Role of Multifunctional Sulfonated Graphene Oxide in Foam Concrete System: Reinforcement and Surfactant

Wei Wang, Chengyu Qiu, Shu Jian Chen and Wenhui Duan

Abstract Foam concrete is one of the most widely used human-made cellular material, but its use as structural element is mainly limited by its low compressive strength. Nanomaterials has attracted much attentions as one of the most efficient reinforcing materials to cement matrix in recent years. However, there are only limited researches about the reinforcing effect of nanomaterials in foam concrete. In this research, a two-dimensional nanosheet, sulfonated graphene oxide (SGO), has been used system as a multifunctional nano-additives to improve the mechanical performance of foam concrete. The results suggest at only a small dosage of SGO (0.1 wt%), the compressive strength of foam concrete was significantly increased about 200% around a dry density of 400 kg/m^3. In addition, the results also suggested the SGO is acted as a surfactant and able to improve the stability of the foam concrete at low dosage.

Keywords Nanomaterial · Sulfonated graphene oxide · Foam concrete · Surfactant

1 Introduction

Foam concrete is a human-made cellular material fabricated from either a cement paste or mortar by introducing air-voids. Foam concrete usually has the properties of high flowability, low self-weight, minimal consumption of aggregate, and superior thermal insulation [18]. The foam concrete has a wide application in the field of

W. Wang · C. Qiu · S. J. Chen · W. Duan (✉)
Department of Civil Engineering, Monash University, Clayton, VIC 3800, Australia
e-mail: wenhui.duan@monash.edu

W. Wang
e-mail: wei.w.wang@monash.edu

C. Qiu
e-mail: chengyu.qiu@monash.edu

S. J. Chen
e-mail: shujian.chen@monash.edu

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energy absorption, thermal insulation and fire resistance. However, the low strength of foam concrete greatly limits its application as a structural material.

Improve the flexural strength of the cement matrix is the key to improve the strength of foam concrete. Lightweight concrete like any other natural or engineering cellular materials generally behaves in a bending-dominated manner [4, 5]. When the foam concrete is loaded under compression, the solid part on the top and bottom of the air voids are subject to bending which leads to the formation of tensile cracks [4]. Due to the low strength of cement in tension, the compression strength of lightweight concrete is usually very low especially when the density is lower than 1000 kg/m^3.

Various researches has been conducted in literature to improve the flexural strength of cementitious material. One of the approach is to reinforce the cement matrix with fibers. Gao et al. [6] reported that the flexural strength can be improved by 62% with the addition of 8% steel fiber. Jones and McCarthy [11] also reported that with a small amount of polypropylene fiber, the flexural strength can be improved by around 50%. However, these macroscale fibers have very limited effects in preventing or delaying the formation of micro cracks [12]. Another approach is to use nanomaterial reinforced cement. Nanomaterials, such as carbon nanotubes (CNT) [1, 9], graphene oxide (GO) [2, 7, 15, 16] and boron nitride nanosheets (BNNSs) [20], usually has a specific surface are and superior mechanical properties. It has been reported that these nanomaterials show a much more effective way to reinforce cementitious material by bridging effect and nucleation effect [1, 20]. However, there are only few studies about the reinforcing effect of nanomaterials in foam concrete.

Here, we proposed to use a novel nano-additives, sulfonated graphene oxide (SGO), to reinforce foam concrete. SGO, a graphene derivative, is expected to have a similar reinforcing effect with other graphene based nanosheets. Recent research has also revealed that graphene oxide (GO) is an amphiphilic material with hydrophilic functional groups distributed on hydrophobic basal plane [10, 13, 14]. It has also been found that GO can act like a surfactant and lower the surface or the interfacial tension [3, 14] which is beneficial to form air bubbles in cement matrix.

In this manuscript, SGO is added into the cement matrix as a multifunctional additives to reduce the surface tension and improve the mechanical strength as a nano-reinforcement. The compressive strength of foam concrete is tested and compared with the literature. The effect of different dosage of SGO on the compressive strength of foam concrete is also investigated.

2 Experiment Program

2.1 Material and Equipment

Type GP ordinary Portland cement (OPC), conforming to the requirements of Australia Standard AS 3972, was used to mix the cement paste. 30% hydrogen peroxide was used as a foam agent. A naphthalene sulphonate based superplasticizer was used

Table 1 Mix design of SGO samples

Mix index	w/c	30% H_2O_2 (wt% cement)	Naphthalene sulphonate based superplasticizer (wt% cement)	SGO (wt% cement)	HMC (wt% cement)
C1	0.5	4	1.00	0.00	0.05625
S1a	0.5	4	0.90	0.10	0.05625
S1b	0.5	4	0.50	0.50	0.05625
C2	0.5	4	1.00	0.00	0.05
S2a	0.5	4	0.90	0.10	0.05
S2b	0.5	4	0.50	0.50	0.05

to reduce surface tension and adjust the workability of cement paste. Hydroxypropyl methyl cellulose (HMC) purchased from Sigma was used as a thickening agent and improve the foam stability. Sulfonated graphene oxide powder was used to reduce surface tension and improve mechanical strength of foam concrete.

A Hobart cement mixer was used to prepare the cement paste. A universal loading machine (Instron 4204, 50 kN) was used to conduct compressive strength of foam concrete.

2.2 *Mix Design*

Before preparing the SGO reinforced foam concrete samples, control samples with different dosage of naphthalene sulphonate based superplasticizer and thickening agent (HMC) are prepared to determine their optimal dosages. The optimal dosage for thickening agent was determined as 0.056 and 0.05 wt% and the optimal dosage of naphthalene sulphonate based superplasticizer was determined as 1 wt% for control samples without SGO. Since the SGO was also added as a surfactant and reduce the surface tension. Hence, the total dosage of SGO and naphthalene sulphonate based superplasticizer was maintained constant at 1 wt%. The detailed mix design was presented in Table 1.

2.3 *Foam Concrete Production and Compression Test*

Surfactants, thickening agent and 45 °C water (with or without SGO aqueous) were first added in the mixer. Cement is gradually added in the mixer operating at slow speed (140 ± 5 r/min) within 40 s, the mixing is then maintained at slow speed for additional 50 s. Next, the cement paste is poured in a container and foaming agent (30% H_2O_2) is added. The slurry is manually stirred for 20 s before cast in a cylindrical mould of 150 mm (diameter) * 100 mm (depth). Plastic film is wrapped above the mould to prevent evaporation of water. The samples are de-moulded after 24 h and stored in a curing room with constant temperature and humidity until testing age (28d) is reached.

After curing the cylindrical sample is thawed into 2 mm cubits for compressive test. The loading rate is set at 0.2 mm/min. Specimens are loaded until failure and peak compressions are recorded.

3 Results and Discussions

3.1 Stability of Foam Structure

Maintaining the stability of the foam concrete before setting to prevent the collapse of foamed structure is essential to the performance of foam concrete. Foam stabilizer [8, 19], hydroxypropyl methyl cellulose in this research, was used to improve the stability of the foam structure. Figure 1 shows the same amount of foam concrete with and without the addition of foam stabilizer. It can be seen that for the sample without foam stabilizer, the structure collapsed and air escaped after the foam structure formed. Compared with the normal foam concrete with similar density, the collapsed structure usually contains a large amount of large interconnected pores which significantly reduced the strength of the structure.

Fig. 1 Foam concrete with (left) and without (right) foam stabilizer during plastic state

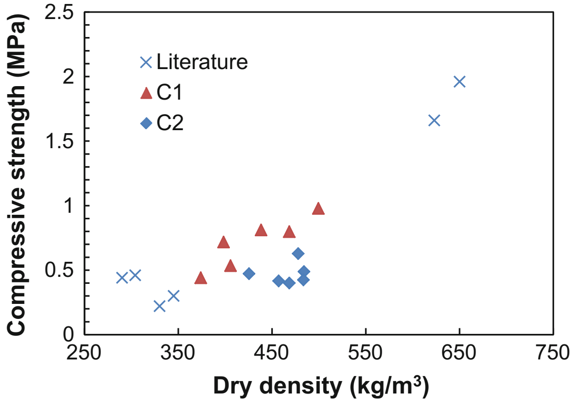


Fig. 2 Strength versus density of control samples compared with literature [17, 19, 21]

3.2 Strength of Control Samples

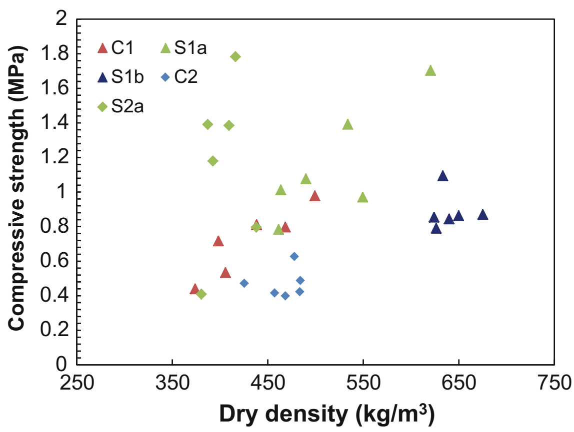
The strength of control samples are tested and validated with literature first. The strength of the two batches of control samples and the results from literature are presented in Fig. 2. It is observed that the compressive strength of the control samples are within moderate levels. Sample C2 has a higher density and lower compressive strength compared with sample C1 which can be explained by the reduced dosage of foam stabilizer and some part of the foam structure was collapsed.

3.3 Effect of SGO Incorporation

Figure 3 indicates the compressive strength of the SGO reinforced samples compared to corresponding referenced samples. The strength of sample S2b is not included since it collapsed during manufacturing.

The results suggest with a small dosage of SGO (0.1 wt% for S1a and S2a), the compressive strength of foam concrete significantly increased. For example, the strength of sample S2a has been improved for more than 200% compared to samples without SGO (C2). The compressive strength of sample S1a has also increased about 25% compared to control samples around density of 450 kg/m^3. Similar to graphene oxide, these 2D nanosheets are expected to accelerate the cement hydration due to nucleation effect and improve the flexural strength due to bridging effect. In addition, the SGO is found to be able to stabilizing the foam structure under a low dosage. For example, control sample C2 has a lower strength and higher density compare to sample C1 due to its instability of foam structure. However, with a small dosage of SGO, the stability of the foam structure is improved which leads to a lower density and a higher compressive strength (sample S2a).

Fig. 3 Compressive strength of SGO samples



However, for samples with a high dosage of SGO (0.5 wt% for S1b and S2b), partial collapse occurred which leads to the increased density and lower compressive strength. This can be explained by the agglomeration of SGO due to the high dosage and the actual surfactant amount is reduced in the system which disturbed the stability of the pore structure.

4 Conclusion

As a widely used engineering product, foam concrete has been subject to intense research on refining its properties. Tensile strength of cement matrix is believed to be the key factor influencing the compressive strength of foam concrete, and researches have indicated the contribution of nano reinforcement to concrete's tensile strength.

This research investigated the effect of a two-dimensional nano-sheet, SGO, on the mechanical properties and foam structure stability of the foam concrete. Results indicated that at low dosage (0.1 wt%), SGO have positive effect on compression strength and improve the stability of the foam structure. However, at higher dosage of (0.5 wt%) SGO, the foam structure is found to be unstable due to agglomeration.

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