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An Experimental Study on Mechanical Properties of Graphene Oxide Concrete with Partial Replacement of Cement by Wollastonite

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Abstract - *Concrete is durable and efficient binding material which is used for construction. India is second largest producer of cement. About 1.5 tons of raw material is required for every single ton production of cement. In order to reduce the consumption of cement, supplementary cementitious materials are used in concrete production. Wollastonite is a naturally occurring mineral formed due to interaction of limestone with silica in hot magmas which imparts additive strength to concrete. In the present work, cement is partially replaced by wollastonite at various percentage in concrete. Graphene Oxide is an extraordinary Nano-material which is accessible in powder, sheets, flakes and oxide form. It is strong, elastic and light weight in nature and recently adopted in construction field. It is having great properties which are beneficiary in construction field. When graphene oxide is added to concrete composites, it increases the rate of hydration, bond strength to concrete structures and reduces permeability. In this project, optimum quantity of graphene oxide (0.2%) is used as an additive to study the strength properties of M25 grade concrete, cement is partially replaced by wollastonite at 0%, 5%, 10%, 15%, and 20% in concrete.*

Key Words: **Concrete, Graphene oxide, Wollastonite, Partial replacement, Compressive, Tensile and Flexural strength.**

1. INTRODUCTION

Graphene oxide is formally called as graphitic acid. Graphene is a two-dimensional honey comb cross section in which one element shapes every vertex and also an allotrope form of carbon. Graphene oxide has numerous remarkable properties such as thermal, electrical, mechanical, chemical properties. Graphene oxide was synthesized by oxidation of graphite.

Carbon nano materials such as graphene, carbon nanofibre, and graphene oxide have been studied and applied to reinforcing materials for cement materials because of their unique properties and also it improves the mechanical properties of ordinary portland cement (OPC) by controlling the nano size cracks before further expansion. The need of concrete as a construction material is increasing due to concrete is a strong and moldable construction material which consists of cement, sand and aggregate mixed with water and also cement production is increasing as well. Cement production is expanding at a rate of roughly 3% per year. For infrastructure development, many countries are observing the utilization of natural resources gives rapid growth in construction industry. Thus, we can replace the costly and limited natural resources with the inventive and environmentally friendly alternate building materials. The usage of waste products in concrete helps in reducing the disposal issues and make it inexpensive. We need to discover alternate sources to deal with environmental issues. From many research conclude that, adding mineral admixtures to the concrete produces a very strong and durable concrete with the greater resistance to degradation of concrete. It is a naturally occurring mineral formed due to interaction of limestone with silica in hot magmas. Even at high temperature wollastonite was originate to possess reinforcing quality as well as chemical resistance. There are two main components that form the mineral wollastonite: CaO and Si02. In a pure CaSi03, each part forms almost half of the mineral by weight percentage. It is a white mineral highly modulus.

1.1 Objectives

1. To investigate the mechanical properties of graphene oxide concrete with partial replacement of cement by wollastonite.
2. To compare the mechanical strength parameters of graphene oxide concrete with partial replacement of cement by wollastonite.
3. To find the optimal amount of wollastonite required to achieve maximum compressive, flexural and tensile strength of graphene oxide concrete.

1.2 Introduction to graphene oxide

Graphene Oxide is an extraordinary nano-material which is accessible in powder, sheets, flakes and oxide form. It is strong, elastic and light weight in nature and recently adopted in construction field. It is having great properties which are beneficiary in construction field. When graphene oxide is added to concrete composites, increases the

strength parameters of the concrete. It also increases the rate of hydration, reduces permeability and also gives high bond strength to concrete structures. Graphene is a single layer sp2-bonded carbon sheet forming a honeycomb crystal lattice. Carbon nanotubes (CNT) and graphene nanoplatelets edges are chemically modified in polymeric composites and have the similar chemical structure. Nanoplatelets are typically less than 5 nm thick and lateral dimensions ranging from < 1 to 100 microns. The use of graphene oxide powder improves the compressive and tensile strength.

Focal points

High compressive and elasticity
High tensile and flexural strength
Corrosion protection
High porosity
More strong and durable
Resistant to environmental deterioration

Parameters	Estimated values
No. of layers	3 - 6
Product Purity	99 %
Surface area	> 120 m^2/g
Bulk density	0.121 g/cc
Thickness	0.8 – 2 nm
Electrical Conductivity	Insulator
Lateral Dimension	5 -10 micrometer

Table - 1.1: various parameters of graphene oxide

2. LITERATURE REVIEW

M. Devasena et al. (2015): Investigated the strength properties of graphene oxide concrete, presents the results on mechanical parameters of graphene oxide concrete and to determine the optimal amount of graphene oxide required to achieve maximum strength of concrete. In three different quantities, graphene oxide was added into the concrete mix and it is varied by 0.05, 0.1, and 0.2 present of cement content. Before crushing all the samples were cured at 7, 14 & 28 days. Test results shown that the use of graphene oxide in concrete improves the compressive, tensile and flexural strength.

K R Mohammad Shareef et al. (2017): Investigate the mechanical properties of graphene oxide concrete and compare the compressive and split tensile strengths of M25 grade concrete with 1% and 2% of graphene oxide replaced by weight of the cement. To study compressive strength 150 mm x 150 mm x 150 mm size of cube is used and for split tensile strength 150 mm dia x 300 mm length of cylinder is used and were casted. At 28 days, 56 days and 90 days of curing, these samples were tested for compressive and tensile strength. Test results shown that the use of graphene oxide in concrete is a good advantage than regular concrete.

Shubham Dahiphale et al. (2018): Studied the properties by replacing the cement by wollastonite upto 30% by weight of cement in this investigation and 0.44 is the w/c ratio. It is observed that there is an increase in compressive strength at 10, 12.5, and 15 percent wollastonite replacement as compared to reference mix and at 15 percent wollastonite replacement optimum quantity was observed.

Supriya Xavier Lopes et al. (2020): In this study, cement is partially replaced by wollastonite at 0%, 10%, 12%, 14%, 16% and 18% in concrete. The effect of wollastonite on strength properties of concrete for M30 grade mix is studied. IS 10262 (2019) is used to carry out the Mix Design. Slump and compaction factor are determined to measure workability. For various mixes of concrete, compression and flexural strengths are determined. Durability in terms of chloride and sulphate resistance is determined by immersing the cubes in HCl and MgSO4 solution for 28 days. The obtained results from various combination of mixes are then compared with conventional concrete mix.

3. MATERIALS AND METHADOLOGY

3.1 Materials

Ordinary Portland Cement: It is a binder material used in the construction field for production of concrete. The most common type of cement used in constructions is Ordinary Portland cement (OPC) which is made by heating limestone and other materials in kiln.

SL.No	Particulars	Obtained results	Permissible limits as per IS 12269-1987
1.	Specific gravity	3.15	3.15
2.	Fineness (%)	8	10%
3.	Normal consistency	33	Minimum 23%
4.	Initial setting time	35	> 30 min
5.	Final setting time	500	< 600 min

Table - 3.1: Physical properties of OPC of 43 grade

Graphene oxide: Graphene Oxide is an extraordinary nano-material which is accessible in powder, sheets, flakes and oxide form. It is strong, elastic and light weight in nature and recently adopted in construction field. It is having great properties which are beneficiary in construction field. When graphene oxide is added to concrete composites which improves the strength parameters of the concrete. It also increases the rate of hydration, reduces permeability and also gives high bond strength to concrete structures. In this paper, to study the strength properties of M25 grade

concrete 0.2% of graphene oxide is used as an additive to the concrete by weight of the cement.

SL.No	Element	%Composition
1.	Carbon	77.5
2.	Sulphur	0.4
3.	Oxygen	16
4.	Hydrogen	1.2
5.	Nitrogen	4.9

Table - 3.2: Chemical composition of Graphene oxide

Fine Aggregate: Locally accessible river sand has been used which is clean, inert and free from organic matter, clay and silt. Sieve analysis and properties of fine aggregate are given in the table 3.3 and 3.4 respectively.

Specific gravity: 2.65
Fineness (%): 2.69
Water absorption (%): 0.9

Coarse Aggregate: Locally accessible crushed stones conforming to graded aggregate of nominal size 12.5 mm as per IS: 383–1970 has been used as coarse aggregate and these are naturally occurring inorganic materials of size retained on 4.75mm sieve.

Specific gravity: 2.64

Wollastonite: Wollastonite is a calcium metasilicate mineral ($CaSio_3$) that may include little amounts of iron, magnesium and manganese substituting for calcium. Wollastonite powder are minerals comprised chemically of calcium, silicon and oxygen. The wollastonite powder contain 86-89% of calcium metasilicate.

Specific gravity: 2.9
Colour: White

Potable Water: Ordinary potable water that is free from all the contaminants, including organic content. The specimen was mixed and cured using turbidity. The water is added into the concrete in the form of water/cement ratio.

3.2 Methodology

Mix design
Mix design as per 10262:2009

Mix proportions
Cement = 394 kg/m^3
Fine aggregate = 790.548 kg/m^3
Coarse aggregate = 1002.35 kg/m^3
W/C ratio = 0.50
Water = 197 litres
394: 790.548: 1002.35 kg/m^3

Sl. No	Particulars	For 1 m^3 concrete	Mix proportions
1	Cement	394 kg	1.00
2	Fine aggregates	790.55 kg	2.00
3	Coarse aggregates	1002.35 kg	2.54
4	Water	197 litres	0.50

Table - 3.3: Mix proportion

3.3 Experimental study

Casting of Specimen: After the mix design of the M25 grade concrete mix proportions were tabulated in table 3.7. The dry materials such as cement, sand & aggregates are mixed. Further, graphene oxide and wollastonite are added into the mixture of dry materials for another 1 minute and finally water is added and mixing continuous for 4 minutes. 5 minutes to be taken for the total mixing of concrete. With the help of 16 mm tamping rod concrete was compacted in 3 layers with 25 strokes which is carried out for each layer and then concrete was allowed to set in the mould for 24 hours. After 24 hours dismantle the cube plates and then kept in the curing chamber until the testing time.

Testing of Specimen: The concrete mix containing combination of wollastonite content which is added in a concrete as a partial replacement of cement by its weight at 0%, 5%, 10%, 15% and 20% with 0.2% of graphene oxide by weight and the specimens were tested. 150mm x 150mm x150mm concrete cubes of various proportions were tested for compressive strength after 28 days curing. Using compression testing machine of 2000KN, compressive strength of cubes is determined. As per IS: 5816 – 1999 testing is carried out for tensile strength and the cylinders of 150mm dia and 300mm length were used to find the tensile strength of concrete for both cases (Graphene oxide concrete and partial replacement of cement by wollastonite). Cylindrical specimen was placed horizontally between the load was applied to the failure of the specimen and the loading surfaces of the compression testing machine. As per IS: 516 – 1959 the concrete beams of size (100 x 100 x 500 mm) were tested for flexural strength.

4 RESULTS AND DISCUSSIONS

4.1 Slump Test

Slump values with various proportions of wollastonite replacing cement in M25 grade graphene oxide concrete were shown in the table 4.1.

Mix Type	Graphene oxide (%)	Wollastonite (%)	Slump (mm)
M1	0.2% added to cement	0	52
M2		5	54
M3		10	57
M4		15	60
M5		20	63

Table - 4.1: Slump values with various proportions of wollastonite in graphene oxide concrete

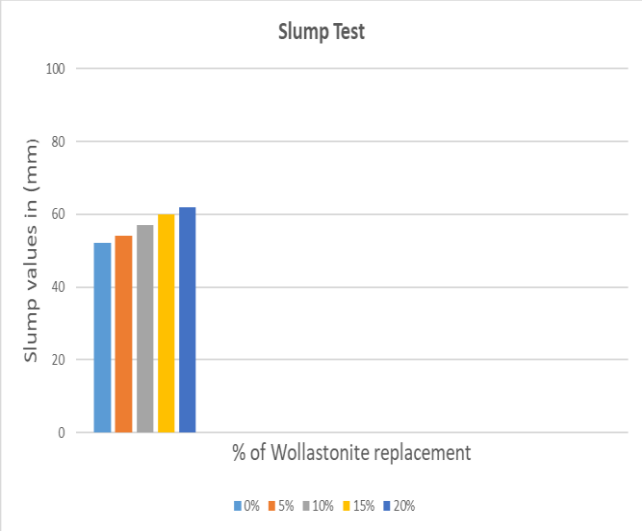

Chart - 4.1: Workability of Concrete with varying % wollastonite content in graphene oxide concrete

4.2 Compaction Factor Test

Compaction factor values with various proportions of wollastonite replacing cement in M25 grade graphene oxide concrete were shown in the table 4.2.

Mix Type	Graphene oxide (%)	Wollastonite (%)	Compaction Factor
M1	0.2% added to cement	0	0.78
M2		5	0.79
M3		10	0.81
M4		15	0.84
M5		20	0.86

Table - 4.2: Compaction factor values with various proportions of wollastonite in graphene oxide concrete

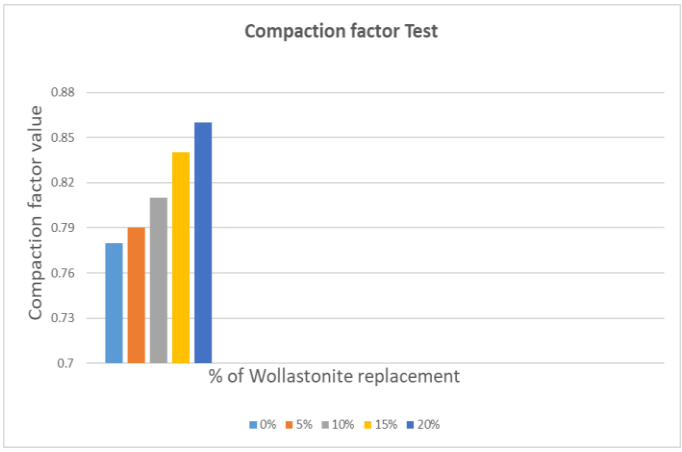

Chart - 4.2: Compaction factor of Concrete with varying % wollastonite content in graphene oxide concrete

4.3 Compressive Strength Test

A cube specimen was cast to find out the compressive strength of the concrete mixtures made with various proportions of wollastonite content replacing by weight of the cement and also 0.2% of graphene oxide used as an admixture which is added to cement and this concrete mixtures was determined at 7, 14 and 28 days of curing. The average of three samples was taken for every testing age. The test results for compressive strength are presented in table 4.2

Mix Type	Graphene oxide (%)	Wollastonite (%)	Average Compressive Strength (MPa)		
			7 days	14 days	28 days
M1	0.2% added to cement	0	19.10	24.80	31.10
M2		5	20.23	26.90	32.20
M3		10	22.39	27.45	33.10
M4		15	23.90	29.50	34.89
M5		20	21.56	28.10	33.79

Table - 4.3: Compressive strength test values with various proportions of wollastonite in graphene oxide concrete

When 5%, 10% and 15% of wollastonite content is used to replace cement in graphene oxide concrete, compressive strength increases, whereas at 20% replacement, compressive strength decreases slightly. Optimum compressive strength is detected at 15% Wollastonite replacement of cement in graphene oxide concrete. As per the codal provisions of IS 456 (2000), the compression strength has reached the expected strength of 25MPa for all the replacement percentages. The compressive strength of concrete mixes at 7, 14 and 28 days results are shown in chart 4.3.

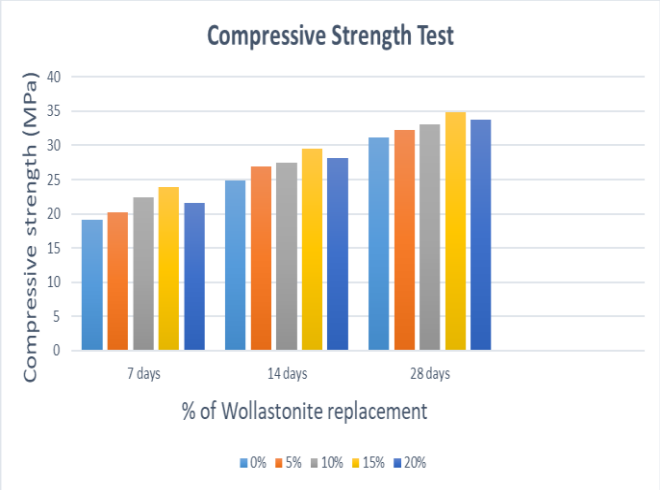

Chart - 4.3: Compressive strength of Concrete with varying % wollastonite content in graphene oxide concrete at 7, 14, 28 days

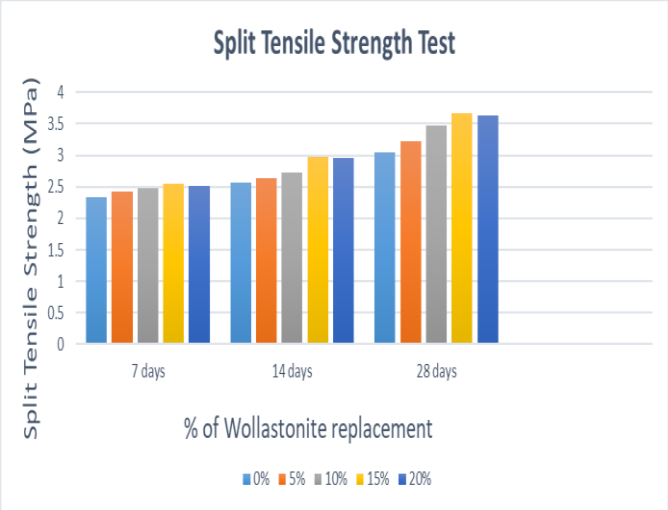

Chart - 4.3: Split tensile strength of Concrete with varying % wollastonite content in graphene oxide concrete at 7, 14, 28 days

4.4 Split Tensile Strength Test

A cylindrical specimen was cast to find out the split tensile strength of the concrete mixtures made with various proportions of wollastonite content replacing by weight of the cement and also 0.2% of graphene oxide used as an admixture which is added to cement and this concrete mixtures was determined at 7, 14 and 28 days of curing.. The average of three samples was taken for every testing age. The test results for compressive strength are presented in table 4.4

Mix Type	Graphene oxide (%)	Wollastonite (%)	Average Split Tensile Strength (MPa)		
			7 days	14 days	28 days
M1	0.2% added to cement	0	2.33	2.57	3.05
M2		5	2.42	2.63	3.23
M3		10	2.48	2.72	3.47
M4		15	2.55	2.98	3.67
M5		20	2.52	2.95	3.63

Table - 4.4: Split tensile strength test values with various proportions of wollastonite in graphene oxide concrete

When 5%, 10% and 15% of wollastonite content is used to replace cement in graphene oxide concrete, tensile strength increases, whereas at 20% replacement, tensile strength decreases slightly. Maximum tensile strength is observed at 15% wollastonite replacement of cement in graphene oxide concrete. The tensile strength of concrete mixes at 7, 14 and 28 days results are shown in chart 4.4.

4.5 Flexural Strength Test

A prism mould specimen was cast to find out the flexural strength of the concrete mixtures made with various proportions of wollastonite content replacing by weight of the cement and also 0.2% of graphene oxide used as an admixture which is added to cement and this concrete mixtures was determined at 7, 14 and 28 days of curing.. The average of three samples was taken for every testing age. The test results for flexural strength are presented in table 4.4

Mix Type	Graphene oxide (%)	Wollastonite (%)	Average Flexural Strength (MPa)		
			7 days	14 days	28 days
M1	0.2% added to cement	0	3.65	4.30	4.74
M2		5	4.13	4.74	5.24
M3		10	4.23	4.89	5.53
M4		15	4.54	5.13	5.76
M5		20	4.43	5.02	5.67

Table - 4.5: Flexural strength test values with various proportions of wollastonite in graphene oxide concrete

When 5%, 10% and 15% of wollastonite content is used to replace cement in graphene oxide concrete, flexural strength increases, whereas at 20% replacement, flexural strength decreases slightly. Maximum flexural strength is observed at 15% Wollastonite replacement of cement in graphene oxide concrete. As per the codal provisions of IS 456 (2000), the flexural strength has reached the expected strength of 3.83MPa for all the replacement percentages. The flexural

strength of concrete mixes at 7, 14 and 28 days results are shown in chart 4.5.

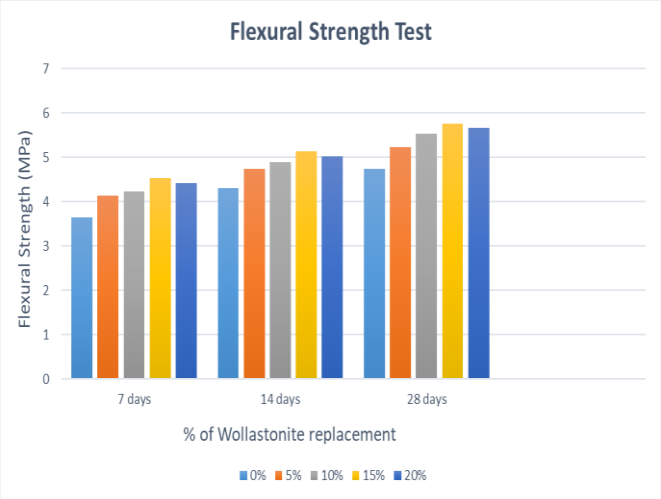

Chart - 4.3: Flexural strength of Concrete with varying % wollastonite content in graphene oxide concrete at 7, 14, 28 days

5. CONCLUSIONS

1. For M25 grade concrete, the slump value and compacting factor value of graphene oxide concrete increases as the wollastonite content increases, and the workability achieves its maximum at 20% replacement.

2. There is a rise in compressive strength at 5%, 10% and 15% of wollastonite content replacement in graphene oxide concrete by weight of the cement and at 20% replacement, compressive strength decreases slightly. Maximum compressive strength is observed at 15% of wollastonite content replacement in graphene oxide concrete.

3. There is a rise in tensile strength at 5%, 10% and 15% of wollastonite content replacement in graphene oxide concrete by weight of the cement and at 20% replacement, tensile strength decreases slightly. Maximum tensile strength is observed at 15% of wollastonite content replacement in graphene oxide concrete.

4. There is a rise in flexural strength at 5%, 10% and 15% of wollastonite content replacement in graphene oxide concrete by weight of the cement and at 20% replacement, flexural strength decreases slightly. Maximum flexural strength is observed at 15% of wollastonite content replacement in graphene oxide concrete.

5. Hence from the above test results, we can conclude that, by replacing 15% of wollastonite to cement, strength of the graphene oxide concrete is increased.

6. Test results indicated that wollastonite can efficiently substitute cement without affecting mechanical parameters of concrete. Replacing 15% cement even enhance the longevity of concrete structures. The gainful utilization of wollastonite as building material will contribute to sustainable development of country by reducing greenhouse emissions and depletion of natural resources.

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