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Research paper



Comparative Microstructural Study on Mechanical Properties of Concrete Enhanced with Graphite and Graphene Compound

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Abstract

The present study is based on nano technology and came up with the idea of introducing nanoparticles in the raw materials used for construction. Nano materials are available in three principal shapes 0, 1 and 2 Dimensional nanoparticles. 0D and 1D nanofibers are such as carbon nanotubes and nanosilica compounds. This study has investigated the physical and chemical properties of graphite and graphene compound and its applicability in construction industry. Graphene has created interest as it is believed to improve the strength of concrete allowing the possibility of controlling properties of concrete. In this work graphene is used as a reinforcing additive in cement-based mortar and concrete. Own Graphene compound is prepared using conventional graphite and concentrated hydrogen peroxide in the laboratory due to the unavailability of graphene. As a part of microstructural investigation, SEM and EDS analysis on graphite and graphene compounds before and after implementation are carried out in the laboratory. Then the two compounds are replaced as a part of small percentage in cement mortar cubes casted for various proportions. The mechanical properties of cement-based composites are studied after incorporating of graphite and graphene compounds at low dosages in concrete and then the results are compared.

Keywords: *Graphite, Graphene, Cement, Fine and Coarse aggregate, SEM, EDS, Mechanical properties.*

1. Introduction

The nanotechnology has moved the world in all aspects. The use of nano particles in construction materials is another innovative move. This introduces the physical, chemical and mechanical properties of nanoparticles [1] [4] [8]. A microscopic level of study is required to be done on the factors affecting the mechanical properties of concrete between the reactive paste and inert aggregates. Inertness is permeable to air and water properties which has greater impact on strength and durability of concrete structures. In the present study, an attempt is made to use this nano technology in concrete. This research work is done in a perspective that if use of nanoparticles in concrete could reduce the porous nature of concrete, improve the compressive strength of concrete and make it more durable. The graphene is chemically composed of carbon, oxygen and hydrogen, a three-dimensional structure composed of millions of layers of graphite. The preparation of graphene material is discussed, and its properties are studied. Graphite layers are exfoliated in layers to produce graphene. Graphene is available in different forms like 0D, 1D and 2D. Graphene is nothing but an allotrope of graphene. It is made from graphite powder. Graphite is exfoliated in layers to produce graphene [2] [5] [6] [7]. Graphene has proven to be the strongest material even tougher than diamond. The elastic module of graphene is around 1000 MPa. Hence, this research is a trail to impart its strength to concrete. This material is rarely available in India [3] [9].

The procedure for the preparation of graphene compound is arrived by referring the literature. Graphite is mixed with concentrated hydrogen peroxide in equal proportions. There is an exothermic reaction liberating vapours which measure a temperature of 110 to 120 ^{0}C. The vapours are cooled down and then the graphene compound is produced. Firstly, graphene compound is tried in cement by replacing cement at various proportions like 1%, 2% ,3%, 4% and 5%. For the proportions of mortar cubes are casted and cured for 28 days. The compressive strengths obtained are compared with conventional mortar cube strengths. Concrete specimens are casted by replacing cement with graphite compounds by 5%. They are cured for 28 days and tested for mechanical properties. They are compared with conventional concrete specimens. Pre - post analysis of SEM and EDS are conducted and discussed the results.

2. Materials and Methods:

The materials used in this experimental work are Ordinary Portland Cement (53grade), Coarse Aggregate of 20mm size, Fine Aggregate of Zone-II and potable Water.

a) Cement: properties of cement are listed in table 1

Ordinary Portland cement of 53 grade of a single lot is used throughout the investigation. Physical properties of cement have been compared with the requirements of IS: 12269:2013. All the required tests on cement are carried out as per recommendation of IS: 4031-1988. Care has been taken while preserving the cement in a store with air tight condition to prevent it from moisture, humidity.

Table 1: Properties of cement

Property	Units	Value Obtained	Limiting value as per IS:12269: 2013 Specifications
Specific gravity	—	3.05	—

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Normal consistency	%	25.5	<30
Setting time			
Initial	Minutes	45	30
Final	Minutes	550	600 (max)

b) Fine aggregate: properties of fine aggregates are listed below. Locally available river sand is used as fine aggregate in this investigation. The sand has clay, silt and other impurities. Based on the particle size distribution as per IS:383-1970, fine aggregate comes under Zone-II. Fineness modulus of fine aggregate is 2.98.

c) Coarse aggregate: properties of coarse aggregates are listed below.Locally available 20mm coarse aggregate is used in this investigation. It is free from impurities like dust, clay particles and organic matter. The fineness modulus of coarse aggregate is 6.26, as per IS:383-1970.

The physical properties of fine and coarse aggregates are shown in table 2.

Table 2: Physical Properties of Fine and Coarse Aggregate

Characteristics	Results Obtained	
	Fine Aggregate	Coarse Aggregate
Grading	Zone II (IS:383-1970)	--
Fineness Modulus	2.98	6.26
Specific Gravity	2.64	2.67
Density (loose) KN/m^3	15.23	16.19
Water Absorption (%)	1.2	0.6
Moisture Content (%)	0.35	Nil

d) Water : Water is used for both the mixing of concrete and curing of beam and cube Specimens in present investigation. Water is free from deleterious materials. Curing of all the specimens were done by immersing in curing tanks by frequent change in water.

e) Procedure for preparation of graphene compound:

- Graphite powder is taken as input product.
- 50% conc.H_2O_2 is used as reactant.
- A few amounts of conc.H_2O_2 is taken in a glass jar.
- Graphite powder is added in a proportion of 1:1.
- The mixture is stirred well to initiate the reaction.
- Then an exothermic reaction could be observed.
- Emitting vapours and liberating heat measures up to temperature of 110^0c to 120^0c
- This is continued until the reaction starts retarding.
- Then it is oven dried and the powder is collected.
- This drying process lasts for 15-20 minutes

f) Methodology adopted for performing the compression strength test

1. The compressive strength tests on mortar cubes of size (70.7mm X 70.7mm X 70.7mm) conducted as per Code of Practice **IS: 4031 – (Part-6)**
2.
3. The compressive tests on concrete Specimens prepared are conducted as per code of practice **IS:516 - 1959.** The typical blocks are (150 x 150 x 150mm) cubes.

g) Experimental Program

- Three conventional cement mortar cubes are casted with cement, sand and water as per Code of Practice IS: 4031 – (Part-6), and they are cured for 28 days.
- These mortar cubes are tested in the compression testing machine as per Indian Standard code of practice.
- 15 Mortar cubes are casted by replacing cement with graphene compound in the proportions of 1%,2%,3%,4% and 5%, and they are cured for 28 days.
- 15 Mortar cubes are casted by replacing cement with graphite compound in the proportions of 1%,2%,3%,4% and 5%, and they are cured for 28 days.
- These mortar cubes are tested in the compression testing machine as per Indian Standard code of practice.
- The results are compared with that of the conventional mortar cubes results.
- Conventional concrete specimens of nominal mix (1:2:4) for various sizes (i.e., cubes, prisms and cylinders) are casted as per code of practice IS:516 – 1959, and they are cured for 28 days.
- They are tested in the compression and flexural testing machine as per Indian Standard code of practice.
- Concrete specimens are casted by above mentioned mix with replacing cement with graphene compound by a proportion of 5%, and they are cured for 28 days.
- Concrete specimens are casted by above mentioned mix with replacing cement with graphite compound by a proportion of 5%, and they are cured for 28 days.
- They are tested in the compression testing machine as per Indian Standard code of practice.
- The results are compared with the conventional specimen's results.

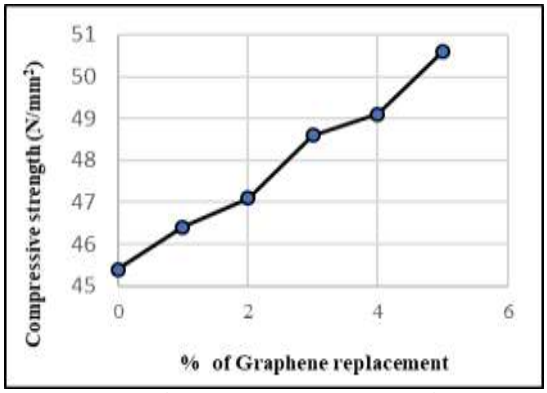
4. Results and Discussions:

a) Study on mortar cubes : Different combination of mixes tried by replacing various proportions of cement with graphene and graphite such as 1%, 2%, 3%, 4%, and 5% and mortar cubes are casted. They are listed down in the table 3 and the corresponding compressive strengths of various mixes are noted down. Their compressive strengths are compared with compressive strength of conventional mortar cubes.

Table 3: Avg. Compressive strength results for mortar cubes (3 Nos.) at 28 days

S. No	Types of mix	Replacement percentage	Avg. Stress (N/mm^2)
1	M1	Conventional	45.4
2	M2	Graphene [5%]	50.6
3	M3	Graphene [4%]	49.1
4	M4	Graphene [3%]	48.6
5	M5	Graphene [2%]	47.1
6	M6	Graphite [1%]	46.4
7	M7	Graphite [%]	42.30
8	M8	Graphite [2%]	42.80
9	M9	Graphite [3%]	41.20
10	M10	Graphite [4%]	40.20
11	M11	Graphite [5%]	38.60

Mortar cubes of graphene compound showed a slight increase in compressive strength when compared to conventional mortar cubes with slight increase of graphene from table-5 and graph-1 as mentioned.



Graph 1 Comparison of compressive strength results for mortar cubes at 28 days

b) Study on concrete cubes : Three concrete cubes are casted for nominal mix of (1:2:4) by replacing cement with graphene and graphite compound by a proportion of 5%. The compressive strength values are given in table-4 and are compared with the conventional cube strength results.

Table 4: Avg. Compressive strength results for concrete cubes (3 Nos.) at 28 days

S. No	Types of mix	Replacement percentage	Avg. Compressive strength (N/mm^2)
1	CM1	Conventional	31.03
2	CM2	Graphene [5%]	36.6
3	CM3	Graphite [5%]	27.93

Concrete cubes of graphene compound showed a remarkable improvement when compared to graphite and conventional concrete cubes for a proportion of replacement by 5% with cement as shown in table-4.

c) Study on concrete cylinders : Three concrete cylinders are casted for nominal mix of (1:2:4) by replacing cement with graphene and graphite compound by a proportion of 5%. The split tensile strength values are given in table-5 and are compared with the conventional specimen's strength results.

Table 5: Avg. Split tensile strength results for concrete cylinders (3 Nos.) at 28 days

S. No	Types of mix	Replacement percentage	Avg. Split tensile strength (N/mm^2)
1	CM1	Conventional	2.35
2	CM2	Graphene [5%]	2.46
3	CM3	Graphite [5%]	1.94

Cylindrical specimens of graphene compound showed a slight improvement when compared to graphite and conventional concrete cylinder for a proportion of replacement by 5% with cement as shown in table-5.

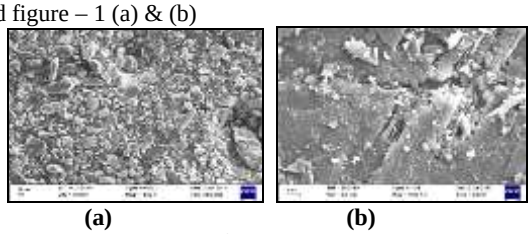
d) Study on concrete prisms : Three concrete prisms are casted for nominal mix of (1:2:4) by replacing cement with graphene compound by a proportion of 5%. The flexural strength values are given in table-6 and are compared with the conventional specimen's strength results.

Table 6: Avg. Flexural strength results for concrete prisms (3 Nos.) at 28 days

S. No	Types of mix	Replacement percentage	Avg. Flexural strength (N/mm^2)
1	CM1	Conventional	4.23
2	CM2	Graphene [5%]	4.46
3	CM3	Graphite [5%]	4.35

Concrete prisms of graphene compound showed a slight improvement when compared to graphite and conventional concrete prisms for a proportion of replacement by 5% with cement as shown in table-6.

e) SEM analysis : Pre - SEM analysis was conducted on graphite powder and graphene compound and presented in the below mentioned figure – 1 (a) & (b)



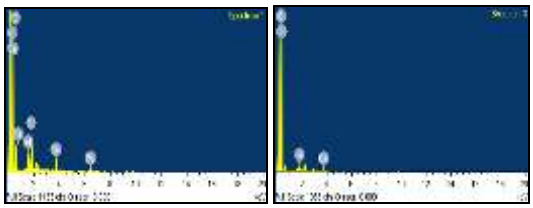
(a) **(b)**

Figure 1 SEM analysis of Graphite and Graphene compound

From the figure – 1 (a) & (b), graphite powder looks like pellets of rock and the particles looks very coarser, segregated and flaky also dispersed. The other way graphene-based compound looks more complex and the bonding seems strong. In continuation of this it is layered and looks denser when compared to that of graphite.

f) EDS analysis

Pre - EDS analysis was conducted on graphite powder and graphene compound and presented in the below mentioned figure – 2 (a) & (b)



(a) **(b)**

Figure 2 EDS analysis of Graphite and Graphene compound

From the figure – 2 (a) & (b), graphite powder is a carbon allotrope and its major composition is of carbon which is around 66%. It has also oxygen in addition to carbon up to 24%. If you consider the graphene-based compound, it comprises of carbon in major proportions it is up to 97% and here it was observed oxygen is completely absent in this compound.

g) Post – SEM & EDS analysis : Post – SEM & EDS analysis was conducted on graphene compound combined with cement are presented in the below mentioned figure – 3 (a) & (b).

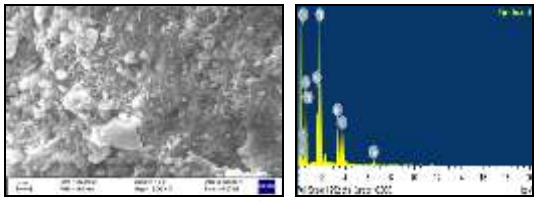


Figure 3 SEM & EDS analysis of Graphene compound with cement

From the figure – 3 (a), graphene compound with cement looks stronger dense with less number of micro voids and cracks. From the figure – 3 (b), cement with graphene-based compound has approximately 6% of carbon which means that the addition of graphene compound has certainly influenced the properties of cement. the presence of carbon is assumed to impart strength and toughness to cement.

5. Conclusion

1. Concrete cubes made with graphene compound showed improvement even up to 25% when compared to conventional concrete cube strength for a proportional replacement by 5% with cement.
2. Concrete made with graphene compound shows less impact on the flexure strength and tensile strength of concrete proportional replacement by 5% with cement.
3. The SEM & EDS reports of the prepared graphene compound prove that the prepared compound is like layered graphene. It is concluded that use of graphene in concrete will enhance its mechanical properties.
4. Concrete cubes made with graphite compound was not showed any improvement when compared to conventional concrete cube strength for a proportional replacement by 5% with cement.

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