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# Effect of Graphene as Additive on the Mechanical Properties of Concrete

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## Abstract

Graphene is a smart and relatively new material that has promising applications in many engineering fields. Recently it was found that graphene can be produced from burning waste materials which will have an impact on cost and the wide applications in many engineering fields including construction. The addition of tiny amounts of graphene in concrete mixes can enhance the mechanical and durability properties. This research investigated the effect of graphene as additive on the mechanical properties of concrete. The addition percentage (by weight of cement) was 0.02%, 0.035%, and 0.05%. Cubic and cylindrical specimens were prepared to assess the compressive strength, flexural strength, and elasticity modulus of concrete. Results showed that adding graphene to concrete led to an increase in both compressive and flexural strength as well as the modulus of elasticity. This will help in reducing concrete dimensions in different structural members like columns and beams and will contribute towards sustainable development.

## Keywords

Graphene, Concrete, Mechanical properties, Additive, Compressive strength, Sustainability

## Introduction

Because of its unique property of being one of the thinnest but strongest materials, graphene has developed as one of the most highly promising nanomaterials. Several attempts are being undertaken by researchers throughout the world to investigate the possibilities of employing graphene in various forms in concrete to improve its properties. A comprehensive study investigated the effect of graphene dispersed in different dosages 0.5, 0.6, 0.7, 0.8, 0.9, and 1 g/L [1]. The authors found that graphene inclusion at 1 g/L in concrete increased the flexural, tensile, and compressive strength by up to 95%, 55%, and 27% respectively. Meanwhile, an increase in water absorption was observed as well as in shrinkage.

Reddy and Prasad [2] examined the workability, mechanical, durability, and microstructure features of cement concrete with graphene oxide (GO) additions of 0.025%, 0.05%, 0.075%, and 0.10%. The test results demonstrated that adding a little amount of GO to cement concrete significantly increased the strength qualities yet diminishing the workability. At 28 days, the addition of 0.1% GO improved compressive, split tensile, and flexural strengths by 38.46%, 14.87%, and 12.07%, accordingly, as compared to control concrete. However, when the water absorption of mixes containing GO increased, this shows that GO considerably reduced the volume of pore space.

Zaid et al. [3] carried out a study in which GO was used to replace cement at various percentages (0%, 0.03%, 0.06%, 0.09%, and 0.12% by cement weight). Steel fibers constituted 2% of the binder weight in this study. The findings revealed that combining 0.12% GO with 2% steel fibers increased compressive and split tensile strength by 56% and 37%, correspondingly. As a result, concrete containing GO and steel fibers may be utilized successfully in building applications as a sustainable and cost-effective construction material.

Mohammed et al. [4] investigated the behavior of GO at high temperatures in ordinary and high strength concrete. The experimental results showed that mechanical strength improved significantly after 800 °C exposure in both normal and high strength specimens with GO. Furthermore, improved resistance to crack formation was reported in GO mixtures, which resulted in the retaining of most of the initial strengths.

A study was conducted about incorporating GO nanosheets in concrete [5]. This study outlines an experimental study of the slump and physical properties of concrete reinforced with GO nanosheets at additions ranging from 0.00% to 0.08% by weight of cement. The results revealed that increasing the level of GO nanosheets from 0.02% to 0.08% increased the compressive strength of the concrete. Meanwhile, the slump of concrete containing GO nanosheets falls from 0.02% to 0.80% with the addition of GO nanosheets. The flexural strength values improved with the addition of GO nanosheets, ranging from 2.77% to 15.60% at 28 days when the GO nanosheet concentration increased from 0.02% to 0.08%. The results also show that 0.03% is the best GO nanosheet dose for increasing the split tensile strength of concrete.

Bellum et al. [6] explored the effects of GO addition on the compressive strength and modulus of elasticity of geopolymer concrete. When 3% GO was added to a 30% ground granulated blast-furnace slag replacement, the compressive strength and modulus of elasticity increased by 38.51% and 28%, respectively, while the chloride ion permeability increased by 65.44%, when compared to the control mix.

Yu and Wu [7] conducted a thorough investigation on the usage of GO to improve the characteristics of ultra-high-performance concrete (UHPC) with fine recycled aggregate. The researchers noted that the addition of GO enhanced the compressive strength, tensile strength, flexural strength, and elastic modulus of UHPC by 2.04% - 16.04%, 7.36% - 30.50%, 5.83% - 23.40%, and 3.62% - 12.95%, respectively. Furthermore, the addition of GO increased the chloride penetration resistance and the freezing and thawing resistance of UHPC.

Chu et al. [8] studied the use of GO as an addition for improving the characteristics of UHPC made from recycled sand in this work. The inclusion of GO increased the compressive strength, flexural strength, splitting tensile strength, and elastic modulus of recycled sand UHPC by 8.24 - 16.83%, 11.26 - 26.62%, 15.63 - 29.54%, and 5.84 - 12.25%, correspondingly.

Shanmuga et al. [9] also conducted research on the reinforcing effects of GO on high-strength concrete prepared with and without rice husk ash. GO was applied in varying ratios of 0.025, 0.050, 0.075, and 0.1% by weight of cement. The results showed that the mechanical and durability characteristics of high-strength concrete improved significantly with the addition of GO. As a result, raising the proportion of GO over 0.075% resulted in a decrease in strength and durability characteristics.

Chen et al. [10] focused on the mechanical properties and shrinkage behavior of concrete containing GO nanosheets. The author prepared concrete mixtures containing 0.02 wt.%, 0.05 wt.%, and 0.08 wt.% GO. The results show that GO may enhance the compressive strength, flexural strength, and elasticity modulus of concrete by 4.04 - 12.65%, 3.8 - 7.38%, and 3.92 - 10.97%, respectively, at a concrete age of 28 days. Furthermore, it was shown that GO enhances the shrinkage strain of concrete.

Based on the previous studies done on graphene, it can be noted that few research was conducted on the effect of graphene on concrete mechanical properties, and the topic is still considered new. Therefore, this article aimed to evaluate the mechanical properties of concrete containing graphene as additive. Moreover, new equations relating different mechanical properties were derived and compared to the ones provided by the ACI code for normal concrete. The expected outputs of this work include density, elasticity modulus, compressive strength, and flexure strength. Some recommendations for future research and practicing engineers were introduced at the end of the article.

## Materials and Method

The cement utilized is CEM1 complied with ASTM C192. The fine aggregate used was 5 mm sand with a density of 2650 kg/m$^3$, while the coarse aggregate utilized was 10 mm crushed limestone with a density of 2550 kg/m$^3$. GO shown in figure 1 (Multi-walled carbon nanotube) was purchased from an online provider. It has a diameter of 5 - 8 nm and a purity of 97%. Table 1 shows the properties of the GO employed.

Based on a series of trial mixes, a concrete mix having a proportion of 1 (cement): 1.65 (fine aggregate): 3.45 (coarse aggregate) by weight was selected as the control mix (GO-0) with no GO. The water to cement ratio was 0.5. In the other mixes (GO-0.02, GO-0.035, and GO-0.05), 0.02%, 0.035%, and 0.05% of GO were added respectively. Details of all concrete mixes are presented in table 2.



**Figure 1:** GO.

**Table 1:** Properties of GO.

| Properties | Value |
|---|---|
| Name | Multi-walled carbon nanotubes |
| Purity | 97% |
| Quantity | 20 g |
| Diameter | 5 - 8 nm |
| Length | 3 - 12 μm |
| Specific surface area | > 233 $m^2/g$ |
| Bulk density | 0.15 $g/cm^3$ |
| Resistivity | 1412 μΩm |
| Water content | < 1.5% |

**Table 2:** Details of concrete mixes.

| Weight ($kg/m^3$) | | | | | |
|---|---|---|---|---|---|
| **Mix** | **Cement** | **Sand** | **Water** | **Gravel** | **GO** |
| GO-0 | 450 | 743 | 225 | 1543 | 0 |
| GO-0.02 | 450 | 743 | 225 | 1543 | 0.02% |
| GO-0.035 | 450 | 743 | 225 | 1543 | 0.035% |
| GO-0.05 | 450 | 743 | 225 | 1543 | 0.05% |

The concrete mix design adopted throughout this study was in accordance with procedure specified by ASTM C192 [11]. The dry components (Figure 2) were blended for 2 minutes at a moderate speed as shown in figure 3 before the wet components were poured and well mixed. The Slump test was conducted for all mixes. The degree of workability was close for all mixes (15 ± 3 mm). The fresh mixture was poured in 100 mm cubic molds and cylindrical molds with 150 mm diameter and 300 mm height for compressive strength and elasticity modulus tests, and beam molds with dimensions 100 x 100 x 400 mm for flexural strength test at 7- and 28-days (Figure 4). After that, all specimens were crushed to eliminate the trapped air. The specimens were then air-cured in their molds for 24 hours, then de-molded and moist cured at room temperature for 28 days. The cured specimens were then placed in an environmental room at 20 °C.



**Figure 2:** Concrete components.



**Figure 3:** Concrete mixing.

The concrete density of specimens was measured as per ASTM C188 [12] requirements. As for elasticity modulus, specimens were tested according to ASTM C469 [13] requirements. The compressive strength test was conducted as per ASTM C109 [14] requirement for cubic specimens and as per ASTM C39 [15] requirements for cylindrical specimens. Regarding flexure strength, ASTM C78 [16] requirements were applied for the beam specimens.



**Figure 4:** Casting concrete.

## Results and Discussion

### Density and elasticity modulus

Figure 5 displays the density results of the different mixes. The density was 2300, 2303, 2310, and 2340 $Kg/m^3$ for GO-0, GO-0.02, GO-0.035, and GO-0.05, respectively. The results showed no significant effect of graphene addition on concrete density. Figure 6 shows the average elasticity modulus for the control mix GO-0 and the mixes with GO (GO-0.02, GO-0.035, and GO-0.05). The modulus of elasticity ranged between 20308 MPa and 23354 MPa. Figure 6 depicts the elasticity modulus improvement of 2.42%, 5%, and 15% respectively for GO-0.02, GO-0.035, and GO-0.05 compared

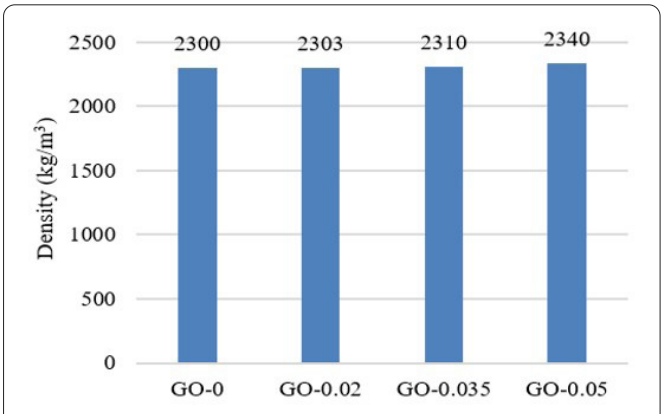



**Figure 5:** Density for concrete mixes.

to the control mix. As reported by Chen et al. [10], composites made of graphene-based cement show that adding graphene increases their elastic modulus at low concentration of GO. According to Ismail et al. [17], graphene at 0.02%, 0.05%, and 0.10% demonstrated a modulus of elasticity improvement of 21.70%, 1.87%, and 3.48%, respectively, over the reference sample.

According to ACI code, there is a relation between the elasticity modulus and both concrete density and compressive strength. The relation is as follows:

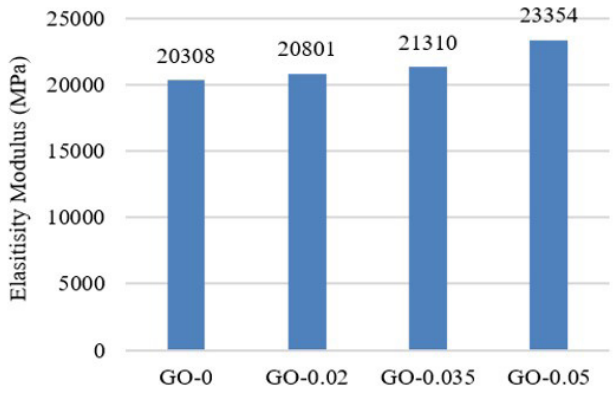



**Figure 6:** Elasticity modulus for concrete mixes.

$$E = 0.043w^{1.5}\sqrt{f'_c} \quad (1)$$

Where, "*E*" is the elasticity modulus in MPa, "*w*" is the density in MPa, and $f'_c$ is the concrete compressive strength in MPa. Based on the experimental findings, a trend line is plotted as shown in figure 7. According to this figure, concrete with GO can have the following trend line equation:

$$E = 0.049w^{1.5}\sqrt{f'_c} \quad (2)$$

A slight change in the constant is realized in the presence of GO in concrete. The "$R^2$" of this equation was around 0.99.

## Compressive strength

The compressive strength of the concrete samples was assessed after curing for 7 and 28 days. The sample with GO has improved compressive strength compared to the control mix GO-0. Figure 8 displays the compressive strength of concrete mixes at 7 and 28 days. The 28 days compressive strength was enhanced by 6.32%, 13%, and 19.25% when adding 0.02%, 0.035%, and 0.05% GO at early age and later ages. The concrete sample GO-0.05 had the maximum enhancement in strength. A similar trend was observed by Ismail et al. [17], showing an increase in compressive strength of 20.82, 8.41, and 9.48% compared to the reference specimen by adding 0.02, 0.05, and 0.10% GO nanoplates. The concrete sample GO-0.05 had the maximum enhancement in strength. Conversely, Ismail et al. [17] showed that adding 0.02% graphene represents the higher strength at different ages. With an increase in GO content in the concrete mixtures, a progressive rise in strength may be seen.

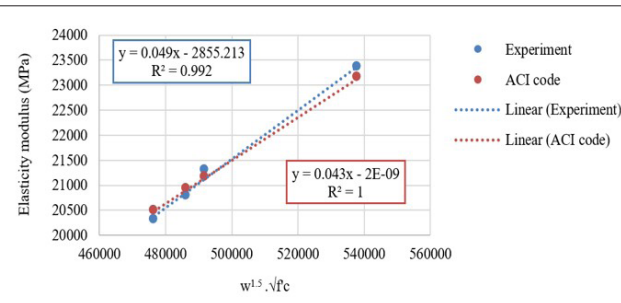



**Figure 7:** Elasticity modulus trend line according to the experimental work and ACI code.

Figure 9 illustrates the cubic compressive strength and cylindrical compressive strength of the four different mixes (GO-0, GO-0.02, GO-0.035, and GO-0.05). The ratio of compressive strength between cubical and cylindrical specimen ranged between 0.73 and 0.8 which is acceptable.

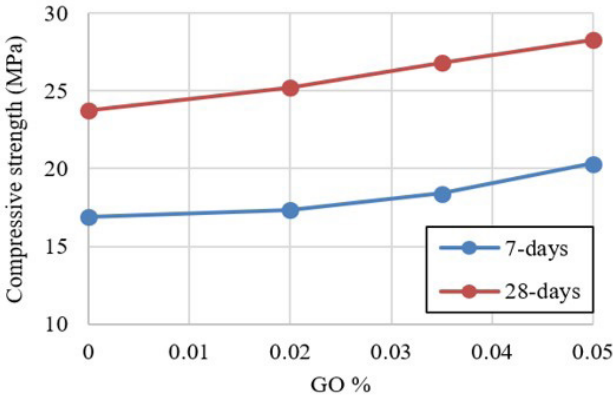



**Figure 8:** Compressive strength for concrete mixes.

## Flexural strength

Figure 10 shows the flexural strength of concrete samples with varying content of GO. The flexural strength results were 4.65, 4.71, 5.05, and 5.51 MPa for GO-0, GO-0.02, GO-0.035, and GO-0.05 respectively. The increase in GO percentages up to 0.05% contributed to the improvement in flexural strength which confirms the results of previous studies. Maximum flexural strength was obtained on addition of 0.05% of

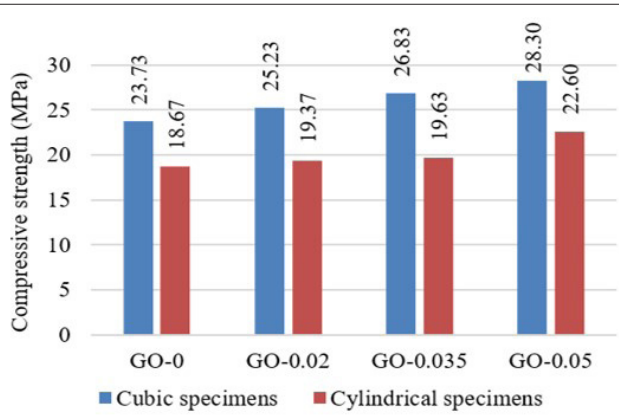



**Figure 9:** Cubic and cylindrical compressive strength of concrete mixes.

GO. The results also outlined that the flexural strength increased by 1.3%, 8.6%, and 18.5% respectively for GO-0, GO-0.02, and GO-0.035. As noted by Shanmuga et al. [9], the flexural strength increased by 26.81% at the end of 28 days, on adding 0.075% of GO. The flexural results in figure 10 confirm the findings of the previous research.

A trend curve was plotted for the experimental results relating both compressive strength and flexure strength. The curve has a formula of:

$$f_r = 0.3541 f'^{0.8816}_c \quad (3)$$

Where, "$f_r$" is the flexure strength in MPa and "$f'_c$" is the compressive strength in MPa. This is different from the relation adopted by the ACI code that relates the same parameters for conventional concrete which is defined as follows:

$$f_r = 0.625 f'^{0.5}_c \quad (4)$$

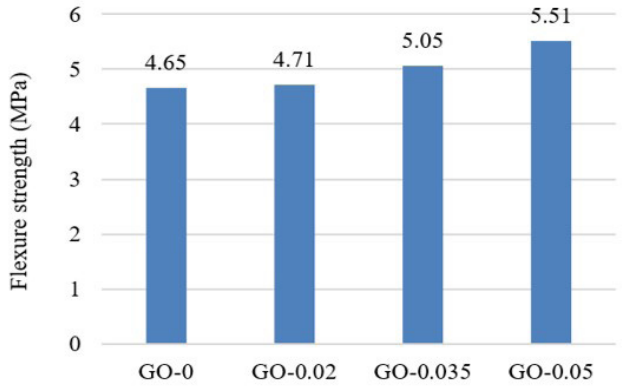



**Figure 10:** Flexural strength of concrete mixes.

Figure 11 shows the plot of both relations. For the same compressive strength, concrete with GO has higher flexure strength than conventional concrete. This means better tensile strength and ductility for GO concrete is achieved compared to conventional concrete.

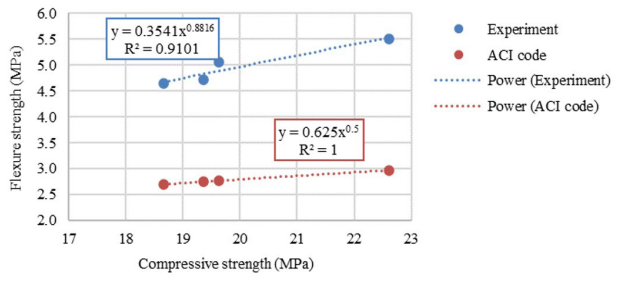



**Figure 11:** Relation between compressive strength and flexural strength.

## Conclusions

The main findings of this study are as follows:

- The addition of GO to the concrete mix resulted in an increase in the elasticity modulus. The addition of 0.05% graphene in concrete showed a 15% improvement in elasticity modulus results.
- Based on the experimental findings, a slight change in the constant was observed in the presence of GO in concrete regarding the relation between the elasticity modulus and both concrete density and compressive strength.
- Adding 0.05% GO resulted in the maximum enhancement of compressive strength (19.25%). The strength of the concrete mixes gradually increased as the GO content was increased.
- The flexural strength results showed a progressive enhancement with the increase of GO percentages. Based on the experimental findings, a different equation was adopted in the presence of GO in concrete regarding the relation between compressive strength and flexural strength. The trend line showed a higher flexural strength at a determined compressive strength for GO mixes. This indicates that GO mixes achieved higher tensile strength and ductility than the control mix.
- In general, the introduction of 0.05% GO resulted in higher compressive strength, more ductility, and tensile strength compared to the control mix.

## Acknowledgments

None.

## Conflict of Interest

All authors declare that they have no conflicts of interest.

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