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Technical note

# Economical graphene reinforced fly ash cement composite made with recycled aggregates for improved sulphate resistance and mechanical performance

Snigdha Sharma, Sumit Arora *

*National Institute of Technology, Hamirpur 177005, Himachal Pradesh, India*

## HIGHLIGHTS

- Novel use of graphene in cement mortars containing fine recycled aggregates (FRA).
- Optimum concentration of graphene found to be 0.05% by wt. of cementitious material.
- Improvement in compressive and flexural strength by 8% and 13% respectively in 0.05% graphene composite.
- High resistance to sulphate attack of 0.05% graphene composite.

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## ABSTRACT

The paper reports the incorporation of graphene into fly ash cement mortars at different doses (% by weight of cement) and evaluation of compressive and flexural strength and resistance to sulphate attack of composites at different hydration times. Fine recycled aggregates (FRA) from have been used as total replacement of fine natural aggregates (FNA) in mortars. Compressive strength and flexural strength results showed that 0.05% graphene produced maximum increase of 8% and 13% respectively with respect to FNA mortar. Excellent resistance to sulphate attack in 0.05% graphene composite could be achieved with minimum loss in compressive strength of 21%.



## 1. Introduction

Cementitious materials are characterized to have inherent brittle nature leading to degradation with environmental exposure. Generally, they possess high compressive but low flexural strength, and the combination of these properties has significant effects on their durability. Therefore, improving the strength, particularly flexural strength, of concrete has been a subject of much research in recent decades. Conventional methods to improve the strength have employed incorporation of reinforcements at millimeter scale and/or at micro-scale using macrofibers and microfibers, respectively [1]. Since the process of cracking originates and propagates at nano-level, researchers have used nano-sized reinforcements such as carbon nanotubes (CNTs), carbon nanofibers (CNFs) and nanoparticles [2–6], due to their high mechanical properties and high surface area. Graphene, a recent emerging nanomaterial, beats these nanomaterials in terms of its strength behavior with highest reported intrinsic strength of 130 GPa and Young's modulus of 1.0 TPa, measured by nanoindentation atomic force microscopy [7]. Fly ash (FA) cement, on the other hand is recognized as an important construction material. It possesses environmental benefits as it is a by-product from coal power plants, and engineering benefits since it produces less heat of hydration, increases workability, strength and improves durability to chemical attacks such as chlorides and sulphates [8–13].

Because of Graphene's exceptional strength, it has been the subject of increasing interest in the reinforcement of new composite materials emphasizing mainly metallic and polymeric matrices [14–18]. However, limited attention has been paid to graphene reinforced ceramic matrix. To the best of knowledge of authors, no study has explored graphene incorporated fly ash based cement

* Corresponding author.
*E-mail addresses:* snigdha.sharma343@gmail.com (S. Sharma), sumit@nith.ac.in (S. Arora).

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mortar composites with regard to their flexural strength and resistance to sulphate attack.

## 2. Experimental

### 2.1. Materials

Graphite (particle size 100 μm), 1,2-dichlorobenzene, sodium sulphate ($Na_2SO_4$) were used in the present study and all the materials were of analytical grade, procured from Merck Specialty Pvt. Ltd. Ordinary Portland cement (Grade 43) with specific gravity 3.15 and Blaine's specific area 230 $m^2/kg$ and polycarboxylate ether based superplasticizer (Glenium) were procured from local dealers. Fine recycled aggregates (FRA) were made in the structural laboratory of the Author's Institute.

### 2.2. Methodology

Graphene was synthesized from graphite using previously reported method [19]. The synthesized graphene was characterized using FT-IR, XRD, FE-SEM and TEM. Cement mortar nanocomposites were fabricated as per mix proportions given in Table 1. Four mortar mixes (M1, M2, M3 and M4) were prepared at constant water-to-binder ratio of 0.4, simultaneously ensuring required consistency. The mortar pastes were filled in cubic molds

**Table 1**
Mix proportions of test specimens.

| Mix Type | Cementitious material | | Graphene (%) | FNA (%) | FRA (%) | W/C ratio | SP dosage (%) |
|---|---|---|---|---|---|---|---|
| | Cement (%) | Fly ash (%) | | | | | |
| M1 | 70.0 | 30.0 | 0.0 | 100.0 | 0.0 | 0.40 | Nil |
| M2 | 70.0 | 30.0 | 0.0 | 0.0 | 100.0 | 0.40 | Nil |
| M3 | 70.0 | 30.0 | 0.05* | 0.0 | 100.0 | 0.40 | 0.2 |
| M4 | 70.0 | 30.0 | 0.10* | 0.0 | 100.0 | 0.40 | 0.3 |

* Ultrasonication time was 15 min and 20 min respectively for 0.05% graphene and 0.10% graphene solutions.

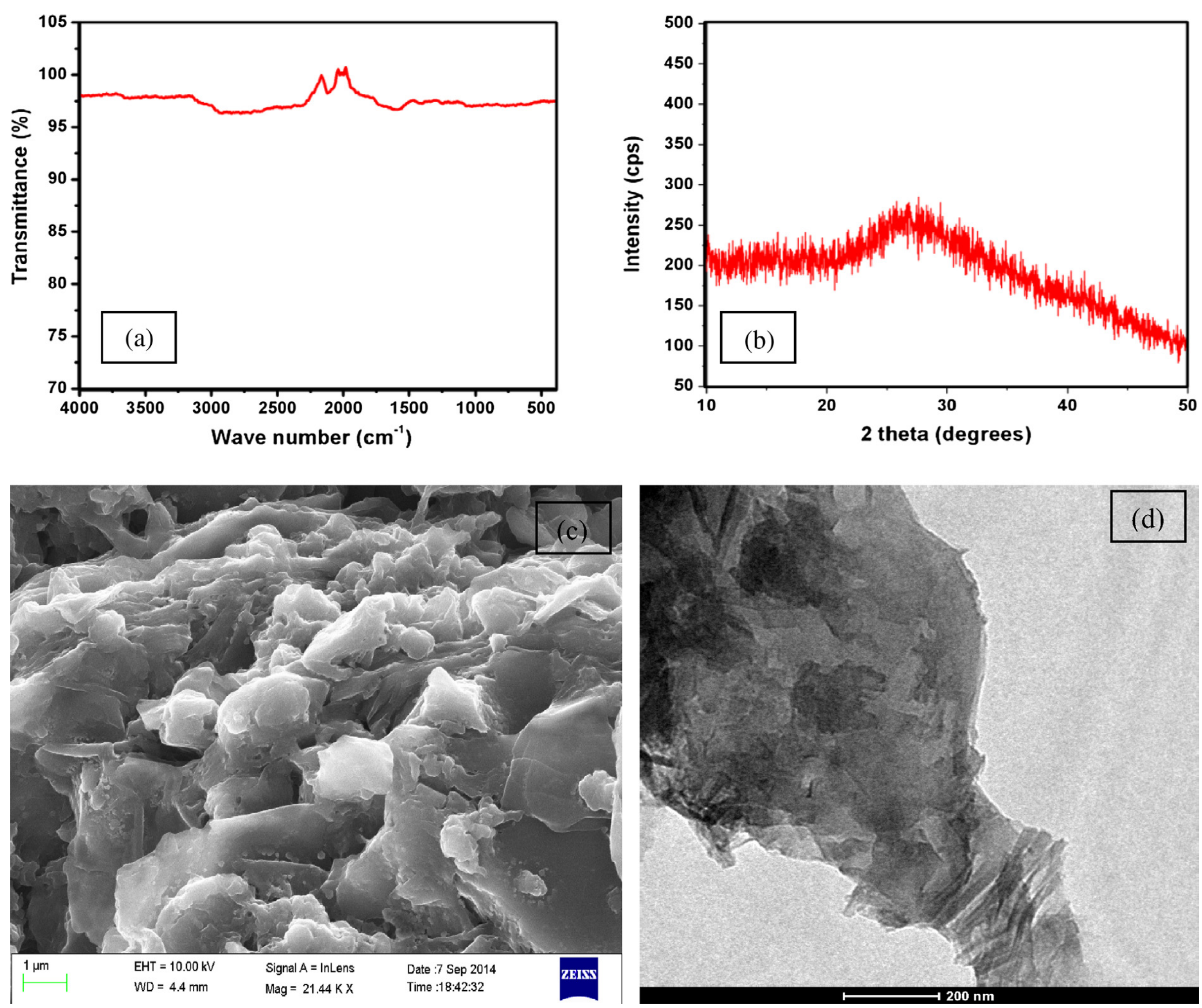


**Fig. 1.** (a) FTIR, (b) XRD, (c) SEM and (d) TEM of graphene nanosheets.