	8	0.4	1
NGP-9	9	0.4	1
NGP-10	10	0.4	1

with excellent electrical conductivity. Meanwhile, there are no lattice imperfection and exterior atoms introduced in the NGPs. When the electrons are moving in the orbit, they will not scatter. Due to the strong interatomic force, the interference between the electrons in graphene is still very small even if the surrounding carbon atoms collide. These characteristics make NGPs excellent conductive fillers. Previous studies have demonstrated that NGPs exhibit good electrical conductivity and the potential to be used in cementitious composites to monitor the loading, deformation and damage [20], in addition to its benefits on strength, durability and functional properties of the cementitious composites [21]. For example, Le et al. investigated the use of NGPs in cementitious composites to quantify the material damage extent [22]. Huang et al. observed that the addition of NGPs increases the flexural strength of cementitious composites by 82% compared to the plain ones. The electrical property of the composites is significantly modified, and the composites become highly conductive [23]. Duan et al. reported that only 0.05% NGPs oxide can improve the flexural strength of cementitious composites from between 41% to 59% and the compressive strength from between 15% to 33% [24]. Lv et al. found that NGPs oxide nanosheets can remarkably increase the tensile/flexural strength of the corresponding cementitious composites. Especially, when the content of NGPs oxide is 0.03%, the tensile, flexural and compressive strength of cementitious composites are increased by 78.6%, 60.7% and 38.9%, respectively [25]. Singh et al. found that the total shielding effectiveness of the NGPs oxide-ferrofluid-cementitious composites is 46 dB, which is much higher than that of the pristine cementitious composites (4 dB) [26]. Peyvandi et al. investigated the contributions of NGPs to the durability of cementitious composites, and observed that NGPs significantly improve the moisture transport performance and acid resistance of composites at a low concentration (0.05 vol% of cementitious composites) [27].

The high electrical conductivity and surface area of NGPs are expected to impart sensitive piezoresistive characteristics to cementitious composites. In this paper, experiments are carried out for verifying this assumption. The cementitious composites filled with NGPs exhibited significant change in resistance when subjected to compressive loadings. The electrical property test and quantitative evaluation of the piezoresistive effect-based sensing capability of cementitious composites filled with different

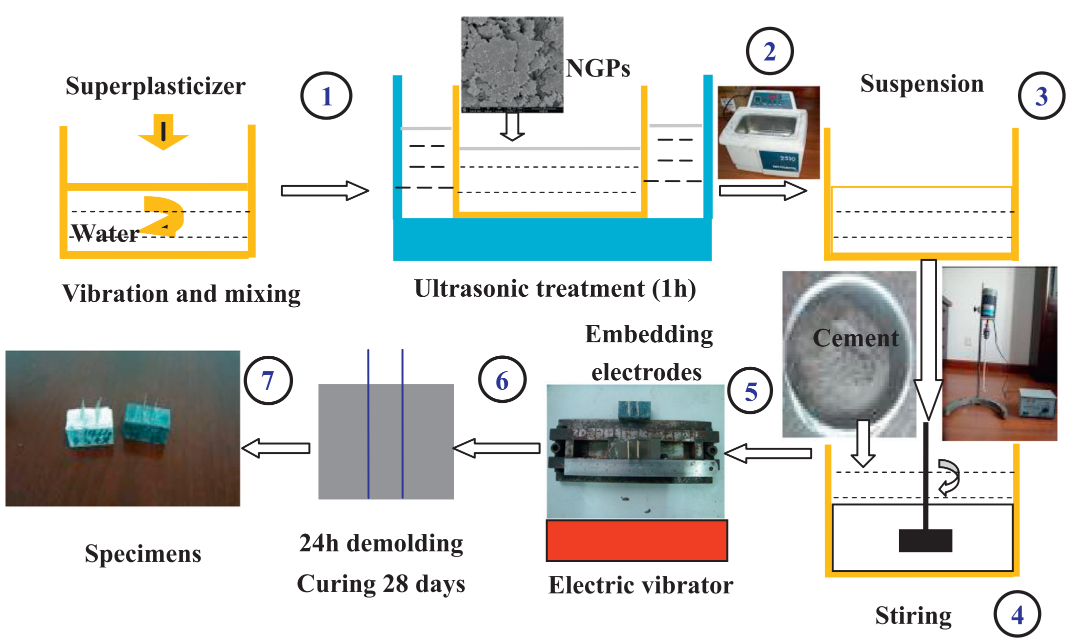

Fig. 2. Preparation process of NGPs filled cementitious composites.