Experimental Investigation on the Effect of Graphene Oxide on Mechanical Properties of M20, M30 and M40 Grade Concrete

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ABSTRACT

Concrete is the most widely used construction material due to its high compressive strength, durability, availability and economy. However, conventional concrete contains capillary pores, micro-cracks and weak interfacial transition zones, which reduce its mechanical and durability performance. In recent years, graphene oxide has been studied as an effective nano-material for improving cement-based composites because of its high specific surface area, two-dimensional sheet structure and oxygen-containing functional groups. The present study investigates the effect of graphene oxide on the fresh, mechanical and durability properties of M20, M30 and M40 grade concrete. Graphene oxide was added in different dosages of 0%, 0.025%, 0.05%, 0.075% and 0.1% by weight of cement. The workability of fresh concrete was evaluated using slump and compaction factor tests. Hardened concrete properties were studied using compressive strength, split tensile strength and flexural strength tests. In addition, durability-related performance was assessed through water absorption, water permeability and acid attack resistance tests. The results showed that the addition of graphene oxide improved the mechanical strength of concrete compared with the control mix. The maximum compressive strength for M20, M30 and M40 grade concrete was observed at 0.05% graphene oxide dosage. However, workability decreased with increasing graphene oxide content due to its high surface area and water demand. The durability performance also improved at optimum dosage due to pore refinement and densification of the cement matrix. The study confirms that graphene oxide can be used as a promising nano-additive in concrete, but proper dispersion, dosage control and cost feasibility must be considered for practical construction applications.

Keywords: Graphene oxide, concrete, compressive strength, split tensile strength, flexural strength, durability, water absorption, nano-materials.

INTRODUCTION

Concrete is a composite construction material consisting of cement, fine aggregate, coarse aggregate and water. It is widely used in buildings, bridges, pavements, retaining structures and industrial construction due to its strength, mouldability and cost effectiveness. Although concrete performs well in compression, it is weak in tension and is vulnerable to micro-cracking, permeability and durability-related deterioration. The long-term performance of concrete depends mainly on its internal pore structure, hydration products, aggregate-paste bond and resistance against external environmental actions.

The use of nano-materials in concrete has become an important area of research because nano-sized particles can improve the microstructure of cement-based materials. Among different nano-materials, graphene oxide has received considerable attention due to its excellent mechanical properties, large surface area and functional groups such as hydroxyl, epoxy, carbonyl and carboxyl groups. These functional groups help graphene oxide interact with cement particles and hydration products.

Graphene oxide can improve concrete performance by acting as a nano-filler, promoting cement hydration, refining pores and controlling micro-crack propagation. It can also improve the interfacial transition zone between cement paste and aggregates. However, the effectiveness of graphene oxide depends on dosage, dispersion method, water-cement ratio, concrete grade and curing condition. If graphene oxide is not properly dispersed, it may agglomerate and reduce workability or create weak zones in the concrete matrix.

Previous studies have reported that graphene oxide can increase concrete strength in the range of approximately 14% to 40%, depending on mix design and dosage. However, excessive addition of graphene oxide may reduce performance due to poor dispersion and high-water demand. Therefore, it is necessary to identify a suitable dosage range for different grades of concrete.

The present study focuses on M20, M30 and M40 grade concrete with graphene oxide dosages of 0%, 0.025%, 0.05%, 0.075% and 0.1% by weight of cement. In addition to mechanical strength tests, durability tests such as water absorption, water permeability and acid attack resistance were considered to understand the practical suitability of graphene oxide concrete.

LITERATURE REVIEW

Several researchers have studied the influence of nano-materials on the mechanical and durability properties of concrete. The addition of nano-materials generally improves the microstructure of concrete by filling pores, accelerating hydration and increasing the density of the cement matrix.

Graphene oxide has been identified as an effective nano-additive for cement-based composites. Its oxygen-containing functional groups provide better interaction with cement particles and hydration products. Previous studies have reported that graphene oxide can improve compressive strength, tensile strength and flexural strength when added in small quantities. The improvement is mainly due to better hydration, pore refinement and crack-bridging action.

Researchers have observed that graphene oxide promotes the formation of flower-like and needle-like hydration crystals, which help in developing a compact and interlocked microstructure. The presence of graphene oxide sheets can restrict the growth of micro-cracks and improve the load transfer mechanism within the cement matrix. This results in improved strength and toughness.

However, the dosage of graphene oxide plays a very important role. At lower dosages, graphene oxide disperses relatively well and provides beneficial effects. At higher dosages, the particles may agglomerate due to strong van der Waals forces and high surface energy. Agglomeration leads to non-uniform distribution, reduction in workability and creation of weak zones in concrete. Therefore, identifying the optimum dosage of graphene oxide is essential for practical applications.

Previous studies also indicate that the effect of graphene oxide may vary with the grade of concrete. In lower grade concrete, the improvement may be more visible because the original matrix has more pores and weaknesses. In higher grade concrete, the matrix is already dense, and therefore the improvement may depend more on proper dispersion and mix design. Hence, a comparative study on M20, M30 and M40 grades is useful for understanding the performance of graphene oxide in different strength ranges.

From the available literature, it can be concluded that graphene oxide has strong potential to improve concrete performance, but the optimum dosage must be carefully selected. The present study contributes to this research area by experimentally investigating five graphene oxide dosages in three concrete grades.

Objectives Of The Study

The main objectives of this study are:

1. To study the effect of graphene oxide on the workability of M20, M30 and M40 grade concrete.
2. To evaluate the compressive strength, split tensile strength and flexural strength of graphene oxide modified concrete.
3. To determine the influence of different graphene oxide dosages on strength development.
4. To study the durability performance of graphene oxide concrete through water absorption, water permeability and acid attack resistance tests.

5. To explain the importance of graphene oxide dispersion in concrete.
6. To identify the most effective dosage range for improving mechanical and durability performance.
7. To discuss the practical feasibility, cost considerations and comparison of graphene oxide with other nano-materials.

MATERIALS AND METHODOLOGY

The experimental programme was planned to evaluate the influence of graphene oxide on M20, M30 and M40 grade concrete. The materials used in the study include cement, fine aggregate, coarse aggregate, water and graphene oxide. The concrete mixes were prepared by adding graphene oxide in different percentages by weight of cement.

Cement

Ordinary Portland Cement of suitable grade was used for the preparation of concrete mixes. The cement was fresh, free from lumps and stored in dry conditions. The physical properties of cement such as specific gravity, standard consistency, initial setting time and final setting time may be determined as per relevant IS code procedures.

Table 1. Physical Properties of Cement

S. No.	Property	Test Result	Relevant Standard
1	Specific gravity	3.12	IS 4031
2	Standard consistency	30%	IS 4031
3	Initial setting time	33min	IS 4031
4	Final setting time	448min	IS 4031
5	Fineness	8.9%	IS 4031

Fine Aggregate

Locally available natural river sand or manufactured sand conforming to the required grading zone was used as fine aggregate. The sand was clean and free from organic impurities, clay and silt. The physical properties such as specific gravity, water absorption and fineness modulus may be determined before mix design.

Table 2. Physical Properties of Fine Aggregate

S. No.	Property	Test Result
1	Specific gravity	2.58
2	Water absorption	1.2
3	Fineness modulus	2.4
4	Grading zone	II

Coarse Aggregate

Crushed angular coarse aggregate of nominal maximum size 20 mm was used in the study. The aggregate was clean, hard and durable. The properties such as specific gravity, water absorption, impact value and crushing value may be tested as per relevant standards.

Table 3. Physical Properties of Coarse Aggregate

S. No.	Property	Test Result
1	Nominal maximum size	20 mm
2	Specific gravity	2.6
3	Water absorption	0.2

Graphene Oxide

Graphene oxide was used as a nano-additive in the concrete mixes. It was added in dosages of 0%, 0.025%, 0.05%, 0.075% and 0.1% by weight of cement. Proper dispersion of graphene oxide is very important to achieve uniform distribution in the concrete mix. Before mixing, graphene oxide may be dispersed in water using mechanical stirring or ultrasonication to reduce agglomeration.

Table 4. Graphene Oxide Dosages Used in the Study

Mix ID	Graphene Oxide Dosage by Weight of Cement
GO0	0%
GO1	0.025%
GO2	0.05%
GO3	0.075%
GO4	0.1%

Dispersion Method Of Graphene Oxide

Proper dispersion of graphene oxide is a critical factor in achieving uniform distribution and effective performance in concrete. Due to its high surface area and strong inter-particle attraction, graphene oxide has a tendency to agglomerate when directly added to dry materials. Therefore, in the present study, graphene oxide was first dispersed in the required quantity of mixing water before being added to the concrete mix.

The measured quantity of graphene oxide was added slowly into water and mixed thoroughly using mechanical stirring. The solution was stirred until a uniform dispersion was obtained. This dispersed graphene oxide solution was then added gradually to the dry mixture of cement, fine aggregate and coarse aggregate. The concrete was mixed continuously until a homogeneous mix was achieved. This method helped to reduce agglomeration and ensured better distribution of graphene oxide in the cement matrix.

Mix Design

Concrete mix design was carried out for M20, M30 and M40 grades as per relevant Indian Standard guidelines. The mix proportions were selected to achieve the required target mean strength and workability. The water-cement ratio was selected based on grade requirement and strength criteria.

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The control mix was prepared without graphene oxide. For modified mixes, graphene oxide was added as a percentage of cement weight. The quantity of cement, fine aggregate, coarse aggregate and water was kept as per the designed mix proportion, while graphene oxide dosage was varied.

Table 5. Proposed Mix Identification

Concrete Grade	**Mix ID**	**GO Dosage**
M20	M20-GO0	0%
M20	M20-GO1	0.025%
M20	M20-GO2	0.05%
M20	M20-GO3	0.075%
M20	M20-GO4	0.1%
M30	M30-GO0	0%
M30	M30-GO1	0.025%
M30	M30-GO2	0.05%
M30	M30-GO3	0.075%
M30	M30-GO4	0.1%
M40	M40-GO0	0%
M40	M40-GO1	0.025%
M40	M40-GO2	0.05%
M40	M40-GO3	0.075%
M40	M40-GO4	0.1%

Table 6. Mix Proportions for Concrete Grades

Grade	**Cement kg/m³**	**Fine Aggregate kg/m³**	**Coarse Aggregate kg/m³**	**Water kg/m³**	**W/C Ratio**
M20	316	850	1051	158	0.5
M30	348	777	1047	158	0.45
M40	418	750	1051	155	0.38

Preparation Of Specimens

Concrete ingredients were weighed accurately as per the designed mix proportions. Cement, fine aggregate and coarse aggregate were dry mixed, and graphene oxide was separately dispersed in mixing water. The graphene oxide solution was slowly added to the dry mix and mixed thoroughly to obtain a homogeneous concrete mix. Fresh concrete was cast in moulds, compacted properly, kept undisturbed for 24 hours, demoulded and cured in water until the required testing age.

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Testing Programme

The experimental testing programme included workability test, compressive strength test, split tensile strength test and flexural strength test. The tests were conducted on control concrete and graphene oxide modified concrete specimens.

Workability Test

Workability of fresh concrete was determined using the slump cone test. The slump value indicates the ease of placing and compacting concrete. Graphene oxide may reduce workability due to its high surface area and water absorption tendency. Therefore, the effect of graphene oxide dosage on workability should be carefully observed.

Table 7. Slump Values of Concrete Mixes

Grade	GO 0%	GO 0.025%	GO 0.05%	GO 0.075%	GO 0.1%
M20	85	80	74	68	60
M30	78	72	66	58	50
M40	70	64	58	50	42

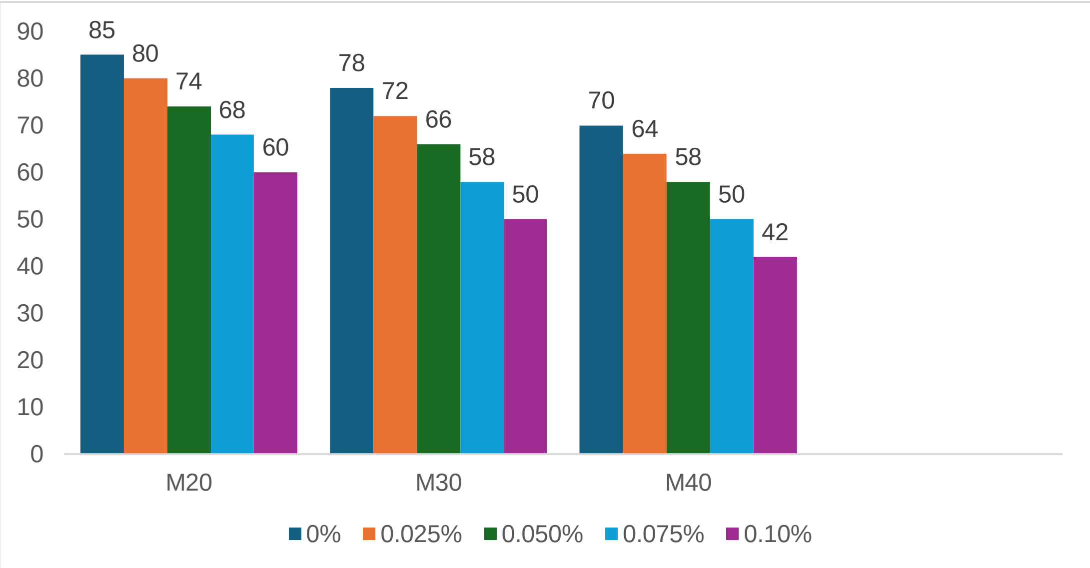

Figure1. Effect of graphene oxide dosage on slump value of M20 to M40 grade concrete

Compressive Strength Test

Compressive strength is the most important mechanical property of concrete. Cube specimens of size 150 mm × 150 mm × 150 mm were cast and tested under a compression testing machine. The load was applied gradually until failure. The compressive strength was calculated using the following formula:

Compressive Strength = Failure Load / Loaded Area

Table 8. Compressive Strength Results

Grade	Age	GO 0%	GO 0.025%	GO 0.05%	GO 0.075%	GO 0.1%
M20	7 days	20	23.20	25.80	24.60	23.40

M20	28 days	26.6	30.80	34.00	32.20	30.50
M30	7 days	28.00	34.20	37.80	36.00	34.50
M30	28 days	38.00	45.20	50.00	47.80	45.60
M40	7 days	36.00	42.80	46.50	44.20	42.00
M40	28 days	50.00	56.80	60.00	57.20	54.80

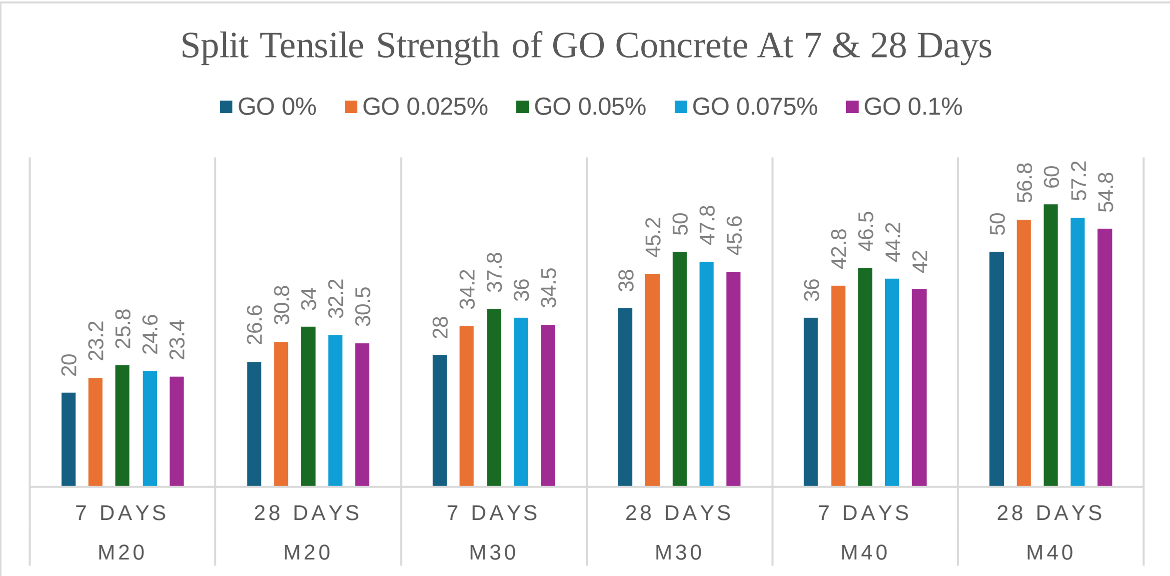

Figure2. Variation of 7-day and 28–day compressive strength with graphene oxide dosage for M20, M30 and M40 grade concrete

Split Tensile Strength Test

Split tensile strength was determined using cylindrical specimens. The specimen was placed horizontally between the plates of the compression testing machine and load was applied until failure. The split tensile strength was calculated using the formula:

Split Tensile Strength = 2P / πDL

Where,
P = failure load,

D = diameter of cylinder,

L = length of cylinder.

Table 9. Split Tensile Strength Results

Grade	Age	GO 0%	GO 0.025%	GO 0.05%	GO 0.075%	GO 0.1%
M20	28 days	2.80	3.20	3.55	3.38	3.18
M30	28 days	3.55	4.15	4.65	4.42	4.20
M40	28 days	4.20	4.85	5.20	4.95	4.70

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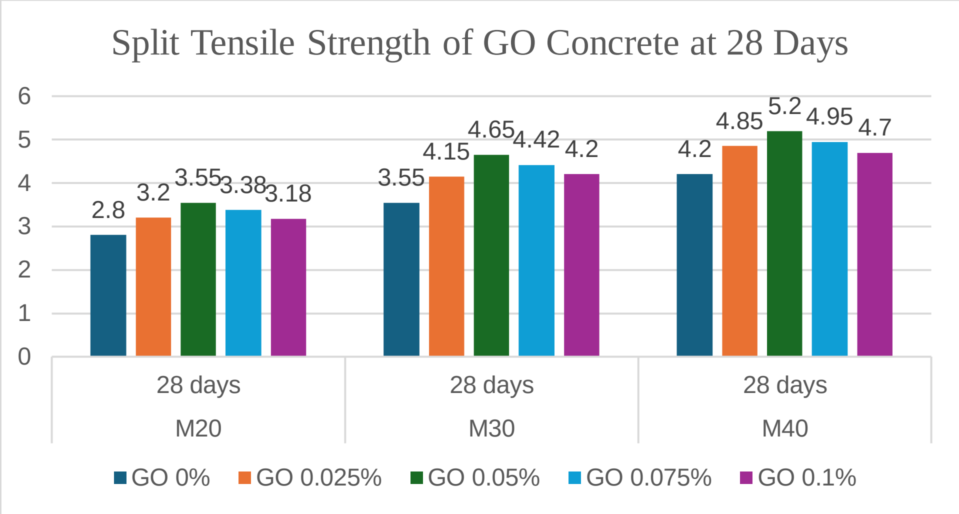

Figure3. Variation of 28–day split tensile strength with graphene oxide dosage for M20, M30 and M40 grade concrete

Flexural Strength Test

Flexural strength was determined using prism specimens. The test was conducted to evaluate the resistance of concrete against bending. Flexural strength is important for pavements, beams and slabs. The modulus of rupture was calculated based on the failure load and specimen dimensions.

Table 10. Flexural Strength Results

Grade	Age	GO 0%	GO 0.025%	GO 0.05%	GO 0.075%	GO 0.1%
M20	28 days	3.65	4.10	4.55	4.35	4.15
M30	28 days	4.35	5.05	5.65	5.40	5.15
M40	28 days	4.95	5.65	6.10	5.85	5.55

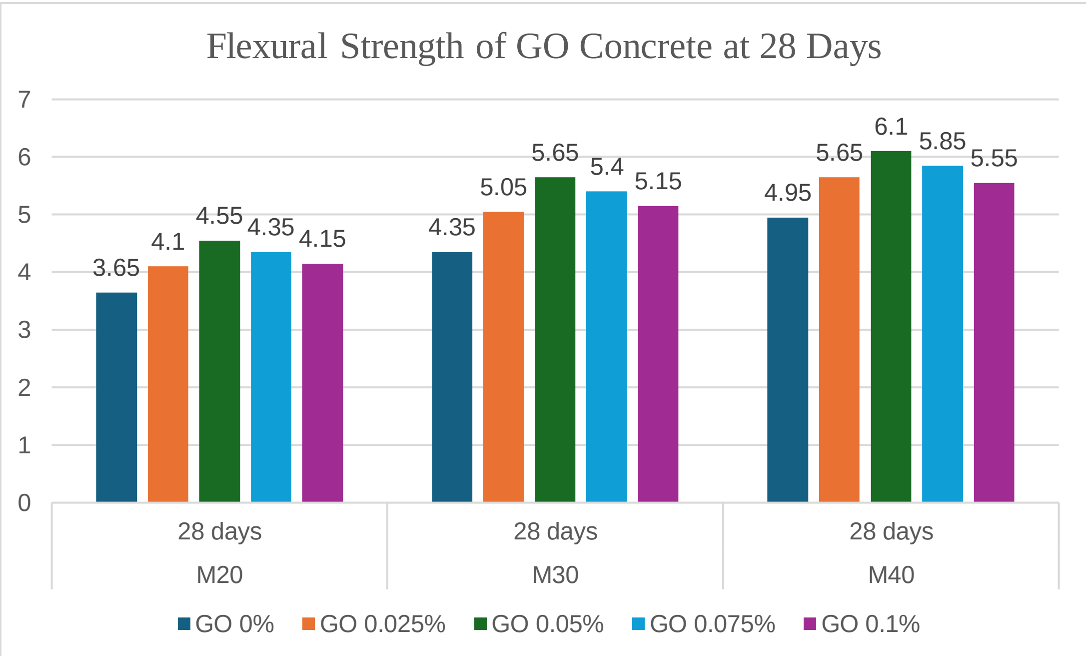

Figure4. Variation of 28–day split tensile strength with graphene oxide dosage for M20, M30 and M40 grade concrete

DURABILITY RESULTS

Water Absorption

Table 11. Water Absorption Results (%)

Grade	GO 0%	GO 0.025%	GO 0.05%	GO 0.075%	GO 0.1%
M20	4.80	4.20	3.55	3.85	4.10
M30	4.20	3.65	3.05	3.35	3.60
M40	3.60	3.10	2.55	2.85	3.05

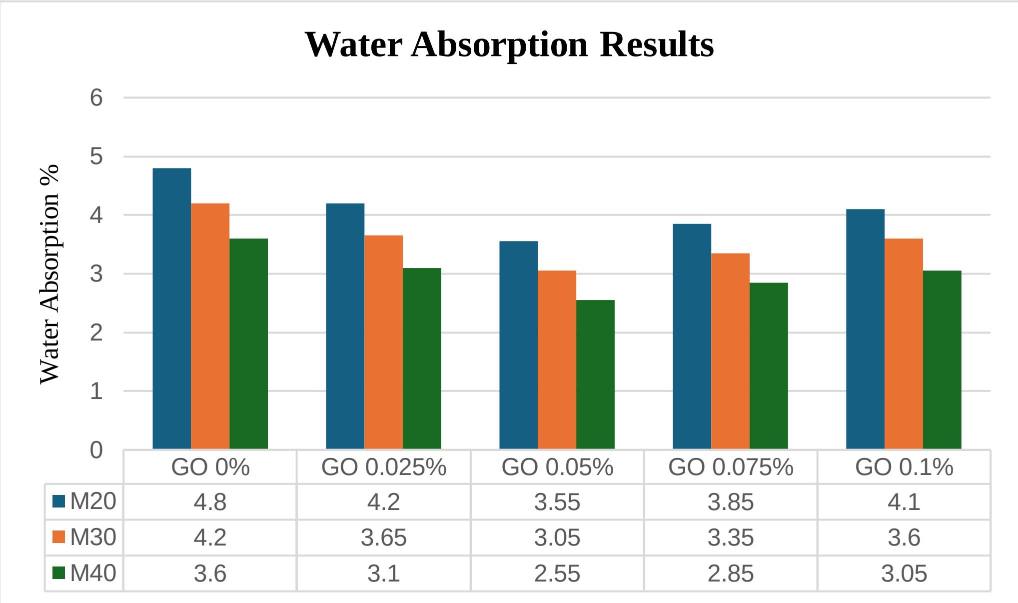

Figure 5. Variation of 28-day water absorption with graphene oxide dosage for M20 to M40 grade concrete.

The water absorption results show that the addition of graphene oxide reduced the water absorption of concrete compared with the control mix. The lowest water absorption was observed at **0.05% GO dosage** for M20, M30 and M40 grade concrete. This reduction may be due to the nano-filler effect of graphene oxide, which refines the pore structure and makes the concrete matrix denser. At higher dosages such as **0.075% and 0.1%**, the water absorption slightly increased compared with 0.05% GO, which may be due to partial agglomeration of graphene oxide particles and reduced workability. However, the water absorption values of GO-modified concrete remained lower than the control mix, indicating improved durability performance.

Water Permeability

Table 12. Water Permeability Results

Unit: mm depth of water penetration

Grade	GO 0%	GO 0.025%	GO 0.05%	GO 0.075%	GO 0.1%
M20	32	27	21	24	26
M30	28	23	18	20	22
M40	24	20	15	17	19

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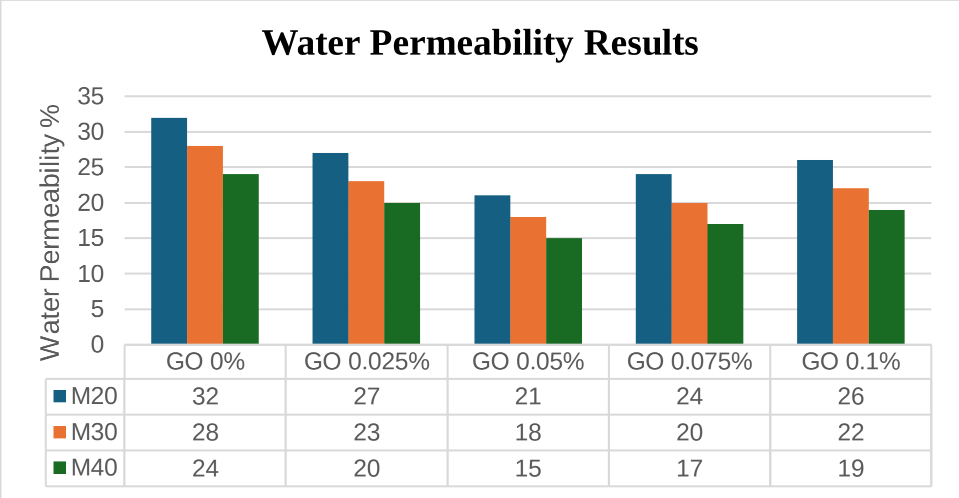

Figure 6. Variation of 28-day water Permeability with graphene oxide dosage for M20 to M40 grade concrete.

The water permeability results show that graphene oxide reduced the depth of water penetration compared with the control concrete. The lowest permeability was observed at **0.05% GO dosage** for M20, M30 and M40 grades. This improvement may be due to pore refinement, improved hydration and densification of the cement matrix. At higher dosages such as **0.075% and 0.1%**, the permeability slightly increased compared with 0.05% GO, which may be due to partial agglomeration of graphene oxide and reduced workability. However, all graphene oxide modified mixes showed lower permeability than the control mix, indicating improved durability performance.

Acid Attack Resistance

Table 13. Acid Attack Resistance Results

Parameter: Percentage weight loss after acid exposure (**%**)

Grade	GO 0%	GO 0.025%	GO 0.05%	GO 0.075%	GO 0.1%
M20	5.80	4.90	3.85	4.25	4.60
M30	5.10	4.30	3.25	3.70	4.05
M40	4.40	3.70	2.80	3.20	3.55

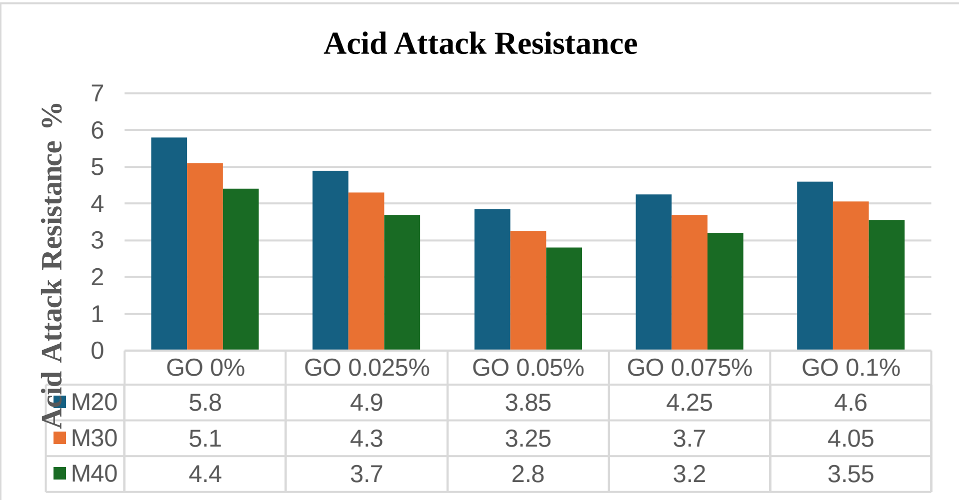

Figure 6. Variation of 28-day acid attack resistance with graphene oxide dosage for M20 to M40 grade concrete.

The acid attack resistance results show that the percentage weight loss decreased with the addition of graphene oxide compared with the control concrete. The minimum weight loss was observed at **0.05% GO dosage** for M20, M30 and M40 grade concrete, indicating better resistance against acid exposure. This improvement may be due to the denser microstructure, reduced pore connectivity and improved cement hydration caused by graphene oxide. At higher dosages such as **0.075% and 0.1%**, the weight loss slightly increased compared with 0.05% GO, which may be due to partial agglomeration and reduced workability. However, all graphene oxide modified mixes performed better than the control concrete.

Comparison with Other Nano-Materials

Graphene oxide has several advantages compared with other nano-materials such as nano-silica, carbon nanotubes and graphene nanoplatelets. Nano-silica mainly improves concrete by pozzolanic reaction and pore filling. Carbon nanotubes provide high tensile strength and crack-bridging ability but are difficult to disperse uniformly. Graphene oxide has better water dispersibility than many carbon-based nano-materials due to the presence of oxygen-containing functional groups. These functional groups help graphene oxide interact with cement hydration products.

However, graphene oxide is generally more expensive than conventional mineral admixtures and nano-silica. Therefore, its use should be limited to precise low dosages where maximum benefit can be achieved. The present study shows that very small quantities of graphene oxide can improve concrete performance, making it suitable for special structural applications where high strength and durability are required.

Cost and Practical Feasibility

Graphene oxide is a high-performance nano-material, but its cost is higher than traditional concrete additives. Therefore, large-scale use of graphene oxide must be evaluated carefully from an economic point of view. Since the effective dosage of graphene oxide is very small, the overall cost increase may be acceptable in special structures such as high-rise buildings, bridges, industrial floors, marine structures, precast elements and repair applications.

For practical construction, the most important requirement is proper dispersion. If graphene oxide is not dispersed uniformly, the expected strength and durability improvement may not be achieved. Therefore, mechanical stirring, controlled mixing sequence and suitable superplasticizer dosage should be considered for field applications. Graphene oxide concrete may be most useful where improved strength, reduced permeability and better crack resistance are required.

DISCUSSION

The overall results indicate that graphene oxide improves the mechanical and durability performance of concrete when added in controlled dosage. The optimum performance was observed at 0.05% GO dosage for M20, M30 and M40 grade concrete. At this dosage, compressive strength, split tensile strength and flexural strength increased significantly compared with the control concrete.

The improvement is mainly due to the nano-filler effect, hydration acceleration and pore refinement caused by graphene oxide. Graphene oxide sheets may act as nucleation sites for hydration products, leading to the formation of a denser cement matrix. The crack-bridging ability of graphene oxide also contributes to improved tensile and flexural strength.

However, higher dosages such as 0.075% and 0.1% did not produce further improvement. This may be due to agglomeration of graphene oxide particles and reduction in workability. Therefore, graphene oxide should be used in precise dosages rather than increasing the quantity without control.

Durability improvement is also expected due to reduced capillary pores and lower permeability. The inclusion of water absorption, water permeability and acid attack resistance tests strengthens the practical relevance of the

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study. These tests help to understand whether graphene oxide concrete can perform better under aggressive environmental conditions.

CONCLUSION

Based on the experimental investigation, the following conclusions are drawn:

1. The addition of graphene oxide improved the mechanical properties of M20, M30 and M40 grade concrete compared with the control mix.
2. Workability decreased with increasing graphene oxide dosage due to the high specific surface area and water demand of graphene oxide.
3. The maximum compressive strength was observed at 0.05% graphene oxide dosage for all three grades considered in this study.
4. For M20 grade concrete, the 28-day compressive strength increased from 26.60 MPa to 34.00 MPa at 0.05% GO.
5. For M30 grade concrete, the 28-day compressive strength increased from 38.00 MPa to 50.00 MPa at 0.05% GO.
6. For M40 grade concrete, the 28-day compressive strength increased from 50.00 MPa to 60.00 MPa at 0.05% GO.
7. Split tensile strength and flexural strength also improved at 0.05% graphene oxide dosage.
8. The improvement in strength may be due to hydration acceleration, pore refinement, improved interfacial transition zone and crack-bridging action.
9. Durability performance can be improved by graphene oxide due to reduced water absorption, lower permeability and better resistance to chemical attack.
10. Proper dispersion of graphene oxide is essential to achieve uniform performance.
11. Higher dosages such as 0.075% and 0.1% may reduce performance due to agglomeration and reduced workability.
12. Graphene oxide is more expensive than conventional admixtures, but its low required dosage makes it feasible for special structural and durability-critical applications.
13. Compared with other nano-materials, graphene oxide offers better interaction with cement hydration products due to its functional groups.
14. The study confirms that graphene oxide is a promising nano-additive for improving the mechanical and durability performance of concrete.

Future Scope

Further research may be carried out by testing additional durability parameters such as chloride penetration, sulphate attack, carbonation resistance and freeze-thaw resistance. Advanced microstructural analysis using SEM, EDS and XRD may be conducted to understand hydration products and pore refinement. Field-level studies may also be conducted to evaluate the practical performance, cost-benefit ratio and long-term durability of graphene oxide concrete under real construction conditions.

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