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by Sagar R R

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.

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CHAPTER 1

INTRODUCTION

1.1 General

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 $Si0_2$. In a pure $CaSi0_3$, each part forms almost half of the mineral by weight percentage. It is a white mineral highly modulus.

1.2 Materials

1.2.1 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.

1.2.1 Wollastonite

We need to discover alternate sources to deal with environmental issues. From many general research conclude that, adding mineral admixtures to 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 and it is chemically called as 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. Even at high temperature wollastonite was originate to possess reinforcing quality as well as chemical resistance. It is white mineral highly modulus.

1.3 Applications of Graphene Oxide

1] Graphene Cement

2] Protective Paints

3] Spray-on Solar Panels

4] Transparent Screens

5] LED Lighting

6] Precast products

7] Marine Construction

9] Sensors

10] Storage cylinders

Properties of Graphene Oxide

It is the lightest and strongest material

It has widest absorption spectrum and largest optical absorption

Without scattering it travels sub-micrometer distance

It has high electrical and thermal conductivity

Advantages of Graphene Oxide

High compressive and elasticity

High tensile and flexural strength

Corrosion protection

High porosity

More strong and durable

Resistant to environmental deterioration

Table 1.1 various parameters of graphene oxide

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

1.4 Objective

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

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE

2.1.1 M. DEVASENA, J. KARTHIKEYAN, in their paper entitled **"INVESTIGATION ON 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.

The following conclusions were made

- The addition of graphene oxide in to the concrete increases the compressive, tensile and flexural strength of the material.
- 0.1% of graphene oxide improves the compressive strength at 11% and flexural strength at 4%.
- The addition of graphene oxide in to the concrete increases the density of the cement matrix and improves the degree of hydration of the cement paste, resulting in a more durable product.

2.1.2 MOHAMMAD SHAREEF K R, SHAIK ABDUL RAWOOF, K SOWJANYA, in their paper entitled **"A FEASIBILITY STUDY ON MECHANICAL PROPERTIES OF CONCRETE WITH GRAPHENE OXIDE"** aim to 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.

The following conclusions were made

- Graphene oxide improves the compressive and flexural strength and the samples were tested with graphene oxide with 1% to 2% by weight of the cement, to obtain high strength for M25 grade of concrete.
- At 28 days of curing, compressive strength of concrete increases to 7% at 1% graphene oxide content and it increases to 17% at 2% graphene oxide content as compared to the reference mix.
- At 56 days of curing, compressive strength of concrete increases to 10.44% at 1% graphene oxide content and it increases to 17.63% at 2% graphene oxide content as compared to the reference mix.
- At 90 days of curing, compressive strength of concrete increases to 9.18% at 1% graphene oxide content and it increases to 15.33% at 2% graphene oxide content as compared to the reference mix.

- At 28 days of curing, tensile strength of concrete increases to 17.41% at 1% graphene oxide content and it increases to 28% for 2% graphene oxide content as compared to the reference mix.
- At 56 days of curing, tensile strength of concrete increases to 24.49% at 1% graphene oxide content and it increases to 35.55% at 2% graphene oxide content as compared to the reference mix.
- At 90 days of curing, tensile strength of concrete increases to 21.30% at 1% graphene oxide content and it increases to 48% at 2% graphene oxide content as compared to the reference mix.

2.1.3 SHUBHAM DAHIPALE, KABIR KHAN, KSHITIJ TIKHE, in their paper entitled **"PROPERTIES OF CONCRETE CONTAINING WOLLASTONITE"** wollastonite was utilized to substitute the cement in concrete mix at 0%, 5%, 10%, 12.5%, 15%, 17.5%, 20%, 25%, 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.

The following conclusions were made

- There was slightly decreases at 5 percent wollastonite replacement in compressive strength but at 10, 12.5 & 15 percent wollastonite replacement there was significantly increases in compressive strength.
- The maximum quantity of cement that can be replaced with wollastonite is 15%.
- The wollastonite contains silica content which is responsible for imparting strength to the concrete.

2.1.4 SUPRIYA XAVIER LOPES, CHIKKANAGOUDAR R S, in their paper entitled **"EFFECT OF WOLLASTONITE AS PARTIAL REPLACEMENT OF CEMENT ON MECHANICAL AND DURABILITY PROPERTIES OF CONCRETE"** 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.

The following conclusions were made

- The addition of wollastonite into the concrete, workability of freshly prepared concrete for M30 mix increase the stiffness.
- 14 to 16 percent addition of wollastonite increase the compressive strength to maximum.
- Maximum flexural strength is observed with the addition of 16% of wollastonite.

2.2 SUMMARY OF THE LITERATURE

The detailed literature review concluded that the optimum quantity of Graphene oxide (0.2%) can be used as an additive to the concrete which improves the mechanical properties such as compressive, flexural and tensile strength of the concrete and also increases the density of the cement matrix and improves the degree of hydration of the cement paste, resulting in a more durable product.

The wollastonite is used as a partial replacement to the cement up to 20%. The use of wollastonite as partial replacement reduces the cost and also saves the cement thereby reduces pollution and making the environmental green and also wollastonite contains silica content which is responsible for imparting strength to the concrete.

CHAPTER 3

MATERIALS AND METHODOLOGY

This part describes the various materials that were used in the experiment. It also briefly discusses the methodology adopted to carry out the various test as per relevant IS codes.

3.1 MATERIALS

Ordinary Portland Cement of (43 grades), graphene oxide, fine aggregate, coarse aggregate, wollastonite and potable water for mixing.

3.1.1 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.

Table 3.1 Physical properties of OPC of 43 grade

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

3.1.2 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.

Table 3.2 Chemical composition if Graphene oxide

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

3.1.3 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.

Table 3.3 Sieve analysis of Fine aggregates

Sieve size (mm)	Percentage passing	ZoneII Gradation	Remarks
10	100	100	Conforming to grading zone II of Table 4 of IS 383-1970
4.75	94.80	90-100	
2.36	91.80	75-100	
1.18	83.20	55-90	
0.6	57.40	35-59	
0.3	24.60	8-30	
0.15	3.90	0.1	

Table 3.4 Physical Properties of Fine aggregates

Physical properties	Indian Codes	Obtained Results	Standard Limits
Specific gravity	IS2386(Part-3)- 1963	2.65	> 2.5
Fineness (%)	IS2386(Part-3)- 1963	2.69	2.63 - 3.2
Water Absorption (%)	IS2386(Part-3)- 1963	0.9	0.5% - 1%

3.1.4 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

Table 3.5 Sieve analysis of Coarse aggregates

<table>
<tr><th rowspan="2">Sieve size in mm</th><th rowspan="2">% Passing</th><th colspan="2">IS 383-1970 Specification</th><th rowspan="2">Remarks</th></tr>
<tr><th>Graded</th><th>Single</th></tr>
<tr><td>40</td><td>100</td><td>100</td><td>100</td><td rowspan="5">Conforming to 20mm sized aggregates</td></tr>
<tr><td>20</td><td>90</td><td>95-100</td><td>85-100</td></tr>
<tr><td>10</td><td>3</td><td>25-55</td><td>0-20</td></tr>
<tr><td>4.75</td><td>0</td><td>0-10</td><td>0-5</td></tr>
<tr><td>PAN</td><td>-</td><td>-</td><td>-</td></tr>
</table>

3.1.5 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

Table 3.6 Chemical composition of Wollastonite

SL.No	Element	% Composition
1.	SiO_2	50.80
2.	CaO	40.88
3.	Fe_2O_3	0.11
4.	TiO_2	0.04
5.	Al_2O_3	0.27
6.	MgO	3.05
7.	LOI	4.85

3.1.6 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

3.2.1 Mix design

Mix design as per 10262:2009

1. Condition for proportioning

Grade designation: M25

Type of cement: OPC 43 Grade

Min. cement content: 300 Kg/m^3

Max. nominal size of aggregate: 20mm

Max. w/c ratio: 0.50

Exposure condition: Severe

Workability: 100mm

Max. cement content: 450 Kg/m^3

Type of aggregate: Crushed angular

2. Test data for materials

Cement used: OPC 43 grade

Sp. gravity of cement: 3.15

Sp. gravity of fine aggregate: 2.65

Sp. gravity of coarse aggregate: 2.64

Water absorption of fine aggregate: 0.9%

Water absorption of coarse aggregate: 0.5%

Sieve analysis of fine aggregate: Confirming grading zone II of IS 383-2002 table 4

Sieve analysis of coarse aggregate: Confirming 20mm down size

3. Target Mean Strength of the Mix Proportion

$F_{ck}' = F_{ck} + 1.65S$

$S = 4\ N/mm^2$ (from table 1, IS 10262:2009)

Characteristic strength @ 28 days = 25 N/mm^2

Target mean strength = 31.6 N/mm^2

4. W/C Ratio

Max. W/C ratio = 0.50 (from table 5 IS 456)

Assume W/C ratio as 0.5

5. Water Content

Max. water content = 186 litre/m^3 (For 25-50 mm slump) (from table 2, IS 10262:2009)

For every 25mm slump 3% additional water is required.

For 100 mm slump = 186 + 186 × (6/100) = 197.16 lit/m^3

6. Cement Content Calculation

W/C ratio = 0.50

Cement content = $\frac{197.16}{0.50}$ = 394 kg/m^3

From Table 5 of IS 456,

Min. cement content for 'severe' exposure condition = 300 kg/m^3

394 kg/m^3 > 300 kg/m^3, hence, O.K.

7. Quantity of fine aggregate and coarse aggregate content

Vol. of coarse aggregate = 0.62 m^3 for w/c of 0.5 (from table, IS 10262)

Vol. of coarse aggregate = 0.62 × 0.9 = 0.56 m^3 (for pumpable concrete)

Vol. of fine aggregate = (1-0.56) = 0.44 m^3

8. Calculation of mix proportion

Vol. of concrete (a) = 1 m3

$$\text{Vol. of Cement (b)} = \frac{\text{Quantity of cement}}{\text{Sp. gravity of cement}} \times 1/1000$$

$$= 394/3.15 \times 1/1000 = 0.125\ m^3$$

$$\text{Vol. of water (c)} = \frac{\text{Quantity of water}}{\text{Sp. gravity of water}} \times 1/1000$$

$$= 197.16/1 \times 1/1000 = 0.197\ m^3$$

Vol. of all aggregate (d) = [a- [b + c]

= [1 – [0.125 + 0.197]

= 0.678 m^3

Quantity of coarse aggregate = d x Vol. of coarse aggregate x Sp. gravity × 1000

= 0.678 x 0.56 x 2.64 x 1000

= 1002.35 kg/m^3

Quantity of fine aggregate = d x Vol. of fine aggregate x Sp. gravity × 1000

= 0.678 x 0.44 x 2.65 x 1000

= 790.548 kg/m^3

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

Table 3.7 Mix proportion

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

3.2.2 Experimental study

3.2.2.1 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.

3.2.2.2 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.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Tests on Concrete

4.1.1 Slump Test

The term “workability” related with freshly prepared concrete and this can be defined as how easily concrete can be placed, mixed, finished, compacted. The frequent way to find ‘workability’ of concrete in a lab or at site of work is the slump test which gives a sign of consistency of concrete. Slump is defined as the vertical settlement of a standard cone of freshly prepared concrete.

Apparatus:

Weighing balance, tray, slump cone, tamping rod, concrete mixer.

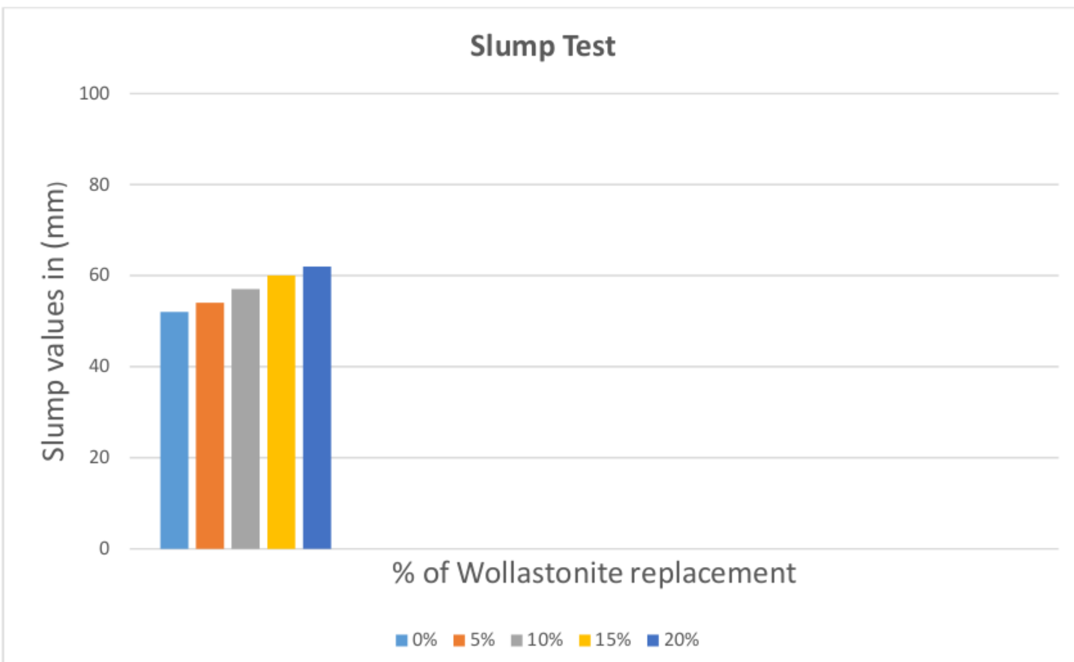
Procedure:

- Take Mix proportion 1: 2: 2.54, W/C ratio = 0.5.
- Fresh the inner surface of the mould completely and it should be free from moisture content.
- In a horizontal, smooth rigid and non-absorbent surface mould can be placed.
- With the compaction of each layer fill the freshly prepared concrete into the mould in a 4 layers by tamping with 25 hits using tamping rod. When the top layer has excesses, extra concrete removed and leveled with a trowel.
- Take out the mould vertically upwards, being careful not to disturb the concrete.
- Slump of concrete is defined as a difference in height measured in millimeters.

Table 4.1 Workability (Slump test) Results

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

Graph 4.1 Comparison of slump values



4.1.2 Compaction Factor Test

When the nominal size of aggregate does not exceed 40mm, the compaction factor is utilized to find the workability of freshly prepared concrete. The density of concrete is measured by the compaction factor test.

Apparatus:

Weighing balance, Compaction Factor Apparatus, tamping rod, trowels.

Procedure:

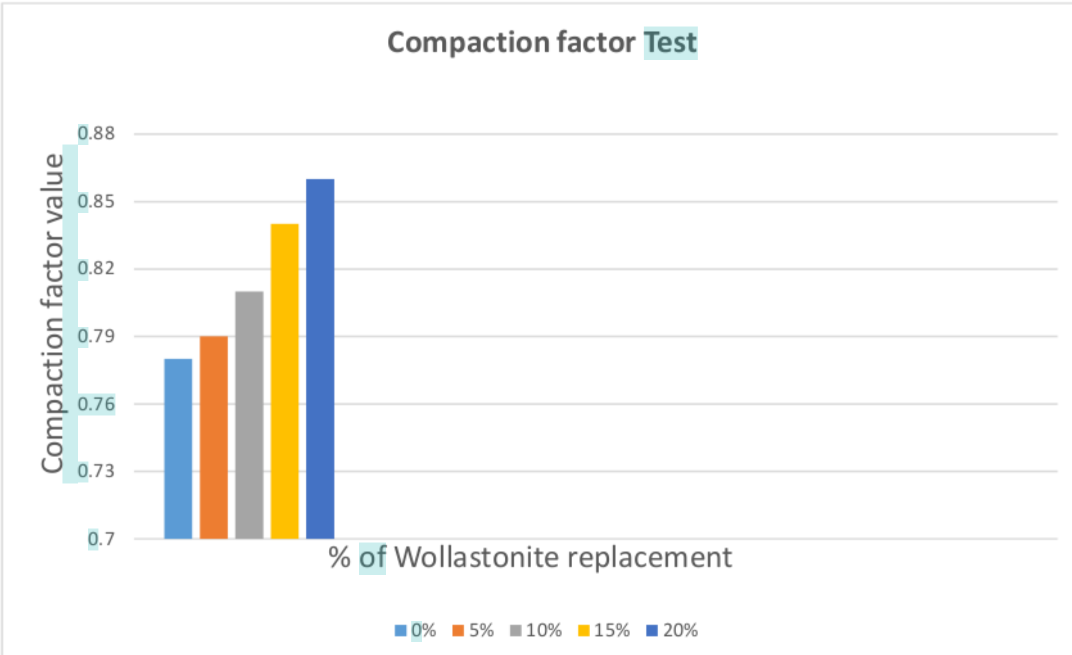
- Fasten the hopper doors and grease the inside surfaces of the hoppers and the cylinder.
- Empty cylinder appropriately weighed (W_1 kg).
- Place the cylinder on the base.
- Mix dry materials until the mixture appears uniform in color and then added with water until the concrete seems to be homogeneous and consistency.
- Without compacting fill the concrete in upper hopper softly with the help of trowel.
- Open the upper hopper trap door which allows the concrete to drop into the lower hopper which brings the concrete into normal compaction.
- After the concrete comes to rest immediately open the lower hopper trap door which allows the concrete to drop into the empty cylinder which brings the concrete into normal compaction.
- Using trowel take out the excess of concrete above the cylinder.
- Measure the weight of the cylinder filled with partially compacted concrete (W_2 kg).

- Top-up the cylinder with same sample of concrete which is used in the compaction factor test in 4 layers by compacting each layer with tamping rod for 25 strokes to get full compaction of concrete.
- Finally take weight of the cylinder completely filled with fully compacted concrete (W3 kg).
- For different proportions repeat the same procedure.

Table 4.2 Compaction Factor Test Results

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

Graph 4.2 Comparison of Compaction factor values



4.1.3 Compression Strength Test

To identify the quality of cement concrete work on testing hardened concrete plays a significant character. The compressive strength of concrete is the most important factor in its application in structures. The important features of the strength of hardened concrete strength refers to its ability to withstand forces. At a given rate of loading the load causes the specimen to fail per unit cross section on compression is called compressive strength test.

Apparatus:

Compression testing machine, cube moulds, weighing machine, tamping rods.

Procedure:

- 3 cube moulds are taken for each proportions. Fix the mould with the base plate to ensure that it is kept together tightly.

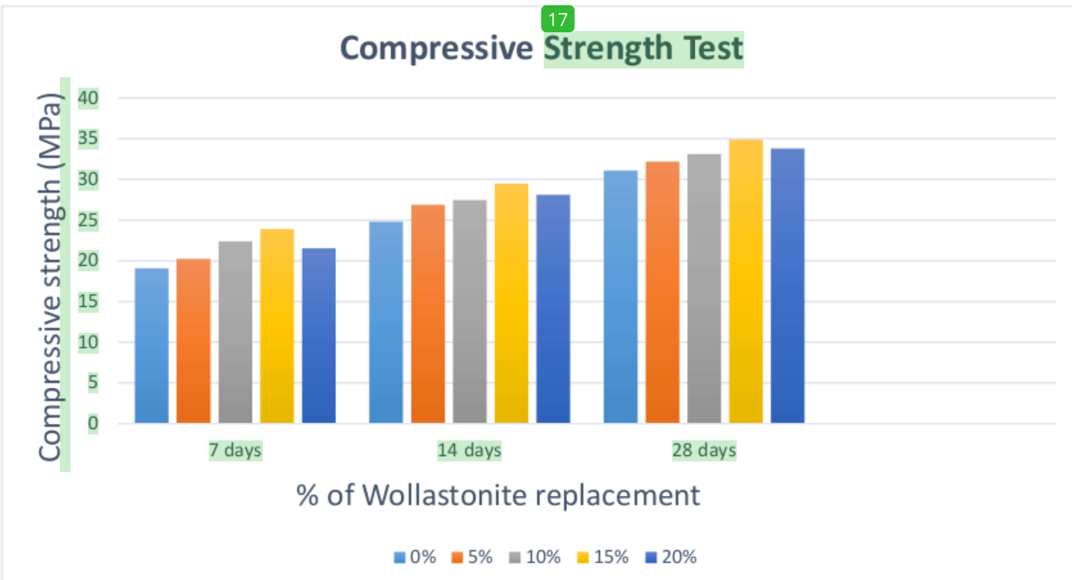
- Freshen the internal surface of the mould and check the joints are perfectly tighten or not.
- Fill the cube moulds with accurately prepared concrete for the given mix.
- In 3 layers hand compaction is to be done using tamping rod by means of 25 blows each layer to be compacted.
- Using a trowel, level the concrete at the top of the mould and for identification of the specimen proper mark is to be given.
- Keep the cubes in lab for at least 24 hours.
- Dismantle the cube mould plates after 24 hours and taken out the concrete cubes carefully without damaging the specimen.
- Immerse the cubes in a water filled curing tank and up to 28 days kept for curing.
- The cubes were tested after 7, 14 and 28 days of curing to find the compressive strength.
- Calculate the average value of the compressive strength for each cube for each proportions.

Table 4.3 Compressive Strength Test Results

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

When 5%, 10% and 15% Wollastonite 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 Graph 4.3.

Graph 4.3 Comparison of Compressive Strength values



4.1.4 Split Tensile Strength Test

Because of its brittle nature and low tensile strength, concrete is not usually expected to withstand direct tension. Tensile strength must be determined in order to calculate the load at which the concrete members may crack.

Apparatus:

Weighing machine, cylindrical moulds, compression testing machine, tamping rods.

Procedure:

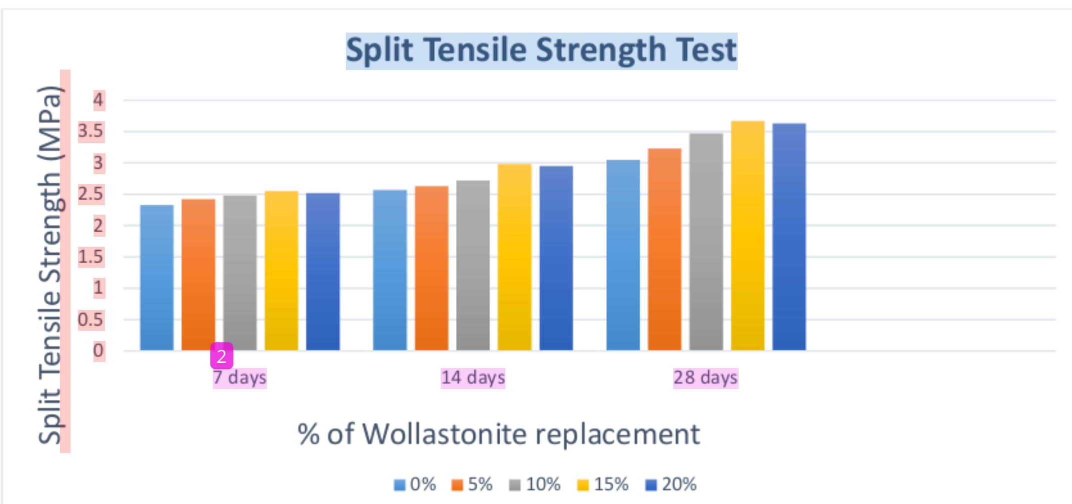
- 3 cylindrical moulds taken for each proportions. Fix the mould with the base plate to ensure that it is kept together tightly.
- Freshen the internal surface of the mould and check the joints are perfectly tighten or not.
- Fill the cylinder moulds with accurately prepared concrete for the given mix.
- In 3 layers hand compaction is to be done using tamping rod by means of 25 blows each layer to be compacted.
- Using a trowel, level the concrete at the top of the mould and for identification of the specimen proper mark is to be given.
- Keep the cylinders in lab for at least 24 hours.
- Dismantle the cylinder mould plates after 24 hours and taken out the concrete cubes carefully without damaging the specimen.
- Immerse the cylinders in a water filled curing tank and kept for curing up to 28 days.
- The cylinders were tested after 7, 14 and 28 days of curing to find the tensile strength.
- Calculate the average value of the tensile strength for each cylinder for each proportions.

Table 4.4 Tensile Strength Test Results

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

When 5%, 10% and 15% wollastonite 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 Graph 4.4.

Graph 4.4 Comparison of Split Tensile Strength values



4.1.5 Flexural Strength Test

In compression, concrete is relatively strong but weak in tension because steel bars are provided to resist all tensile stresses. Due to rusting of steel reinforcement, drying shrinkage, temperature gradient, tensile stresses are probable to develop in concrete.

Apparatus:

1. Universal Testing Machine
2. Prism mould

Procedure:

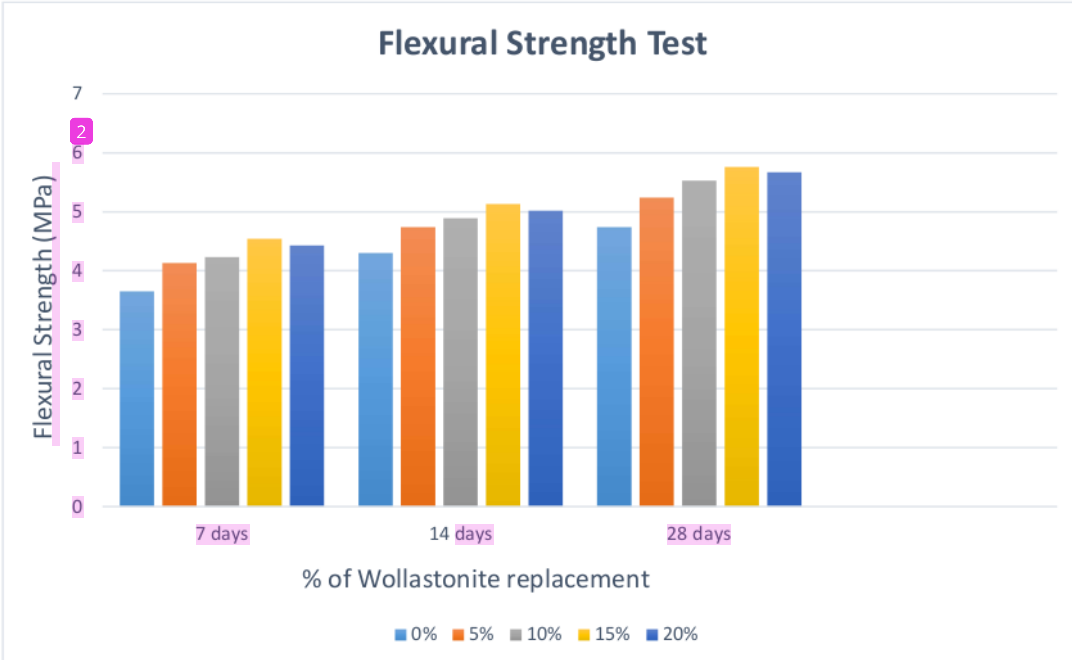
- Before testing, test samples were kept in water for 48 hours at a temperature of 24^{o} C to 30^{o} C. They were tested immediately after removal from the water.
- Before testing, make a note on of the dimensions of each specimen.
- The surface of the loading rollers and supporting is wiped and clean, and any loose sand or other material that has been taken out from the top of the specimen where the rollers will come into contact with them.
- The specimen is then kept in the machine so that the load is evenly distributed.
- The axis of the specimen and the loading device are precisely aligned.
- Load is applied without shock and gradually increases at a rate of the sample. The loading rate is 4 kN/min and 18 kN /min for the 15 cm and 10 cm sample respectively.
- The load is gradually increases until the sample fails, at which point the maximum load applied to the sample is note down.

Table 4.5 Flexural Strength Test Results

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

When 5%, 10% and 15% Wollastonite 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 Graph 4.5.

Graph 4.5 Comparison of Flexural Strength values



CHAPTER 5

CONCLUSIONS

- 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.
- There is a rise in compressive strength at 5, 10 and 15% wollastonite content replacement of cement in graphene oxide concrete and at 20% replacement, compressive strength decreases slightly. Maximum compressive strength is observed at 15% wollastonite replacement of cement in graphene oxide concrete.
- There is also rise in flexural and tensile strength at 5%, 10% and 15% wollastonite replacement of cement in graphene oxide concrete and at 15% replacement, flexural strength and also tensile strength decreases slightly. Maximum flexural and tensile strength is observed at 15% wollastonite replacement.
- 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.
- 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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