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Experimental study on partial replacement of concrete constituents with demolition wastes and carbon compounds

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This research has detailed the formulation and performance assessment of a new composite concrete mix for increased strength and sustainability. According to the conventional M20 mix design proportion, the concrete mixture has comprised cement, sand, aggregates, and partially substituted aggregates with demolition waste to ensure sustainable building practice. In an attempt to enhance the mechanical properties of the mix, two advanced modifiers—concrete mix with Graphene Oxide (GO) and a mixture of GO with superplasticizer (SP)—have been added. Six concrete cubes (150 mm × 150 mm × 150 mm) have been cast and cured for compressive strength tests at 7 and 28 days. Sieve analysis tests, fineness tests, and other various tests have been performed to ensure the quality of aggregates and cement. Compressive strength values have indicated that the mix containing only GO has exhibited a 9.1% and 22.2% increase at 7 and 28 days, respectively, when compared to normal M20 concrete. Interestingly, the mix containing both GO and SP has performed best, exhibiting a 33.1% increase at 7 days and a 55.5% increase at 28 days. This research study has validated that the application of demolition waste, Graphene Oxide, and superplasticizers not only has conserved resources but also has significantly improved concrete performance, paving the way for sustainable and high-performance construction materials.

Keywords: Composite concrete, Graphene oxide, High strength concrete, Sustainable construction

1 Introduction

Over the past few years, composite concrete mixtures have been in the spotlight in the construction sector. Concrete is amongst the most common construction materials owing to its high compressive strength, durability, and flexibility. Nevertheless, as demand for sustainable and high-strength construction materials continues to rise, researchers and engineers are investigating innovative methods for enhancing the strength, durability, and eco-friendliness of concrete. With the addition of high-tech materials like graphene oxide and super-plasticizers, scientists are working towards creating concrete with improved mechanical properties and sustainability. The use of demolition waste in conventional concrete, in a lower quantity, as aggregate replacement also supports the concept of sustainable construction by minimizing the use of virgin raw materials and waste disposal problems.

Conventional concrete is comprised of cement, sand (fine aggregates), gravel or crushed rock (coarse aggregates) and water. Concrete is amongst the most common construction materials owing to its high compressive strength, durability, and flexibility. Nevertheless, as demand for sustainable and high-strength construction materials continues to rise, researchers and engineers are investigating innovative methods for enhancing the strength, durability, and eco-friendliness of concrete. Over the past few years, composite concrete mixtures have been in the spotlight in the construction sector. With the addition of high-tech materials like graphene oxide and super-plasticizers, scientists are working towards creating concrete with improved mechanical properties and sustainability. The use of demolition waste in conventional concrete, in a lower quantity, as aggregate replacement also supports the concept of sustainable construction by minimizing the use of virgin raw materials and waste disposal problems. Regular concrete, although it has its benefits, has its own weaknesses in terms of strength, durability, and environmental effects. Cement used in making concrete is a major contributor to CO_2 emissions, and the ongoing extraction of natural aggregates exhausts natural resources. Additionally, regular M20-grade concrete gains its design strength with time, but further adjustments can improve its early strength and long-term durability.

The study proposes to frame an optimum composite concrete mixture providing enhanced

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mechanical performance along with environmentally reduced effects. Also, the study is aimed to highlight the following objectives:

- To formulate a composite concrete mix using demolition waste, graphene oxide, and super-plasticizer.
- To test the compressive strength of samples of concrete mixes of varying compositions after 7 and 28 days of curing.
- To determine the strength performance of ordinary M20 concrete compared to the modified concrete mixtures.
- To study the function of graphene oxide and super-plasticizers in improving the bonding and hydration process of the concrete.
- To evaluate the viability of replacing natural aggregates in part with demolition waste.

The above section presents an overview of the study, covering the background of the study, problem statement and objectives of the study.

This section provides a review of the research relevant to graphene oxide in concrete, super-plasticizers, demolition waste, and methods for enhancing compressive strength.

Numerous studies have explored the effects of graphene oxide (GO) in concrete, noting enhancements in mechanical and durability characteristics. Recent research shows that adding small amounts of GO can greatly improve compressive strength. For instance, some studies indicated that the addition of approximately 0.05% by weight of cement of GO Meng[1], Gong[2] increased compressive strength by 20–30% mainly owing to enhanced particle bonding and porosity reduction Friese[3], Kumar[4]. GO has also been found to enhance hydration by acting as a nucleation site for calcium silicate hydrate (C–S–H) gel, thus increasing strength development Chu[5], Alateah[6]. As far as durability is concerned, GO-modified concretes are more resistant to chemical attack and have lower water absorption, thus contributing towards increased service life Udumulla[7]. But excessive content of GO can result in particle agglomeration Yang[8], Kako[9], which is detrimental to workability and strength; research indicates that there is an optimal dosing of 0.02–0.1% Joseph[10], Huang[11], the most balanced performance being achieved by 0.05% Dimov[12], Jing[13].

Super-plasticizers or high-range water reducers are commonly used to improve workability without any rise in the water–cement ratio Singh[14], Wang[15]. They are most significant in high-performance concretes to enhance strength, minimize porosity, and raise durability Lin[16], Asim[17]. Some studies critically reviewed their mechanisms and observed that polycarboxylate-based super-plasticizers have the capacity to lower water demand by as much as 30%, resulting in higher compressive strength Balqis[18], Krystek[19]. Few experimental findings further attest to the fact that proper dosages of water-reducing admixtures enhance strength and durability Chen[20], Radman[21], Yuan[22]. Notably, super-plasticizers synergize with GO to enhance dispersion and facilitate optimization of GO's advantage in cementitious matrices Xu[23].

In parallel with advances in materials science, concerns with sustainability have given impetus to recycling construction and demolition (C&D) waste in concrete. Recycling such wastes and reusing them as aggregates in new concrete reduces landfill disposal and the environmental impact of construction. Research has shown that substituting 20–30% of natural aggregates with demolition waste only results in a modest decrease in strength while keeping structural performance intact (Contreras-Munuera[24], Pei[25]. Cement manufacturing alone contributes almost 8% of anthropogenic CO_2 emissions worldwide Sedaghat[26]. Therefore, the use of demolition waste aggregates not only saves natural resources but also helps decrease the carbon footprint of concrete making overall.

Although substantial research has been done on graphene oxide, super-plasticizers, and demolition waste in concrete, little research is available regarding their combined effects. Most work done has also been on high-strength concrete as opposed to M20-grade concrete used in most general construction. This research aims to bridge these gaps by:

- Exploring the combined effect of 0.05% graphene oxide and 5% super-plasticizer in M20 concrete.
- Assessing the effectiveness of using demolition waste as a substitute for part of aggregates.
- Carrying out a comparative ranking of various mix designs against their strength performance.

The above section discusses the current literature on the application of graphene oxide, super-plasticizers, and demolition waste in concrete. It indicates their effects on strength, durability, sustainability, and hydration process. The chapter also summarizes previous studies, which reveal gaps this study intends to fill.

2 Materials and Methods

Concrete is a composite material consisting of cement, fine aggregate, coarse aggregate, water, and mineral admixtures. The below section provides an overview of the research approach adopted to examine the performance of composite concrete mixes containing graphene oxide, super-plasticizer, and demolition waste. The research is conducted using a systematic method, involving the selection of materials, formulation of mix design, preparation of samples, and testing in the laboratory. A number of experiments were performed to compare the physical and mechanical characteristics of various concrete mixes, with special emphasis on compressive strength.

2.1 Cement

Ordinary Portland Cement (OPC) of 43-grade as per IS:8112:2023 was used. Cement serves as the binder in concrete by undergoing hydration reactions with water to form calcium silicate hydrates that impart strength and durability.

2.2 Design mix

The mix design of the concrete was according to the M20 grade (1:1.5:3) with a standard water-cement ratio of 0.40. Three mixes were prepared with varying mix proportions as shown in Table 1.

2.3 Fine aggregates

River sand through a 4.75 mm sieve was taken as fine aggregate of zone-I category with 3.13 fineness modulus and 2.547 specific gravity. The fine aggregate occupies the space between coarse aggregates, enhances workability, and adds to the total strength of the mix. The sand was examined for parameters like specific gravity, fineness modulus, and water absorption as per IS:2386 (Part I–III).

2.4 Coarse aggregates

Crushed stones of maximum nominal size 12.5 - 20 mm were employed as coarse aggregate with specific gravity 2.609. The coarse aggregates contribute most of the volume of the concrete and are responsible for the load-bearing capacity of the hardened concrete. Contributing to the volume of coarse aggregates, demolition wastes crushed to the similar size of coarse aggregates have been used. The aggregates were graded, washed, and tested for specific gravity and impact value.

Table 1 — Mix design samples.

S.N	Sample	Cement	Fine aggregate	Coarse aggregate	GO	SP
01	M20	1	1.5	3	0%	0%
02	M20+GO	1	1.5	3	0.5%	0%
03	M20+GO+SP	1	1.5	3	0.5%	1%

2.5 Water

Potable water, not containing any harmful chemicals, was employed for mixing and curing operations. Water triggers the hydration reaction of cement and affects workability, setting, and development of strength. The water–cement ratio was kept as per mix design specifications.

2.6 Graphene Oxide (GO)

Graphene oxide (GO) is a two-dimensional nanomaterial that is based on graphene and is distinguished by its high tensile strength, large surface area, and oxygen-containing functional groups that improve bonding with cementitious materials, was incorporated with 0.05% weight of cement dosage. The GO was in the form of powder and was pre-dispersed in water before mixing to have an even distribution. Studies proved that too much GO content can result in agglomeration with unfavorable effects on workability and strength. Earlier work indicates an ideal dosage between 0.02% and 0.1% by weight of cement with 0.05% performing the most equitable performance with regard to strength and workability, thus, implemented in this study.

2.7 Super-plasticizer (SP)

Super-plasticizers, also referred to as high-range water reducers, are chemical admixtures that enhance the workability of concrete without raising its water-cement ratio. The additives find extensive applications in high-performance concrete for strength, porosity reduction, and increased durability. In this study, 1% SP by weight of cement was used.

2.8 Preparation of samples and testing

2.8.1 Preparation of samples

For measuring the compressive strength, standard 15 cm × 15 cm × 15 cm cube moulds were employed. The inner faces of moulds were well cleaned and lightly coated with mineral oil in thin layer to prevent concrete adhesion on the mould surface. The moulds were well closed in order to avoid leakage while filling. Six concrete cubes of size 15 cm × 15 cm × 15 cm were casted to test compressive strength where first two cubes were M20 standard mix, other two cubes were M20 + 0.05% Graphene Oxide and the last two cubes were M20 + 0.05% Graphene Oxide + 1% Super-Plasticizer. Two cubes were casted which were tested at 7days and 28 days of curing respectively. Fresh concrete was filled in the cube moulds in three equal thicknesses. Each layer was tamped with a 16 mm diameter tamping rod by giving

Fig. 1 — Preparation of mix design sample in concrete laboratory.

Fig. 2 — Compressive strength experiment set-up

Table 2 — Compressive strength results at 7 days.

Sample	Compressive strength
M20 concrete	210 KN
M20 concrete + 0.5% GO	270 KN
M20 concrete + 0.5% GO + 1% SP	370 KN

Table 3 — Compressive strength results at 28 days.

Sample	Compressive strength
M20 concrete	450 KN
M20 concrete + 0.5% GO	600 KN
M20 concrete + 0.5% GO + 1% SP	700 KN

25 strokes to ensure even distribution and elimination of air pockets. The surface on top was leveled and smoothed with a trowel. The specimens were removed from the mould after 24 hours of casting and subsequently placed in a curing tank at 27 ± 2°C until test time. Compressive strength tests were conducted on 7 and 28 days as per IS: 516–2018. The preparation of samples is depicted in Fig. 1.

2.8.2 Testing procedure

Compressive Strength Test: The cube specimens were positioned in the center of the compression testing machine (CTM). Load was applied step by step at a rate of 140 kg/cm²/min until the specimen failed. The maximum load withstood was noted, and compressive strength was computed. The experimental set-up is also depicted in Fig. 2.

3 Results and Discussion

The below section deals with the presentation and discussion of the results derived from the experimental tests on various concrete mixtures. The research is mainly concerned with the physical property enhancement through compressive strength of the concrete specimens at 7 days and 28 days, with ample curing procedures. The efficacy of graphene oxide (GO) and super-plasticizer (SP) to enhance concrete strength is evaluated. The influence of demolition waste as a partial substitute for aggregates is also discussed. The findings are substantiated with tables, graphs, and comparative studies to underscore performance differences across various mix types.

Thus, from the sieve analysis tests, it is justified that the fine aggregates satisfy the grading requirement according to IS383:2016 and coarse aggregates retained a high percentage above 4.75 mm, which will provide good strength and durability.

The observations at compressive strength tests after 7 days reveal that M20 Standard Mix reached 13.5 N/mm², about 65% of its design strength, as per design strength. Along with, M20 + GO Mix exhibited a 9.1% improvement in strength over normal M20 because of the improved hydration process and nucleation effect of GO. And, M20 + GO + SP Mix exhibited a 22.2% improvement in strength, marginally less than the GO-only mix, possibly because of the retarded setting due to the super-plasticizer. Thus, high compressive strength at early stage is observed in the third sample, as shown in Table 2 and Table 3.

The observations at compressive strength tests after 7 days reveal that Standard M20 design mix achieved 20.0 N/mm², fulfilling its design strength requirement. Along with, M20 + GO Mix exhibited a an increase of 33% than standard M20 sample, verifying the long-term effects of GO-improved hydration and better bonding.. And, M20 + GO + SP Mix demonstrated the maximum rise of 55.5% than standard M20 sample owing to the combined effect of GO and super-plasticizer, which enhanced workability and

Table 4 — Compressive strength at 7 days and 28 days (in N/mm^2).

Types of concrete	Compressive strength at 7 days (N/mm^2)	Compressive strength at 28 days (N/mm^2)
M20 concrete	13.5	20
M20 concrete + 0.5% GO	14.8	26.6
M20 concrete + 0.5% GO + 1% SP	16.5	31.1

Table 5 — Strength gain comparison.

Types of concrete	Compressive strength at 7 days (N/mm^2)	Compressive strength at 28 days (N/mm^2)
M20 concrete	65%	100%
M20 concrete + 0.5% GO	9% more than Standard M20	24% more than Standard M20 at 7 days
M20 concrete + 0.5% GO + 1% SP	22% more than Standard M20	33% more than Standard M20 at 7 days

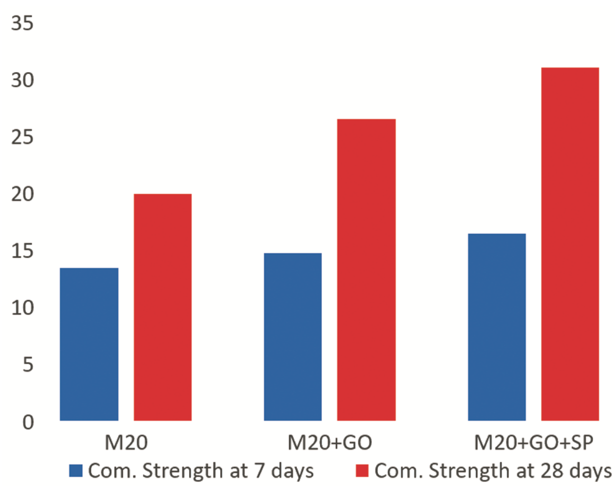

Fig. 3 — Comparison of compressive test results.

decreased micro-cracks. Thus, high compressive strength at later stage is observed in the third sample.

The observations, as in the Table 4 and Table 5, clearly indicate that the M20 Standard mix had the expected strength increase of 34% from 7 to 28 days. Interestingly, the GO mix recorded a modest 9% increase, suggesting that it developed the major part of its strength during initial stages by speedy hydration. Apparently, The GO + SP mix reported the maximum combined gain of 19%, demonstrating the contribution of super-plasticizers to long-term strength gain.

Overall, The M20 + GO + SP mix was the best, recording 31.1 N/mm² after 28 days, representing a strength of 55.5% higher than regular M20 concrete. The M20 + GO mix was also better than regular

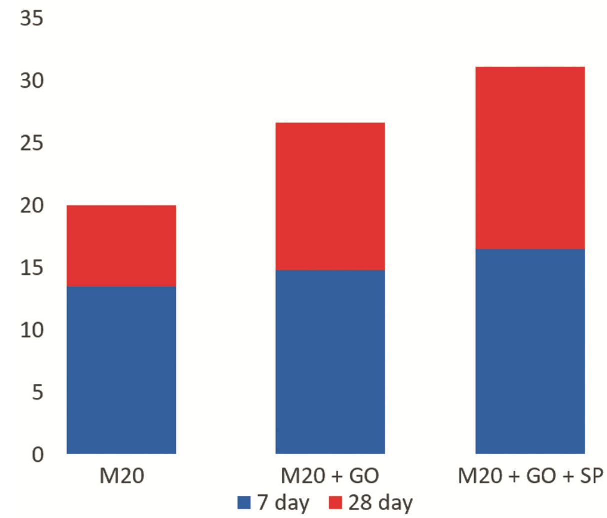

Fig. 4 — Comparison of strength gain w.r.t time.

concrete, but the difference in strength after 7 days was more pronounced compared to that at 28 days, as shown in Fig. 3. The incorporation of demolition waste into concrete was successful in demonstrating that sustainable materials can be used without affecting performance in a negative way. The laboratory results confirm the hypothesis that graphene oxide and super-plasticizers enhance strength in concrete by altering hydration and particle bonding.

4 Conclusion

This research focused on the formulation of a composite concrete mixture using demolition waste, graphene oxide (GO), and super-plasticizer (SP) according to the M20 mix design ratio. Six concrete cubes of size 15 cm × 15 cm × 15 cm were prepared in total, with two cubes per mix type, and underwent sieve analysis, soundness test, and compressive strength tests after 7 and 28 days, with proper curing. Compressive strength at 7 days depicted that conventional M20 mix recorded a strength of 13.5 N/mm², which amounts to 65% of the design strength whereas, M20 + GO mix resulted in 9.1% more strength compared to conventional M20, standing at 14.8 N/mm² and M20 + GO + SP mix showed a 22.2% increase in strength, reaching 16.5 N/mm². Compressive strength at 28 days depicted that Standard M20 mix reached its target 20.0 N/mm² with a 48.1% increase in strength from 7 to 28 days whereas, M20 + GO mix recorded a further 24.1% increase in strength, reaching 26.6 N/mm² with 33% more strength gain over time and M20 + GO + SP mix recorded the maximum strength gain, reaching 31.1 N/mm² with strength gain of 55.1%, as shown in Fig. 4.

Hence, The experimental research was conducted successfully to show that the addition of graphene oxide (GO) and super-plasticizer in M20 concrete mix enormously enhanced compressive strength. Graphene oxide (GO) increases early strength development because it can accelerate hydration and strengthen the C-S-H (Calcium-Silicate-Hydrate) gel matrix. Super-plasticizers (SP) enhance workability, dispersion, and long-term strength gain with improved flowability and minimized porosity of concrete. A blend of GO and SP exhibited optimal performance, with an improvement in 28-day strength by 28% compared to regular M20 concrete. The incorporation of demolition waste into concrete is possible without compromising its strength, enabling sustainable construction. In summary, the research verifies that the incorporation of graphene oxide and super-plasticizer into conventional M20 concrete is an effective approach to developing its mechanical characteristics, especially compressive strength, while assisting in sustainable material usage. The study considered only 7-day and 28-day strengths, but long-term performance (90 days, 180 days, etc.) was not evaluated. The economic viability and reduction of carbon footprint attained by utilizing graphene oxide and demolition waste were not assessed in the study. This research may be further extended to conduct durability tests to analyze water absorption, chloride resistance, and freeze-thaw resistance over time, optimize dosage of graphene oxide to identify its optimal percentage to enhance cost-efficient strength and evaluate sustainability and life cycle assessment to measure the environmental advantages of using demolition waste as a component of concrete.

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