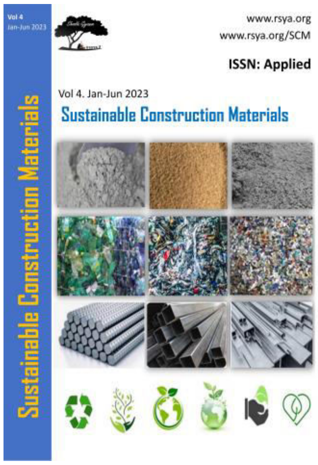


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Sustainable Construction Materials

Vol 3, Issue 1, Jan-Jul 2023
www.rsya.org/scm


# Mortar made of cement and graphene oxide


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**Abstract.** A comparative experimental investigation into the performance of mortar composed of Portland Pozzolana Cement (PPC) and Ordinary Portland Cement (OPC) was carried out with the addition of graphene oxide in each instance. Prior to its incorporation into the mortar, the graphene oxide (GO) powder was ultrasonically mixed with a portion of the necessary mixing water in varying quantities (ranging from 0.03 percent to 0.06 percent based on the weight of the cement). For OPC and PPC based mortar, respectively, the optimal proportion of GO addition was achieved to be 0.05 percent at different ages, and 0.04 percent overall. This was determined based on the strength requirements. It's possible that the refining of the pore structure in the mortar matrix is what's responsible for the increase in strength of GO-based cement mortar.


**Keywords:** *Graphene oxide, compressive strength, flexural strength, cement-sand mortar.*


## 1. INTRODUCTION

Cement is a substance that is utilised extensively in the construction and building industries. It is the primary binder in concrete because, when combined with water, it undergoes a process called hydration that causes it to bind the particles together. However, the most significant drawbacks of using cement-based construction materials are that they are fragile and have a poor tensile strength. In recent years, researchers have been concentrating their efforts on utilising a wide variety of additives and fibres in cementitious materials in order to improve the performances of these materials. Because of their excellent mechanical qualities and large specific surface area, nanomaterials such as 0D nanoparticles, 1D nano-fibers, and 2D nanosheets have attracted a lot of attention as nanotechnology has advanced. It has been demonstrated that cementitious materials' compressive strength, flexural strength, and tensile strength can all be significantly affected by the presence of silica micro particles (0D) [1-4]. It has been found that the addition of silica nanoparticles to cementitious materials can have an effect on the durability of the material, the drying shrinkage, and the water permeability of the material [2, 5, 6]. After 28 days of curing age, the compressive strength rose by 26 percent due to the addition of 10 percent nanosilica with dispersing agents [7]. Even the insertion of a little amount of nano $SiO_2$ particles into cement composite led to a 10% and 25% improvement in the material's compressive and flexural strengths after a curing age of 28 days [5]. It was generally agreed upon that the nano-SiO2 particles stuffed the pores of the cement composite [8, 9]. The hydration process can be sped up by the addition of a tiny amount of nano SiO2 into cement composite, which also results in improvements to the material's strength and microstructure features [10-15]. Carbon nanotubes, often known as CNTs, are a type of 1D nanomaterial that is based on carbon. It is made up of sheets of carbon atoms that are only one layered and folded up. CNTs can be broken down into two distinct types: single layered and multi layered, with sizes ranging from 1-3 nm and 5-50 nm, respectively [16]. Single layered CNTs have a diameter of 1-3 nm. On the other hand, it was discovered that including even trace amounts of CNTs into cementitious materials was enough to significantly improve their mechanical properties [17–19]. After 28 days, the introduction of a tiny number of CNTs in cement mortar enhanced both the compressive strength and the flexural strength by up to 23 percent and 17 percent, respectively, according to the findings of Parveen et al. [20]. The primary mechanisms responsible for the incorporation of CNTs into the cement matrix include the effects of nucleation, the bridging of micro-size capillary pores, and the filling of nano-size pore areas [18]. According to a study conducted by G.Y. Li and colleagues [21], the incorporation of CNTs resulted in an increase in the material's compressive strength, flexural strength, and failure strain. The use of CNTs not only produces high strength but also improves the efficiency with which loads are passed from the cement to the reinforcement. This is due to the interfacial interaction that occurs between the CNTs and the hydration of the cement. In recent times, graphene oxide (GO), a nanomaterial based on carbon, has attracted attention for possible incorporation into the cement matrix. It is a single-layered, two-dimensional (2D), nanomaterial that is composed of several oxygen-containing functional groups [22, 23]. These groups include hydroxyl, carbonyl, epoxy, and carboxylic. Because of the existence of a variety of oxygen-containing groups in the aqueous solution, GO can be disseminated in a way that is both practical and easy. These oxygen-containing functional groups in GO's chemical structure are responsible for the enhancement of the different host materials' chemical and physical properties, as referenced in [2 4]. GO possesses remarkable mechanical qualities such as ultra-high strength and elasticity [25-28], in addition to having a large specific surface area. Because GO has such a high specific surface area, it can encourage both chemical and physical interaction with the host materials [29]. It has been established that GO, when combined with ceramic and polymer materials, can readily create composites and, by monitoring the microstructure of crystal, can enhance the material's toughness [29, 30]. It is possible to highlight that GO can be produced in huge numbers through the vigorous oxidation of low-cost graphite powder [31]. This can take place. GO, on the other hand, has found widespread application in a variety of fields, including those dealing with materials for the storage of energy [31], semiconductors [32], biological composites [33], and photo catalytic materials [34].

Previous research has led researchers to the conclusion that incorporating a little amount of graphene oxide (GO) into cement paste can boost the material's compressive strength, tensile strength, and flexural strength. Not only did the introduction of GO into cementitious materials cause an increase in the mechanical properties of cement composite, but it also promoted an improvement in the microstructure of cement composite [35-37]. It was reported that the incorporation of a very small amount (0.03 percent) of GO into cement paste increased the compressive strength and tensile strength by approximately 40 percent. This incorporation did not only increase the compressive and tensile strength but also reduced the pore structure of the cement paste [38]. According to research conducted by S. Lv et al. [39], the addition of 0.03 percent GO to a cement composite was found to boost the material's compressive strength by 38.9 percent, flexural strength by 60.7 percent, and tensile strength by 78.6 percent accordingly. It was demonstrated that the integration of GO into cement composite plays a key role in the creation of the microstructure of hydration crystal, resulting in a significant reduction in brittleness and an increase in toughness. The addition of a relatively tiny amount, 0.04 percent of GO by weight of cement, into cement paste resulted in an improvement in the material's compressive strength of around 34 percent and flexural strength of approximately 42 percent respectively [40]. After 28 days, an increase in flexural strength and compressive strength of 41-58 percent and 15-33 percent respectively can be achieved with the integration of a little amount of GO into cement paste at a concentration of 0.05 percent [42]. According to the findings of an examination into the microscopic structure of GO-based cementitious material, the integration of GO into cement composites results in the production of finer pores [40, 41]. It was discovered that adding as little as 0.05 percent of GO to the weight of cement will lower the workability of cement paste by approximately 42 percent [42]. It is common knowledge that increasing the amount of free water and decreasing the amount of lead in the cement composite was necessary in order to successfully wet the large specific surface area of GO agglomerates. According to several reports, the incorporation of GO into cement not only affects the workability of cement composite but also causes an increase in the viscosity of cement composite [43-45]. This is a clear indicator that GO has a significant potential to be used as a reinforcement material in cement composites. According to the author's understanding, the majority of the earlier researchers looked into the impact graphene oxide had on ordinary portland cement. Comparing the effects of adding GO to mortar made with ordinary Portland cement and mortar made with Portland pozzolana cement at varying dosages such as 0.03 percent, 0.04 percent, 0.05 percent, and 0.06 percent by weight of cement is the purpose of the current study, which aims to determine which type of mortar produces better results.

**Table. 1.** List of nomenclature used

| **Acronyms** | **Full Name** |
|---|---|
| GO | Graphene Oxide |
| PPC | Portland Pozzolana Cement |
| nano $SiO_2$ | Nano Silica |
| OPC | Ordinary Portland Cement |
| CNTs | Carbon Nano tubes |

## 2. MATERIALS AND EXPERIMENTAL METHODS

### 2.1 Materials

This experimental investigation made use of Ordinary Portland Cement (OPC) grade 53 and Portland Pozzolana Cement (PPC), both of which confirmed to IS: 269-2015 [46] and IS: 1489 (part-I) 2015 [47] respectively. Both types of cement are known as Portland Cements. Both OPC and PPC are provided in Tables 2 and 3, respectively, with their distinct chemical compositions. We selected river sand that was readily available in the area and had a specific gravity of 2.66. This sand was classified as Grade-II according to IS:383-2016. Table 4 contains a presentation of the characteristics of the GO that was obtained from M/s Ad-Nano Technologies Pvt. Ltd. in Karnataka, India. The majority of the GO is depicted in figure 2 as having a dark colour.

**Table 2**. Chemical composition (% by weight) of Ordinary Portland cement (OPC) grade 53

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ | LOI |
|---|---|---|---|---|---|---|---|---|---|
| % | 21.94 | 4.95 | 3.74 | 62.33 | 2.08 | 2.22 | 0.56 | 0.32 | 1.89 |
| | | | | | $SO_3$ | | | | |
| | | | | | 2.45 | | | | |

**FIGURE 1.** Graphene oxide

**Table 4.** Technical properties of Graphene Oxide.

| | |
|---|---|
| Purity | > 99 % |
| Numbers of layers | 1-3 layers |
| Average thickness (z) | 0.8-1.6 nm |
| Average lateral dimension (x & y) | 5-10 μm |
| Surface area | 450 $m^2$ /g |
| Carbon | 66% |
| Oxygen | 32% |
| Others | 2% |

## 2.2 Mix proportion and curing

The cement-sand weight ratio was set at 1:2 for all the mixtures with and without GO, and the water:cement ratio was left at 0.45. In various mixes for both OPC and PPC, GO was added to cement sand mortar at a rate of 0.03 percent, 0.04 percent, 0.05 percent, and 0.06 percent by weight of cement. Go was used to create GO solution, which was then sonicated for 45 to 60 minutes using an ultrasonic probe sonicator. The details of various mixes made using OPC and PPC are displayed in Tables 4 and 5, respectively. To create a homogenous mixture, the cement and locally accessible sands were first vigorously mixed for 3–4 minutes in a dry environment. The proper amount of GO and water were then sonicated and added to the dry mix. The mortar was then thoroughly crushed before being put into the various standard moulds. After 24 hours, the cement mortar had solidified enough to be removed from the mould and cured in water until testing.The cement-sand weight ratio was set at 1:2 for all the mixtures with and without GO, and the water:cement ratio was left at 0.45. In various mixes for both OPC and PPC, GO was added to cement sand mortar at a rate of 0.03 percent, 0.04 percent, 0.05 percent, and 0.06 percent by weight of cement. Go was used to create GO solution, which was then sonicated for 45 to 60 minutes using an ultrasonic probe sonicator. The details of various mixes made using OPC and PPC are displayed in Tables 4 and 5, respectively. To create a homogenous mixture, the cement and locally accessible sands were first vigorously mixed for 3–4 minutes in a dry environment. The proper amount of GO and water were then sonicated and added to the dry mix. The mortar was then thoroughly crushed before being put into the various standard moulds. 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After 24 hours, the cement mortar had solidified enough to be removed from the mould and cured in water until testing.

## 3. PREPARATION OF CEMENT MORTAR SAMPLE AND TESTING

### 3.1 Sample preparation for compressive strength test

The cement-sand weight ratio was set at 1:2 for all the mixtures with and without GO, and the water:cement ratio was left at 0.45. In various mixes for both OPC and PPC, GO was added to cement sand mortar at a rate of 0.03 percent, 0.04 percent, 0.05 percent, and 0.06 percent by weight of cement. Go was used to create GO solution, which was then sonicated for 45 to 60 minutes using an ultrasonic probe sonicator. The details of various mixes made using OPC and PPC are displayed in Tables 4 and 5, respectively. To create a homogenous mixture, the cement and locally accessible sands were first vigorously mixed for 3–4 minutes in a dry environment. The proper amount of GO and water were then sonicated and added to the dry mix. The mortar was then thoroughly crushed before being put into the various standard moulds. After 24 hours, the cement mortar had solidified enough to be removed from the mould and cured in water until testing.

### 3.2 Sample preparation for flexural strength test

On cement mortar bars of 50 mm by 50 mm by 200 mm, a flexural strength test was likewise performed at the same GO doses and curing ages of 28 days. For the purpose of determining the flexural strength (AASHTO T 67) [48] of a span 150 mm, the centre point loading method was used. Each set of test findings involved six samples. The mortar bar was held at both ends of the centre point method at a distance of 25 mm from the margins. applied load near the middle of the clear span. Load is progressively raised until mortar bar failure. The rapture modulus listed as flexural strength. An example of a centre point loading mechanism is shown in Fig. 3.

## 4. RESULTS AND DISCUSSION

### 4.1 Compressive strength

The compressive strength of harden cement-sand mortar sample with and without GO using OPC and PPC respectively at the age of 3 days, 7 days and 28 days. After 3 days curing age, it was observed that compressive strength of OPC based cement sand mortar GOPC-3, GOPC-4 and GOPC-5 increase around 12%, 25% and 49% respectively compared to control sample. At 7 days curing age increased the compressive strength around 11%, 17% and 25% for GOPC-3, GOPC-4 and GOPC-5 respectively. After 28days curing age maximum increment of compressive strength observed for GOPC-5 around 20%. The compressive strength of GOPC-3 and GOPC-4 after 28 days noted 9% and 13% compared to control sample respectively. For GOPC-6, compressive strength observed at 3 days same as control sample and 7 days it slightly decreased. After 28 days compressive decreased around 7.8% compare to control sample for GOPC-6. It was noted that the compressive strength of OPC based mortar was increased with the addition of GO up to 0.05% by weight of cement at all ages. Further addition (at 0.06% of GO) the strength was decreased at all curing ages.

However, compared to the control sample, the compressive strength enhancement for GOPPC-3, GOPPC-4, and GOPPC-5 PPC-based cement sand mortars was 9 percent, 26 percent, and 13 percent, respectively, at 3 days. The compressive strength of GOPPC-3, GOPPC-4, and GOPPC-5 rose by approximately 7%, 15%, and 10% at 7 days of curing age, respectively. After 28 days of curing, GOPPC-4's compressive strength increased by a maximum of 12 percent. After 28 days, GOPC-3 and GOPC-5's compressive strengths were 6 and 9 percent lower than those of the control sample, respectively. On the other hand, GOPPC-6's compressive strength has a similar impact to GOPC-6. Approximately 9% less after 28 days as compared to the control group. It was discovered that PPC-based cement and sand mortar compressive strength enhancement peaked at a dosage of 0.04 percent by weight of cement.

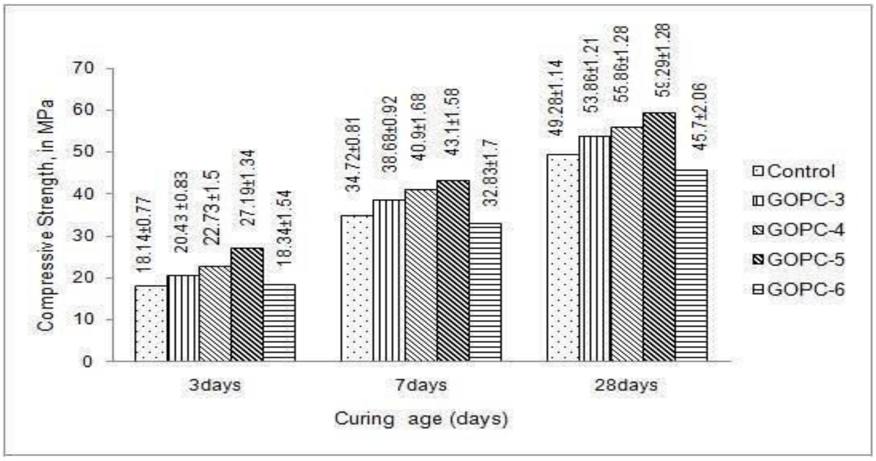


**FIGURE 3.** Compressive strength of different mixes of OPC based mortar at different ages.

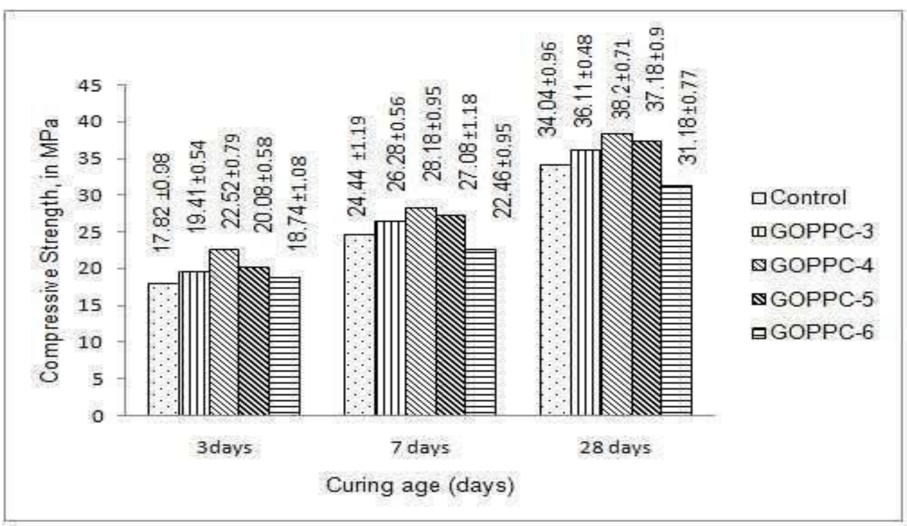


**FIGURE 4.** Compressive strength of different mixes of PPC based mortar at different ages.

### 4.2 Flexural strength

The differences in flexural strength of cement-sand mortar with and without GO employing OPC and PPC, respectively. Tensile strength for GOPC-3, GOPC-4, and GOPC-5 as compared to control sample increased by 11%, 21%, and 26% for OPC-based cement sand mortar, respectively. When 0.05 percent of GO was added to an OPC-based mortar, it was discovered that the maximum tensile strength was 6.09 MPa as opposed to 4.83 MPa for a control sample. The tensile strength was enhanced for GOPC-6 by adding additional GO in comparison to the control sample, but decreased for GOPC-5. On the other hand, for GOPPC-3, GOPPC-4, and GOPPC-5 compared to the control sample, the tensile strength of PPC-based cement sand mortar rose after 28 days by 17 percent, 32 percent, and 21%, respectively. MPa The tensile strength was raised for GOPPC-6 by adding additional GO in comparison to the control sample, but decreased for GOPPC-4. The greatest tensile strength for PPC-based mortar was 5.6 MPa at 0.04 percent addition of GO as opposed to 4.23 MPa for a control sample. Both OPC and PPC based mortars showed similar tensile strength behaviour and compressive strength findings.

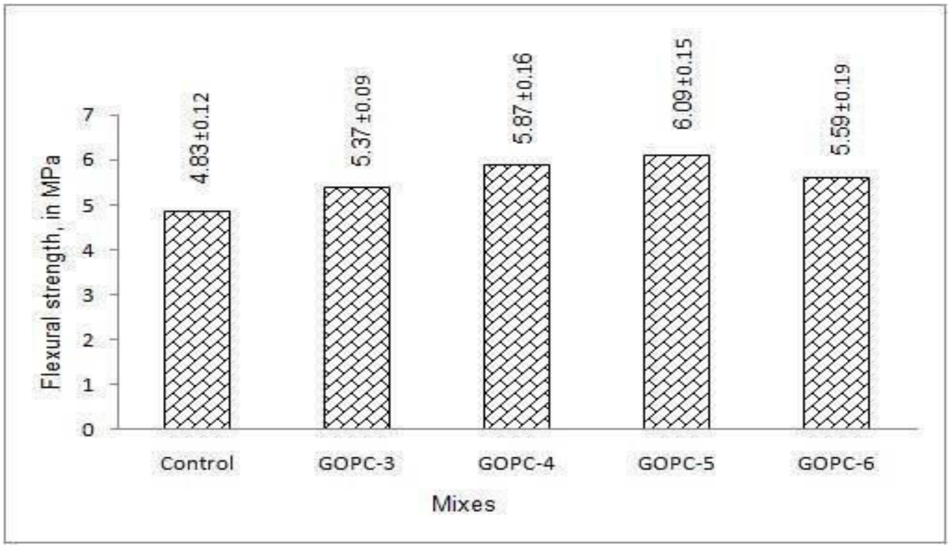


**FIGURE 5.** Flexural strength of different mixes of OPC based mortar at 28 days.

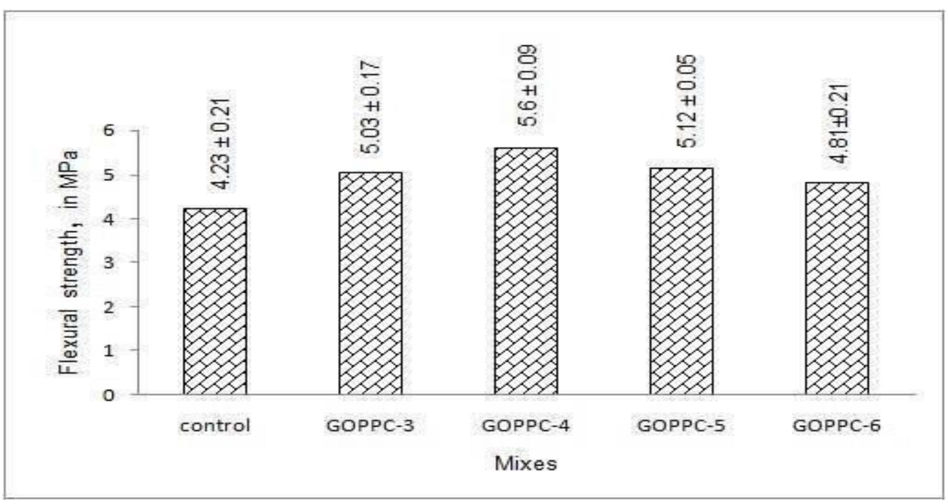


**FIGURE 6.** Flexural strength of different mixes of PPC based mortar at 28 days

## CONCLUSION

In comparison to the control sample, the tensile strength of GOPC-3, GOPC-4, and GOPC-5's OPC-based cement sand mortar rose by 11 percent, 21 percent, and 26 percent, respectively. The maximum tensile strength was found to be 6.09 MPa when 0.05 percent of GO was added to an OPC-based mortar, as opposed to 4.83 MPa for a reference sample. In contrast to the control sample, adding more GO to GOPC-6 increased the tensile strength, while doing the opposite for GOPC-5. However, after 28 days, the tensile strength of PPC-based cement sand mortar increased for GOPPC-3, GOPPC-4, and GOPPC-5 in comparison to the control sample by 17%, 32%, and 21%, respectively. MPa In compared to the control sample, adding more GO increased the tensile strength of GOPPC-6, whereas it decreased it for GOPPC-4. When 0.04 percent of GO was added, the PPC-based mortar's maximum tensile strength was 5.6 MPa, compared to 4.23 MPa for a control sample. Both OPC and PPC-based mortars displayed comparable compressive strength and tensile strength behavior.

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