Effect of reduced graphene oxide on mechanical properties of concrete

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Abstract. M40 grade concrete's balanced strength and endurance make it a popular choice for structural applications. The usage of nanoparticles to enhance the characteristics of conventional concrete has increased recently due to the need for high-performance and sustainable building supplies. Concrete's strength and microstructural integrity may be improved by reduced graphene oxide (rGO), a nanomaterial with unique mechanical and chemical properties. The impact of rGO on the mechanical characteristics of M40 grade concrete that contains Alccofine as an additional cementitious ingredient is assessed in this study. The effects of four varied rGO dosages (0.015%, 0.03%, 0.045%, and 0.06% by weight of cement) on flexural, tensile, and compressive strengths were evaluated. Studies show that, up to an optimum dosage, adding rGO to M40 concrete greatly improves its mechanical performance; after that, the advantages decrease. The potential of rGO as a useful nanomaterial for enhancing the functionality of traditional concrete in structural applications is highlighted by this investigation.

1 Introduction

Concrete is the material that best demonstrates the compressive strength (compressive resistance), durability, and availability, serving as the most common building material today. It is made of a mixture of cement, aggregates, water, and admixtures. Although it is true that standard concrete is suitable for many of the existing structural applications, the continual development and growth of the construction industry require new materials with improved mechanical and durability properties as well as long term sustainability [1]. High strength M40 grade concrete, defined by a characteristic compressive strength of 40 MPa, is more durable than lower grades. It is suitable for flexibly loaded structural elements such as office and commercial buildings, banded foundations and pavements if higher strength and durability are expected. Supplementary cementitious materials and chemical admixtures are also used to improve the workability, durability, and strength. M40 is an economical and high-performance concrete for many applications and carries a lower environmental impact than most mixes.

The usage of nanoparticles in concrete has increased significantly in recent years because of their capacity to improve durability and strength [2,3]. Better permeability and strength result from their vast surface area and tiny size, which also enhance pore structure, packing

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density, and C-S-H gel formation. Numerous nanomaterials have been investigated, including graphene compounds, carbon nanotubes, and nano-silica however, Reduced Graphene Oxide (rGO) has demonstrated especially good results [4,5].

Among nanomaterials, reduced graphene oxide (rGO), a derivative of graphene oxide, is unique because of its remarkable mechanical, chemical, and electrical characteristics. Its high surface area and ultra thin layers enable effective interaction with the cement matrix, strengthening the interfacial transition zone (ITZ), enhancing hydration, improving crack resistance, and refining pore structure. Higher compressive and flexural strength as well as increased durability are the results of these impacts. The ideal dosage of rGO must be managed, however, as high concentrations can reduce workability and result in difficulties in dispersion [6,7].

The ultrafine supplementary cementitious material (SCM) alccofine is well known for its strong reactivity and capacity to enhance concrete's performance. It has fine particles that aid in the pozzolanic reaction, which results in further C-S-H gel formation, and is categorized as a high performance mineral additive. Alccofine (12%) is added to concrete to increase durability, decrease permeability, and improve strength development. It is anticipated that its use in conjunction with rGO will enhance the overall mechanical qualities and further optimize the concrete microstructure [9].

The key objective of this work is to check the mechanical behaviour of M40 grade concrete by incorporation with rGO. This work further investigates the impacts of various rGO contents (0.015, 0.030, 0.045, and 0.060%) along with 12% Alccofine on the compressive, tensile, and flexural strengths of the concrete. The objective is to evaluate rGO's potential as a nanomaterial to improve M40 concrete's performance and make it more appropriate for structural applications requiring increased material efficiency, strength, and durability.

2 Materials

2.1 Materials

To attain higher strength and longevity, concrete is constructed with carefully chosen materials. Strong hydration processes are ensured by the principal binder, Cement (OPC 53 grade) (as shown in Figure 1). The required bulk and structural integrity are supplied by coarse aggregates (16 mm in size) and fine aggregates (sand). Although water is essential to the hydration process, M40 grade concrete maintains a water to binder ratio (0.36) to achieve high strength. Auramix 400, Despite the low water content, workability is enhanced by the addition of a high range water reduction admixture (superplasticizer). This enhances flowability, boosts strength development, and reduces water need [10]. To improve early strength, decrease porosity, and boost density, an ultrafine supplemental cementitious material named Alccofine 1203 (12%) is applied. In addition, tiny amounts of the nanomaterial rGO (0.015%, 0.030%, 0.045% & 0.060%) are added to concrete to improve bonding, refine the microstructure, and greatly increase compressive and flexural strength [11,12]. These components work together to provide a high performance, well balanced concrete mix which is suitable for demanding structural applications.

(a) Cement. (b) Alccofine.

(c) Fine aggregate. (d) Coarse aggregate.

Fig. 1. Materials.

3 Methodology

The systematic approach used to prepare and test M40 concrete with different rGO doses and Alccofine is described in the methodology (as shown in Figure 2). It covers material selection, mixing, casting, curing, and mechanical strength evaluation.

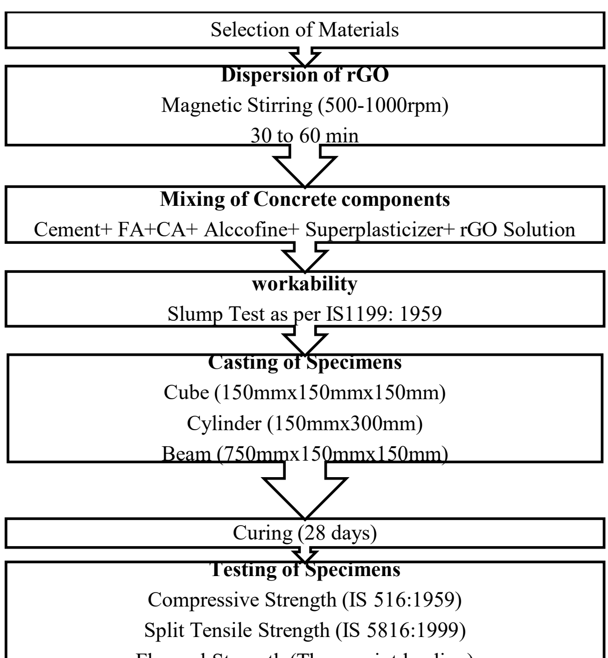

Fig. 2. Methodology flow chart.

3.1 Dispersion of rGO

rGO was dispersed in water by magnetic stirring prior to incorporating into the concrete mix. A specific amount of rGO was added to distilled water and the solution was stirred by a magnetic stirrer at a constant speed (500 to 1000rpm) for 30 to 60 min. The above process was to separate the rGO (as shown in Figure 3) particles and avoid agglomeration to facilitate even distribution in the mix. For rGO to interact with the cement matrix on a surface area basis and improve mechanical properties, adequate dispersion is essential. The mixing water was then added to the agitated rGO solution while the concrete was being prepared.

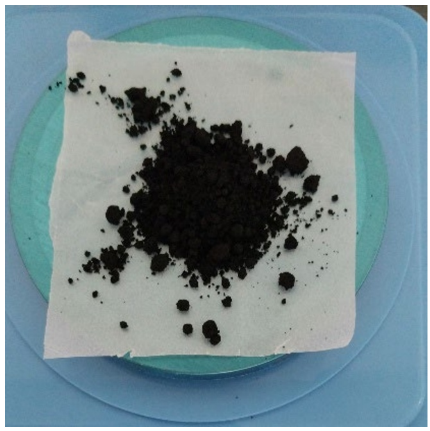

Fig. 3. Reduced graphene oxide.

3.2 Casting

M40 grade concrete with different rGO percentages (0.015%, 0.030%, 0.045%, and 0.060%) and a control concrete were used to cast the concrete specimens. For even dispersion, the pre dispersed rGO solution was combined thoroughly [13]. Alccofine (12%) was added as an additional cementitious substance [14]. For tests of compressive, tensile, and flexural strength, standard cube (150x150x150 mm), cylinder (150x300 mm) and beam (750x150x150 mm) specimens were cast. Prior to testing, specimens were compressed using a vibrating table, demoulded after a day, and cured in water at (27+2°C) for 28 days. Maintaining this temperature will maximize the hydration process, which is essential for enhancing the concrete's mechanical characteristics.

Workability of concrete mix was measured by means of Slump Test as per IS 1199:1959. The mixture (as shown in table 1) was placed in a conventional slump cone of 300mm height and 200mm bottom diameter and 100mm top diameter. Using a tamping rod, 25 tamping strokes were used to compact each of the three layers of material that were placed inside the cone. The concrete was allowed to sink after the cone was raised vertically after filling. A measurement was made of the vertical difference between the original and slumped heights. To guarantee appropriate workability and compaction, a target slump of 100 mm was maintained for M40 grade concrete with rGO [13,14].

Table 1. Mix proportions.

Mix	OPC (kg/m^3)	rGO (gm/ m^3)	Water (kg/ m^3)	Fine Aggregate (FA) (kg/m^3)	Coarse Aggregate (CA) (kg/m^3)	Alccofine (kg/ m^3)	Super Plasticizer (kg/ m^3)
0	345	0	141	689	1266	47	1.96
M1	345	51	141	689	1266	47	1.96
M2	345	103	141	689	1266	47	1.96
M3	345	155	141	689	1266	47	1.96
M4	345	207	141	689	1266	47	1.96

3.3 Testing of specimens

The compressive, tensile, and flexural strength were performed for the assessment of mechanical properties of concrete. The Compressive strength of 150 x 150 x 150 mm cube specimens which is an important measure of concrete's strength to bear the load was tested using compression testing machine (CTM) as per IS 516:1959. Results were recorded at 28 days. Using 150x300 mm cylindrical specimens, tensile strength a measure of a material's resistance to tensile stresses was calculated in accordance with IS 5816:1999. In the CTM, the specimens were positioned horizontally, and the force was applied regularly until it failed. In accordance with IS 516:1959, flexural strength a measure of concrete's resistance to bending was analysed on 700 x 150 x 150 mm beam specimens under a three-point loading technique. The modulus of rupture was computed after a gradual load was applied till failure. These investigations help to understand in depth of the mechanical behavior of concrete with the addition of rGO [13].

4 Results

4.1 Compressive strength of concrete

The compressive strength of the concrete increased with the addition of rGO until an optimum proportion of rGO. The rGO included control mix (without rGO) resulted in 46.66 MPa, the mixtures with rGO as 0.015%, 0.030% and 0.045% gave strengths of 48.00 MPa, 50.66 MPa and 52.80 MPa respectively (as shown in table 2). Maximum strength was recorded in 0.045% which is 13.17% excess above the control. However, at rGO level 0.060%, the strength dropped to 49.77 MPa (as shown in Figure 4). This behaviour indicates that rGO promotes densification and interfacial bonding with low rGO proportion, but higher ones will induce the particles agglomeration, weak zones creation. Therefore, 0.045% rGO was identified as the optimum dosage to enhance the compressive strength.

Table 2. Compressive strength of concrete.

S. No	rGO Percentage (%)	Compressive strength (MPa)
1	0	46.6
2	0.015%	48.0
3	0.030%	50.66
4	0.045%	52.8
5	0.060%	49.77

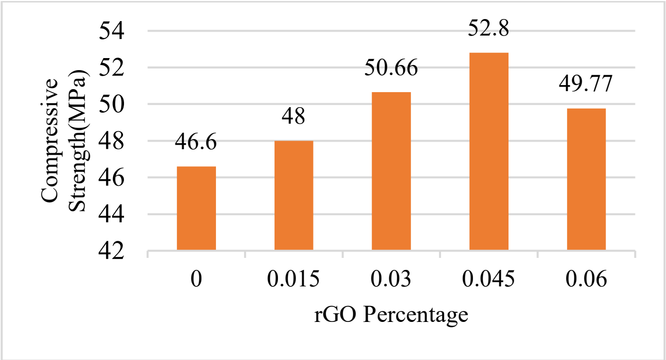

Fig. 4. Compressive strength of concrete.

4.2 Tensile strength of concrete

Table 3. Tensile strength of concrete.

S. No	rGO Percentage (%)	Tensile Strength (Mpa)
1	0	4.16
2	0.015%	4.95
3	0.030%	5.23
4	0.045%	5.65
5	0.060%	5.37

The inclusion of rGO up to an optimal percentage has a beneficial effect on the tensile strength of M40 grade concrete. The tensile strength of the rGO free control mix was 4.16 MPa. The strength increased to 4.95 MPa (0.015%), 5.23 MPa (0.030%), and a high of 5.65 MPa at 0.045% as the rGO level increased (as shown in table 3). Compared to the control, this indicates a 35.8% rise. But the strength somewhat dropped to 5.37 MPa at 0.060% (as shown in Figure 5). The better stress distribution and crack bridging capability that the rGO nanosheets in the cement matrix offer are responsible for the improvement. The minor decline above the optimal limit could be the result of poor particle agglomeration and dispersion, which can weaken matrix cohesiveness overall. Therefore, it was determined that the ideal content of rGO for increasing the tensile strength at 0.045%.

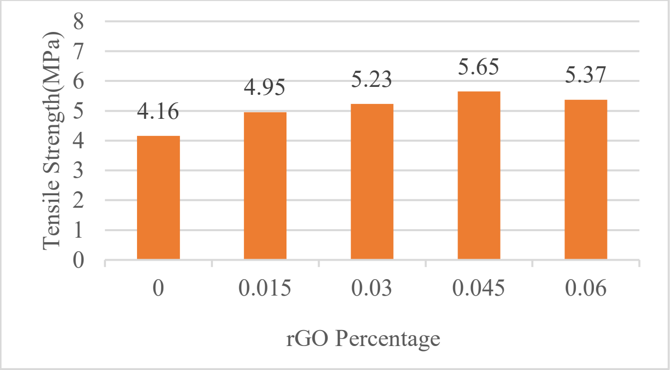

Fig. 5. Tensile strength of concrete.

4.3 Flexural strength of concrete

Table 4. Flexural strength of concrete.

S. No	rGO Percentage (%)	Flexural Strength (Mpa)
1	0	5.19
2	0.015%	5.67
3	0.030%	6.44
4	0.045%	6.66
5	0.060%	6.22

The flexural strength of M40 concrete followed a similar pattern about rGO concentration. A flexural strength of 5.19 MPa was attained by the reference mix (0% rGO). The strengths were increased to 5.67 MPa and 6.44 MPa, respectively, by adding 0.015% and 0.030% rGO (as shown in table 4). The highest value, which represented a 28.3% increase over the control, was measured at 0.045% rGO with a strength of 6.66 MPa. At 0.060% rGO, there was a minor decrease to 6.22 MPa (as shown in Figure 6). The enhanced post cracking load carrying capacity of the concrete is a result of the nanoscale reinforcing effect and crack bridging ability of rGO, which also improves flexural performance. Particle clustering, however, may lessen load transfer efficiency at greater rGO concentrations, resulting in a slight decrease in strength. Consequently, the ideal dosage for optimizing flexural strength in M40 concrete is determined to be 0.045% rGO.

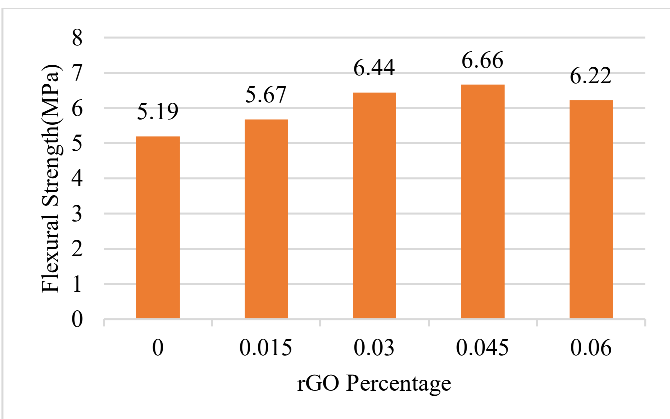

Fig. 6. Flexural strength of concrete.

Experiments on compressive, split tensile, and flexural strength showed that the ideal dosage was 0.045% rGO (as shown in Figure 7). The strength of the concrete was increased at this level due to consistent dispersion. After this, agglomeration caused strength reduction because excess rGO created clumps that disrupted the cement matrix and decreased overall performance.

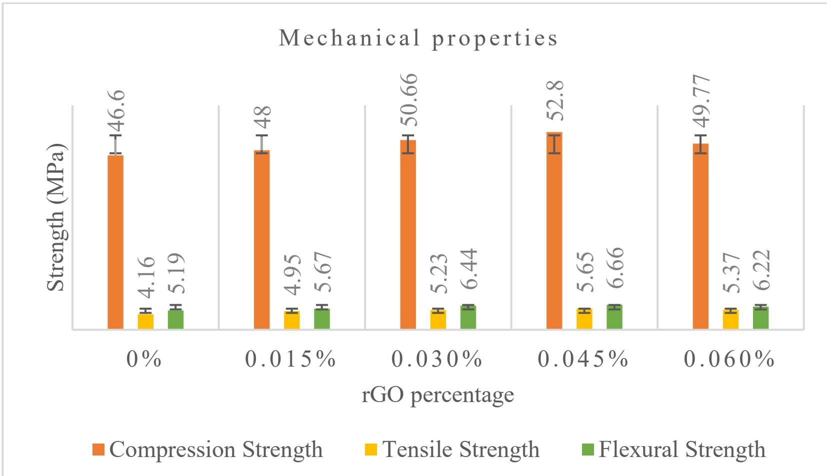

Fig. 7. Comparison of mechanical properties.

5 Conclusion

The mechanical performance of M40 grade concrete can be improved by using rGO as a nanomaterial additive, as this study shows. In comparison to traditional M40 concrete, the addition of rGO in small doses (0.015% to 0.060%) and 12% Alccofine 1203 resulted in significant increases in compressive, tensile, and flexural strengths. The use of Auramix 400 superplasticizer alongside with the low w/c ratio ensured the desired development of workability and strength. According to these results, M40 concrete that has been treated with rGO and Alccofine may be a good choice for structural applications requiring increased durability and performance. For wider adoption, more research into long term durability and cost effectiveness is advised.

5.1 Compressive strength of concrete

Compressive resistance increased noticeably after rGO was added. With increasing rGO content, the strength got significantly until it reached a maximum of 52.80 MPa at 0.045%, or 13.15% greater than the control mix's (46.66 MPa). A minor decrease was noted at 0.060% (49.77 MPa), however, suggesting that too much rGO may have an undesirable impact on bonding and dispersion inside the cement matrix.

5.2 Tensile strength of concrete

As the amount of rGO increased, a notable improvement in tensile strength was noted. At 0.045%, the maximum strength of 5.65 MPa was measured, which is a significant 35.8% increase over the control mix (4.16 MPa). At 0.060% (5.37 MPa), the strength was still greater than the control, but the modest decline indicates that the optimum range was reached.

5.3 Flexural strength of concrete

When rGO was added, flexural strength improved steadily up to 0.045%, reaching a peak of 6.66 MPa a 28.3% increase over the control mix (5.19 MPa). At 0.060%, the strength dropped slightly to 6.22 MPa, reinforcing the trend observed in other tests that excessive rGO may hinder performance.

6 Future scope

- Future research can address the limits of this study, including the necessity for improved dispersion verification to ensure consistent performance and difficulties with workability at higher rGO dosages.
- To assess real life performance, more research should concentrate on durability factors as permeability, resistance to chemical attack, and long term strength retention.
- Deeper understanding of the hydration process and interfacial bonding mechanisms can be obtained by microstructural studies employing SEM/EDS and XRD.
- Building on the current research, rGO can be used as an additional additive in high strength concrete to improve structural integrity and mechanical characteristics.
- Practical uses for its inclusion include high-rise structures, precast components, and other high performance concrete systems.
- By bridging the gap between lab research and large scale building, this strategy can support the establishment of infrastructure that is more durable, long lasting, and sustainable.

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