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Analysis of GO & R-GO Based on Cementitious Composites

Resham* [a], *Jitender Ravish* [b]

[a] Student, Dept. of Civil Engineeing, ICL Group of Inst., Santholi
[b] Asst. Professor, Dept. of Civil Engineeing, ICL Group of Inst., Santholi
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A B S T R A C T

A novel technique for identifying different structural stability asserts has just been developed by lowering the composite's resistance and generating a piezoresistive a layer of matrix using steel as well as carbon fibres. Intelligent cement-based small particles of graphene derivatives, such as carbon-fibre as well as nanotube-based cementitious combinations, or just a combination between the two, are actually piezo-resistive to be SHM detectors, that indicates that resistance differs along with the applied load or strain. This shows the fact that a cement-based specimen or building is devoid of any extra components or exterior sensor attachments. Rather, the cement-based composite is capable of sensing numerous variables, including its own strain.

In the current study, various experiments which were performed to assess the mechanical as well as characteristics of cementitious grout samples with different proportions residing in oxide of graphene in addition reduced graphene oxide are described. Tests were carried out conducted 7, 28, as well as 56 days after the cure was administered. Electrical characteristics included resistance to electricity testing, while mechanical characteristics encompassed compression strength testing and bending (flexural) strength testing.

The incorporation of reduced-graphene oxide (r-GO) and oxides of graphene which is additionally known as GO in cementitious mortar leads to appreciable increases with respect to the compressive strength as well as flexural strength while 28 days as well as 56 days after curing, the according to the experimental findings from a variety of tests. These results demonstrate how those materials made from graphene have improved the mechanical characteristics that comprise the mortar.

Keywords: R-go, GO, Cementitious composites.

1. Introduction

The necessity to track and analysed concrete performance throughout maintenance or service life using condition evaluation technologies and varied materials has gotten increased attention over the years. Structural Health Monitoring (SHM) is a new technique that may detect any deficiencies in a structure's performance before it leads to a major loss of capacity, (Wong and Ni 2009. The goal of structural health monitoring is to use a sensory system to continually and precisely measure the functioning of structures. Currently developed cement-based detectors tend to be piezoresistive, allowing for guide strain/stress detection through analysis of their electrical resistance. (Azhari and Banthia 2012). The capacity of cementitious materials containing conductive particles to self-sense for SHM has piqued interest in recent decades. Different materials and sensors have evolved, according to previous literature, but they are still not widely utilised in practise, since the components required for the conducting phase might be quite expensive. It is hard to disseminate throughout the matrix of cementitious material i.e.is particularly the case for nano-scale materials like carbon nanotubes (CNTs).) s.

Nano-Engineering in Cementitious Composites
oxide of graphene (GO)
Carbon Nano – Fibres (CNFs)
Graphene Oxide (GO)
Carbon Nanotubes (CNTs)

1.1 Graphene Derivatives

Graphene comprises of a just one layer lattice of atoms of carbon that is often stripped from graphene. It includes a honeycomb hexagonal structure formed by sp2 hybridised links. The rectangular unitary cell of just one layer graphene is made up of a pair of carbon atoms A as well as B **(Figure 3 (a&b))** having C-C spacing is 0.142 nm. Each graphene crystalline is certainly not a pure 2D plane, but it does have little irregularities approximately one nm in length. Each graphene crystalline is certainly not a pure 2D plane, but it does have little irregularities approximately one nm in length. An endless 2D structure represents the perfect graphene. Armchair and zigzag edges stand out among the two main forms of edges. These two varieties of edges result in various electronic characteristics of graphene flakes (Yoo et al. 2018).

Reduced or diminished oxide of graphene (r-GO), & graphene that has been functionalized have been extensively researched and characterised because their distinctive features and prospective applicability

- ***(i) Graphene Oxide***

Graphene oxide (G-O) and graphene have structural similarities. Both of the products feature a hexagonal carbon matrix, but when it is connected to the oxygen - containing groups, the GO layer is often deformed

- ***(ii) Reduced Graphene Oxide***

In contrast to graphene oxide, which is created when graphite is oxidised and results in enhanced interlayer positioning and functionalization of the basal planes of the substance, oxides of reduced or diminished graphene oxide(r-GO) is basically a type of graphene oxide that has undergone chemical thermal, and other processing to reduce the oxygen amount(Dideikin and Vul' 2019).The oxygen content present in rGO ranges from 5-10% as compared to GO which has 15-32% oxygen content respectively. rGO can be used to make chemical sensors (Dideikin and Vul' 2019)

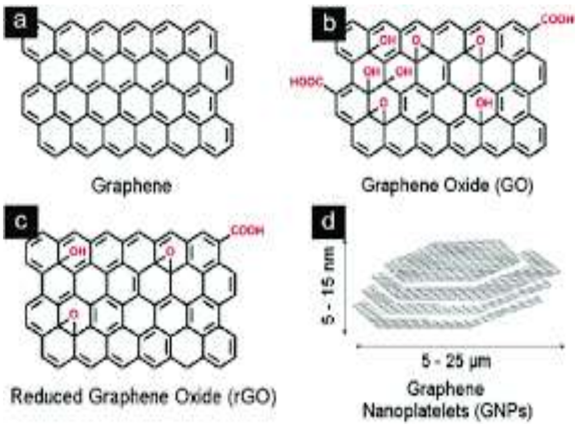


Figure 1 Chemical depiction of Graphene along with its derivatives: (a) Graphene, (b) Graphene Oxide, (c) Reduced Graphene Oxide, (d) Common sizes of Graphene Nanoplatelets. (Dideikin and Vul' 2019Figure 4 Chemical depiction of Graphene along with its derivatives: (a) Graphene, (b) Graphene Oxide, (c) Reduced Graphene Oxide, (d) Common sizes of Graphene Nanoplatelets. (Dideikin and Vul' 2019

1.2 Self Sensing Concrete

Self-Sensing Concrete (SSC) has received much research due to its potential to offer a practical and affordable answer for the structural health surveillance guarantees that civil or building infrastructure is continually assessed & properly maintained, making it particularly appealing for use in practical scenarios (Konkanov et al. 2020).Concrete's capacity for self-awareness is a result of the piezoresistive activity of functional additive particles that are dispersed all through the mixture's composite stage and establish a conductive interaction. This means that whenever building materials becomes compelled in a specific manner, the structure of the network modifications as well as the resistance to electricity transforms (Konkanov et al. 2020). Altogether, the self-sensing concrete has a highly complicated framework. The use of self-sensing concrete might enhance the safety, longevity, service life, and dependability of structural concrete by allowing them to detect and monitor them (Dong et al. 2019a Tables

1.3 Evaluation of an electrical signal from a sensor of Cement Mortar Composite

The sensitivity of the concrete may be determined by a variety of parameters, including piezo-resistivity, electrical resistivity, dielectric constant, conductivity, and capacitance (Han, Ding, and Yu 2015). However, one of the simplest techniques is the utilisation of electrical resistance or resistivity being as a sensitivity indicator. The electrical resistivity, which fluctuates with compression, temperature, or damage, is influenced by the fibre conductivity found inside cement-based composites. To evaluate electrical conductivity in various setups, electrodes constructed of suitable materials are utilized (Nguyen et al. 2015). Before selecting an electrode, three parameters (material, fixing placement, and pattern) should be taken into account. The material should have two major qualities: Low electrical resistance and stable conductive quality. These electrodes may be affixed to the composite's surface, inserted deep inside the composite, or positioned in a clipping pattern. Among these, embedding and attaching are two of the most popular techniques. Experiments can be performed using a two-probe method or even a four-probe set-up with The electrical current pole along with the voltage pole constitute electrodes. (Al- Dahawi et al. 2016). In contrast to a two-probe method, the inner probes are employed to examine voltage while the outside probes serve as current detectors in a four-probe method. Comparing the two-probe approach to the four-probe method, the two-probe method is more practical and easier to apply(Figure. 5).However, when low resistance values are measured using the four-probe approach , it is typically preferred because the outcomes are precise (Han, Ding, and Yu 2015) .

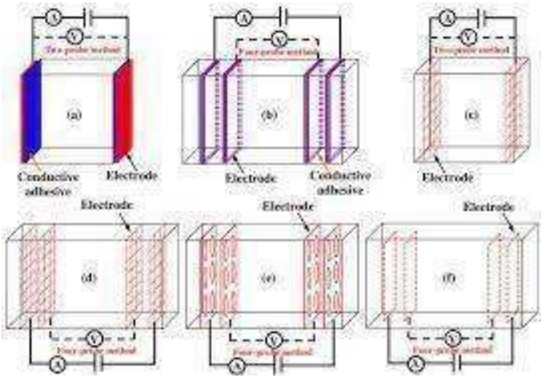


Figure 2 Modifying the electrode design and placement in self-sensing concrete; (a,b): Surface-attached electrodes include loop electrodes, (c-f) embedded mesh electrodes, and perforated plates (c-f).(Han, Ding, and Yu 2015

2. EXPERIMENTAL DESIGN AND METHODOLOGY

2.0 General

The main purpose of the experimental research is to investigate the characterstics of cement mortar on addition of different percentages of Oxide of grapheme (GO) & Reduced-Graphene Oxide (r-GO). GO and r-GO were incorporated as filler in varied proportions to cement mortar specimens with a cement to sand proportion of 1:3.The Water/Cement ratio was maintained at 0.35.The mechanical and microstructural properties of the specimens were examined..

2.1 Materials Utilized in Research.

- **(i) Ordinary Portland Cement Grade43 (OPC-43)**

In the research Ordinary Portland Cement having Grade 43 also called as (OPC-43) had been used in a number of tests. OPC-43 designates a particular kind of cement that complies with requirements established by the Bureau of Indian Standards (BIS). The specifications for OPC-43 cement are laid out in the cited code, the International Standard IS: 4031 (P-2)-1999 (RA 2013). In India, a national norms body known as the BIS has the charge of creating and upholding the standard of excellence requirements for a variety of goods, which includes cement. The requirements which cement of Grade 43 must satisfy in order for it to be deemed in accordance are laid out in the standards IS: 4031(P-2)-1999 (RA 2013).

The standard IS: 4031(P-2)-1999 (RA 2013) conformity assertion denotes whether the cement utilised during the experiments conformed with the specifications given in the standard edition released in 1989.

The statement emphasises the particular kind of cement (OPC-43) used in the tests, its conformity with the applicable regulation IS: 4031(P-2)- 1999 (RA 2013), and its usage of cement within a single batch. These details improve consistency and standardisation of the procedures for experiment

- **(ii) Standard Sand**

The particle measurement intervals, first grade I (1-2 mm), the second grade (0.5-1 mm), & the third grade (0.09-0.5 mm) can all be categorised as fine sand.

The sand can generally be divided into the following categories according to particle size:

Sand that is coarse: Particle sizes vary between 2.0 mm - 0.5 mm.

0.5 to 0.25 millimeter-sized particles make up medium sand.

0.05 mm to 0.25 mm is the diameter range for fine sand particles.

Particle sizes for extremely fine sand vary between 0.05 mm in order to 0.006 mm.

The above grades are considered to be fine sand. Indian Standard sand of 3 types of grades (Grade1, Grade2 & Grade3) having the difference of particle size was used throughout there search. The specifications provided by thev end or are listed in (Table 1), and they correspond to the IS: 650-1991 regulations.

Table 1 Particle Size Specifications of Standard Sand (IS: 650-1991)

Grade	Particle size specification of standard sand(mm)	% Used as per casting.
I	1-2	25
II	0.5-1	50
III	0.09-0.5	25

(iii) Water

Since charged particles from the natural surroundings, pipelines, and other sources exist in ordinary tap water. Usually, with the use of nanofillers, deionized water is utilized for scientifice and research applications. Deionized water was used for all the experimental mixing except the curing process in which normal tap water was used.

(iv) Superplasticizer

Auramix-400 was used as a superplasticizer in the mix. It is a superplasticizer with high performance developed on Poly-carboxylic Ether (PCE) based technology that's designed for applications that demand a significant impact on water reduction and workability retention. As per the manufacturer, Auramix- 400 attributes which had been used in the experimentation work are shown in Table 2 below:

Table 2 Characteristics ofAuramix-400

Characteristics	
Appearance	Pale yellow coloured liquid
pH@27°C	Minimum6.0 Maximum 8.0
Volumetric mass@20°C	1.09kg/litre
Chloride Content	Nil to IS:456
Specific Gravity	1.205-1.215
Alkali Content	Typically, less than 1.5g Na2 equivalent/litre of admixture.

(v) Stainless Steel Plates

Stainless steel (Grade 304) plates were used for testing electrical properties. These plates were installed in the samples during the casting process in electrical and piezoresistive specimens which had been shown in **(Figure 17).** The specifications of the plates used for determining electrical properties can be seen in **Table 3**

Table 3 Specification Details of Stainless-Steel Plates

Grade of stainless- Steel	Type of mortar mix	Specified size of plate in (mm)	No of plates for each Specimen	Spacing between plates(mm)
304	Cube	20×75×1	4	10
304	Prism(beam)	40×60×1	4	60 (Between internal plates). 30 (Between external plates).

(vi) Graphene Oxide

Oxide of graphene Graphene oxide (GO) is a one-of-a-kind substance that is comprised of a single monomolecular graphite layer by layer along with epoxide, carbonyl, carboxyl, and hydroxyl groups within it. (Koh et al, 2014)

vii) Reduced-Graphene Oxide

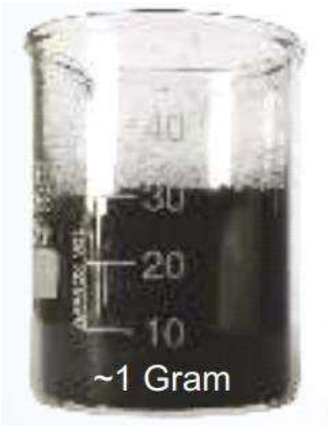


Figure 21 Powdered for of r-GO Used

Reduced- graphene oxide (rGO) is a basically a type of graphene oxide that has undergone chemical, thermal, and other processing to reduce the oxygen amount (Qureshi 2020).It is a fluffy,very-light black powdered nanofiller (Figure 21). The oxygen content present in rGO ranges from 5-10% as compared to GO which has 15-32% oxygen content respectively.

Table 6 Specification details for Rgo used

Reduced-Graphene Oxide	Description
Purity	~99%
Thickness(Z)	~0.8-2nm
Mean lateral dimension	~5-10µm
Quantity of layers	1-3Layers
Proportion of C- Content	~85-92%
Proportion of O- Content	~5-10%
Proportion of O- Content	~1-2%
Proportion of H- Content	~1-2%
Proportion of N- Content	<1%
Proportion of S- Content	80-200* m^2/g
Surface Area	$0.03 g/cm^3$
Bulk/Mass Density	CxOyHz
Physical form	Fluffy, very light powder

2.2 Testing of Raw Materials

Cement-For the purpose of determining cement's purity and the suitability for various uses, many tests are carried out on the material. The following list of typical tests for cement were performed as follows

(i)Fineness of Cement (ii)Consistency of Cement

(iii) Setting Time of Cement

(iv) Soundness of Cement

2.3 Calculation for Quantites of Materials

Ratio of Mortar=1:3

Calculaion of Material Quantities Volume of Cement (m3) =1*1.33/4

=0.3325m3

Volume of 1 bag of Cement= Weight of bag/Density of Cement

= 50/1440

=0.0347 m3

No of Bags = 0.0347/0.3325

= 1 bag

Cement Quantity =200gm*162

=32400 gm=32.4Kg

Sand Quantity =600gm*162

=97200 gm=97.2 Kg

Quantity of each grade of Sand=34.2Kg

Water Quantity = P +3*Total weight of Sample % 4

= (30/4+3)*(800/100)

Table 7 Number of Specimens

Test	Mould Size (mm)	Days of Testing	Control Specimen	GO (%)	rGO (%)	Total No of Samples
Compressive Strength	50x50x50	7,28,56	9	27	27	54
Flexural Strength	40x40x160	7,28,56	9	27	27	54
Electrical Resistivity	40x40x160	7,28,56	9	27	27	54

Number of Specimens

Volume of Material=Volume of Specimen*Number of Specimens Material Waste= 1.5*Total Volume of Material /100

Total Volume of Material (m3) = Volume of Material+ Material Waste

Table 8 Total Quantity of material

Specimen	Size (mm)	Volume of Specimens (m^3)	Number of Specimens	Total Volume of Material (m^3)	Waste (m^3)	Total Volume of Material
jCube	50*50*50	0.000125	63	0.07875	0.00118	0.0799
Flexural	40*40*160	0.000256	108	0.03225	0.0048	0.0370

Table 9 Quantity of GO & rGO

Test	Mould Size (mm)	GO (%)	GO (mg)	rGO(%)	rGO (mg)
Compressive Strength (Cube)	50x50x50 50x50x50 50x50x50	0.1 0.2 0.3	35.52 106.56 177.6	0.02 0.04 0.06	14.20 28.41 42.62
Flexural Strength (Beam)	40x40x160 40x40x160 40x40x160	0.1 0.2 0.3	72.5 217.5 362.5	0.02 0.04 0.06	29 58 87
Electrical Resistivity (Beam)	40x40x160 40x40x160 40x40x160	0.1 0.2 0.3	72.5 217.5 362.5	0.02 0.04 0.06	29 58 87

3.4 Batching, Mixing and Casting of Specimens

Cement Mortar Samples with GO and rGO.

Mortar specimens were made in accordance with ASTM guidelines using cement-to-sand proportion of 1:3. Additionally, after being ultrasonically blended in water that had been deionized, both materials namely as grapheme-oxide (GO) as well as reduced-graphene oxide (rGO) had been both added into the mortar the matrix.

Three distinctive GO (cement sand admixture GO deionized water) mortar cube specimens, designated GO-M1, GO-M2, as well as GO-M3, were produced. These specimens may have been created by mixing GO and rGO through the mortar mixture. A mortar's characteristics or capabilities may be improved or added when GO or rGO is added into the mortar matrix as shown in Table (3.7).

The reason or meant advantages of adding graphene oxide to an existing mortar aren't stated, nor are the precise information with regard to the amount and percentage of GO or rGO stated. However, it has been demonstrated that using graphene oxide in materials composed of cement may have advantages like more effectively electrical or thermal properties, a longer lifespan, boosted durability against cracking, and also enhanced mechanical strength.

The GO-M1, GO-M2, and GO-M3 samples were probably made to examine the impact of various concentrations or quantities of GO on the characteristics of the leading mortar. To assess the way they performed with regard to of flexural strength, compressive strength, ability to absorb water, permeability, or other relevant characteristics, these samples could undergo additional analysis and testing.

The mortar samples were prepared in accordance with ASTM guidelines, which guarantee that they are manufactured in a standardised manner while allow for precise comparisons and assessments of the way they perform.

Table 10 Mix Proportions of Cementitious Cube Specimens with GO & r-GO

MIX	**Cement (kg/m^3)**	**Grade I Sand(kg/m^3)**	**Grade II Sand(kg/m^3)**	**Grade III Sand (kg/m^3)**	**Water (kg/m^3)**	**Super plasticizer (%)**	**GO ($kg\text{-}m^{-}3$)**	**rGO(kg - m-3)**
Control	568.32	426.24	852.48	426.24	198.4	0.8	-	-
GO- M1	568.32	426.24	852.48	426.24	198.4	0.8	0.57	-
GO- M2	568.32	426.24	852.48	426.24	198.4	0.8	1.14	-
GO- M3	568.32	426.24	852.48	426.24	198.4	0.8	1.71	-
rGO- M1	568.32	426.24	852.48	426.24	198.4	0.8	-	0.34
rGO- M2	568.32	426.24	852.48	426.24	198.4	0.8	-	0.45
rGO- M3	568.32	426.24	852.48	426.24	198.4	0.8	-	0.57

Figure 24 Material for Cementitious Cube Specimens with GO

(iii) Dispersion of GO/r-GO

The dispersion of Go/r-GO fibres is a crucial a stage in developing a cement-based self-sensing nano composite before using GO/r-GO in dispersed form for casting. To establish a conductive network and lower the non-conducting matrix's resistivity, the GO/r-GO must be dispersed uniformly throughout the cement matrix. Over the last few years, several ways for appropriately dispersing nanomaterials in cement matrix have evolved. Physical and chemical procedures are the two types of approaches available. Sonication, ball grinding, and mechanical stirring are examples of physical procedures, while chemical methods incorporate the use of dispersing agents to scatter nanomaterials

(iv) Casting of Specimens

The moulds were thoroughly cleaned and lubricated before casting. Before casting, the screws were precisely tightened to the exact dimensions. before measuring GO and r-GO, the beakers were thoroughly cleaned with acetone. The appropriate quantities of components were weighed for the design mix. For compressive strength along with piezoresistivity specimens, 50x50x50mm moulds were employed. For flexural strength and electrical resistivity samples, 40x40x160mm moulds were used following (IS-4031-PART-6-1988-2).

The procedure of casting is as follows: Along with cement, standard sand of three grades were precisely weighed.

For mixing, only clean equipment was utilized.Cement and sand were dry mixed thoroughly for 60 seconds in a mortar mixer machine at low rpm.

Water, super-plasticizer and GO for GO samples & rGO for rGO samples dispersed in liquid form were combined in a mortar mixer to get a homogenous mix.Lastly, the mortar mixer was made to run for another 120seconds at high rpm. Each batch's ingredients were prepared separately (Figur 27).

At each of the specified curing age, a minimum of three test samples must be prepared for testing. Curing ages ranging from 7 to 56 days were used for testing the specimens i.e., 7days, 28 days, 56 days. Figure 27 Casting of Mortar Specimen

Figure 28 Incorporation of steel plate in specimens-

Figure 29 Specimens after Casting.

3. Experimental Methods

Figure 30 shows the test matrix & methodology depicting varying dosages of GO & r-GO along with the various properties which have been evaluated throughout the below tests.

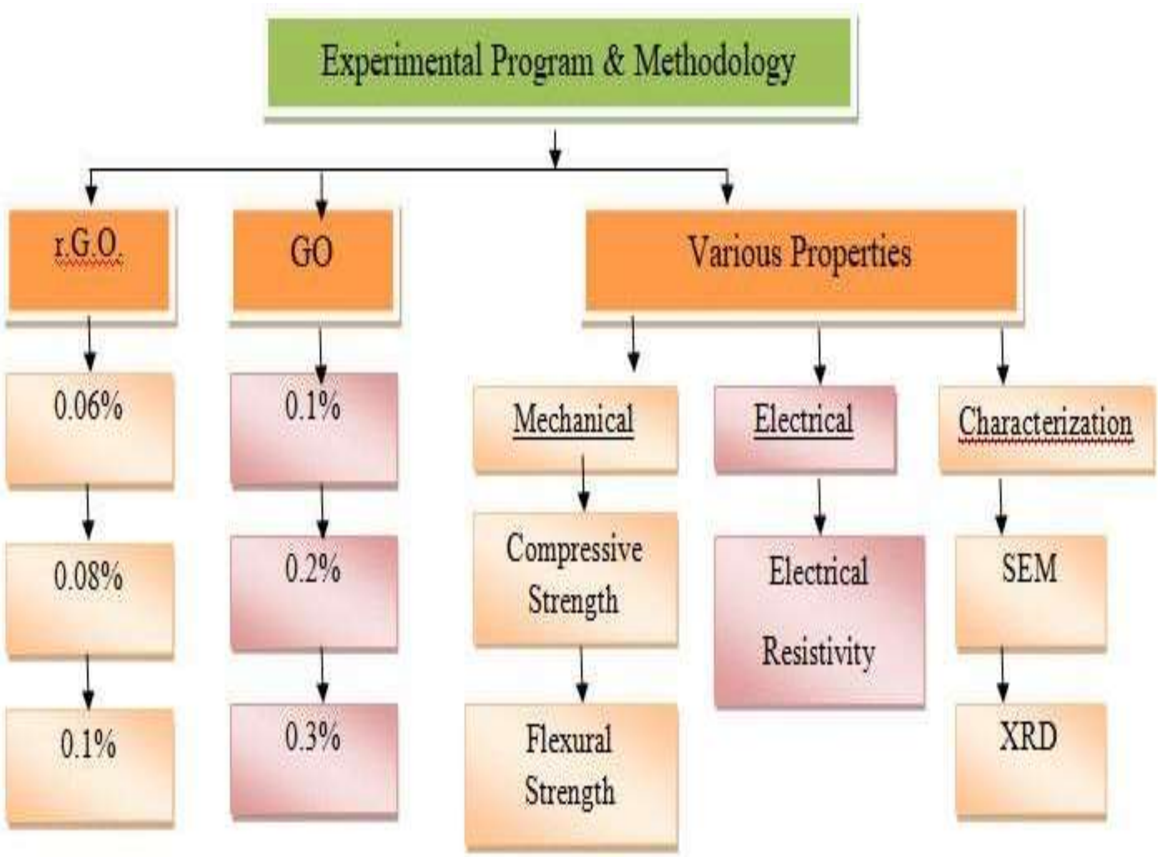


Figure 30 Schematic of Research Methodology.

3.3.1 Mechanical Properties

To fully comprehend mortar's performance as well as appropriateness for a number of usages in construction, the material's mechanical characteristics must be evaluated. The properties can be find out by performing tests such as compression strength and flexural strength which is discussed below.

I. **Compression StrengthTest (Indian Standards:516-1959)**

II. **Flexural Strength Test (Indian Standards:516-1959)**

III. Electrical Resistivity Test

$$\rho = RA/L \quad (ii)$$

(ii)

where, ρ = Electrical Resistivity, R = Resistance of the Sample,

L = Distance b/w two Internal Electrodes of the sample and A=Cross Sectional Area within electrodes.

IV. X-Ray Diffraction (XRD)

V. SEM

4. RESULTS AND DISCUSSION

1.Tests and Analysis of Cement (1.)Fineness of Cement

- Type of Cement= Ordinary Portland Cement =43
- Brand of Cement=Ultratech Cement
- Room Temperature= 26℃
- Relative Humidity=65%

Physical Characteristics	Values as per Test Result	Limits	Method as per IS Code
Fineness (%)	7.54	Max10%	(IS:4031 (Part-1) 2004)
Standard Consistency	29.13	26-33%	(IS-4031-(Part-4)-1988)
Initial Setting time(minutes)	36	Not less than 30 minutes	((Kisan et al. 1988a)) (IS:4031 (Part-5) 2004)
Final Setting time (minutes)	5 hrs 5 minutes	Minimum 600 minutes	((Kisan et al. 1988a)) (IS:4031 (Part-5) 2004)
Soundness of Cement	1.59	Maximum 10	(IS:4031-2005 Part 3)
Specific Gravity	3.15	Maximum 3.29	(Kisan et al. 1988b) (IS:4031 (Part-5) 2004)

(2.) Compressive Strength

(i) Graphene Oxide

The change in the compressive strength of cementitious mix due to the addition of varying dosages of GO at different curing ages had been shown in Table in Figure 4.1. On comparing with control mix, an increase in compressive strength was witnessed in all GO-M1, M2 & M3 specimens for 28 days curing age. But reduction of compressive strength with increased percentage of GO was also noticed for 28&56-days curing age.

Table 17 Compressive Strength of Cementitious Cube Specimens with control mix &G.O

• Curing Days • for Specimen	Control Mix	• G.O.(% Dosage)		
•	•	**0.1**	**0.2**	**0.3**
7	20.13	13.97	16.5	22.71
14	32.18	36.48	34.30	34.63
28	39.66	46.61	41.26	34.01

Reduced Graphene Oxide

In comparison with the control specimen, the compressive strength of 0.06%,0.08% and0.1%addition of r-GO increased by 59.6%, 53.8% and 40% respectively at 7 days as shown in Table 5 Figure 36). However only 2% increase in strength is observed at 56 days for 0.08% addition of r-GO. This increase in strength is mainly attributed to high physical strength of r-GO (Qureshi and Paneshar2019). Thus, for rGO specimens the increment in strength is higher in early age (7 days), compared to later age (28 days) in r-GO based cementitious composites.

Table 18 Compressive Strength of Cementitious Cube Specimens with control mix& r-GO

Curing Days for Specimen	Control Mix	rGO (% Dosage)		
	Control	0.06	0.08	0.1
7	20.13	32.13	30.96	28.19
28	32.18	29.68	32.9	29.62
56	39.66	33.4	34.9	30.5

Figure 36 Compressive Strength results for r-GO & Control Mix Specimens

2 Flexural Strength

(i) Graphene Oxide

The result of flexural strength for varying dosages of GO at different curing ages can be seen in the Table 18 and also shown in Figure 37. Similar to compressive strength, mixes with GO showed increased flexural strength compared to the control mix.

• Curing Days • for Specimen	Control Mix	G.O.(% Dosage)		
•	•	0.1	0.2	0.3
7	8.79	4.95	6.39	10.95
14	9.04	8.31	9.58	11.76
28	12.81	12.34	13.98	14.21

(ii) Reduced-Graphene Oxide

Results for flexural strength show a decrease in flexural strength with an increasing percentage of r-GO. On comparing rGO-M1 at 7- days and 28-day curing age, an increase of 19.17% flexural strength was noticed. The maximum flexural strength was reported tobe11.5 MPa for rGO-M1 after 28days of curing age. But, as the r=GO percentage increased from 0.06% to0.1%,a decrease of 17.34%was found in the case of 28days of flexural strength were shown in Table 19 &Figure 39.

Table 20 Flexural Strength of Cementitious Cube Specimens with control mix& r-GO

Curing Days for Specimen	Control Mix	r-GO (% Dosage)		
		0.06	0.08	0.1
7 Days	8.79	9.65	9.28	9.19
28 Days	9.04	11.5	11	9.8
56 Days	12.81	13.6	13	10.4

Electrical Resistivity

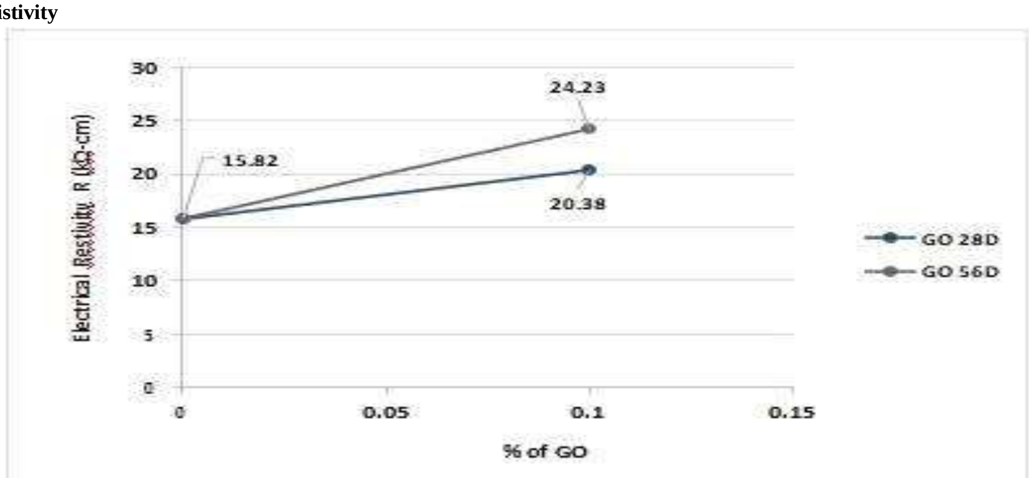


Figure 40 Electrical Resistivity of GO Specimen

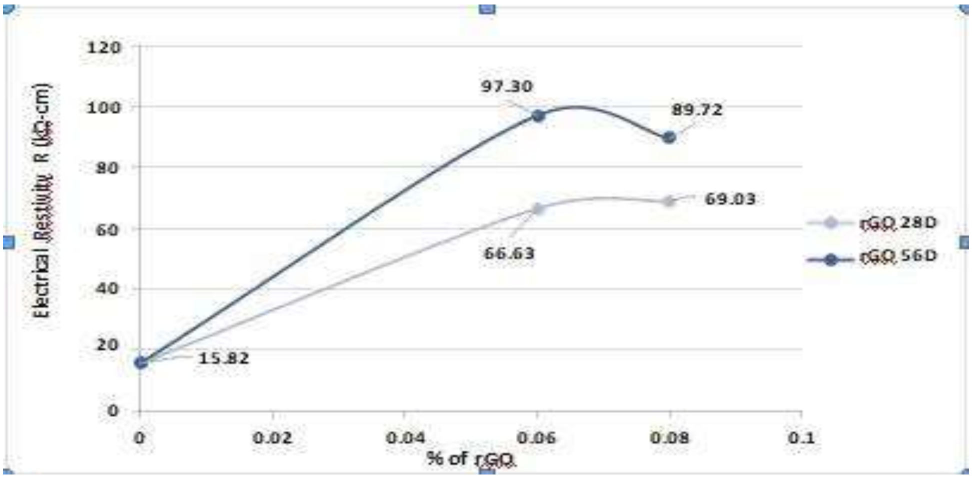


Figure 41 Electrical Resistivity of r-GO Specimen

4.4 Micro structural Image Analysis

As can be seen from Figure 42, it can be observed that microstructure of cementitious mortar (Fig 42 (a) and (b)) got densified by addition of 0.1% GO (Fig(c)and(d)) and 0.06% r-GO (Fig(e) and (f)),This confirms, the pore filling nature of the composites. Further in GO-M1 mix, at few locations agglomeration of GO canals observed, this leads top ore refinement, hence increase in the mechanical properties

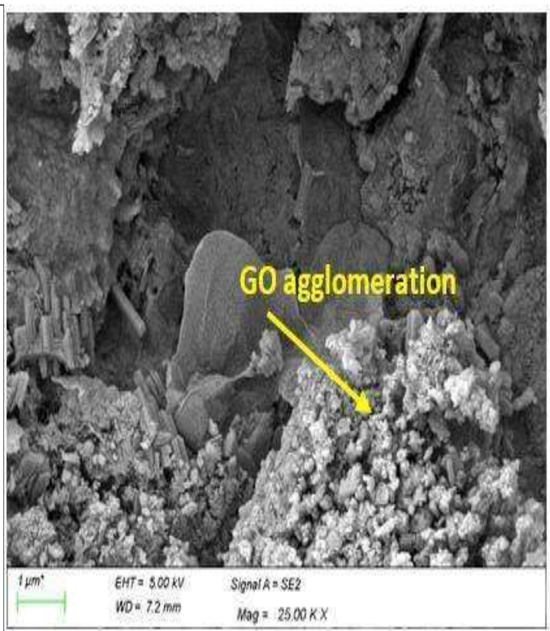
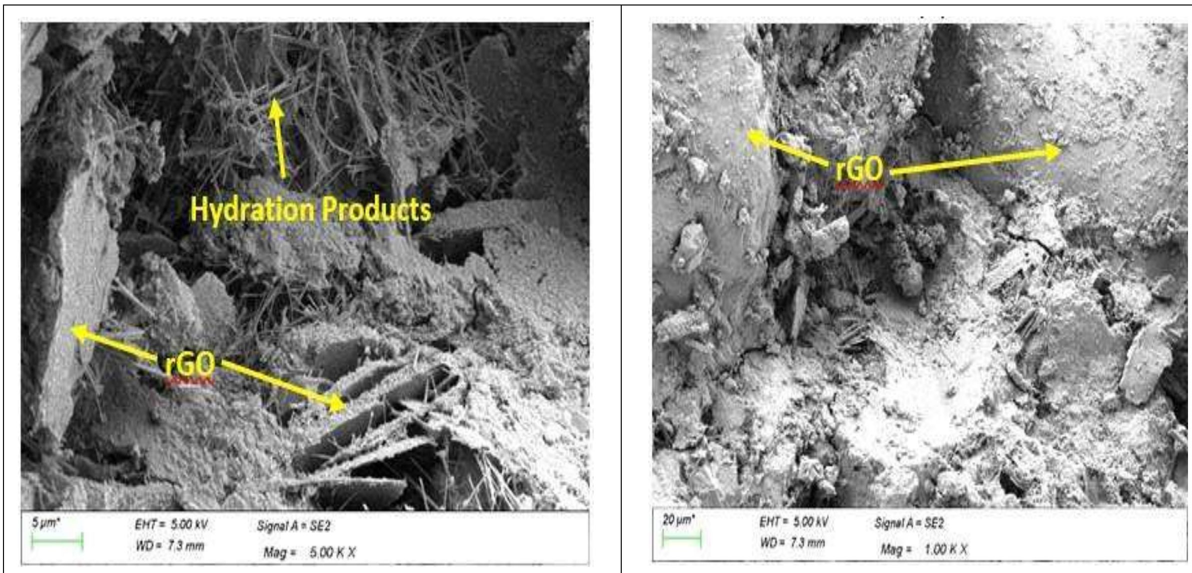
	
(a)	(b)

Figure 42 SEM images of (a), (b) Graphene Oxide



(c) (d)

Figure 43 SEM images of (c), (d) reduced-GrapheneOxide

CONCLUSIONS

The compression strength of the cementitious based mortar had been improved by incorporation of nanomaterial such as GO as well as rGO at 28 days and 56 days of age of curing respectively.

In comparison with the control specimen, the compressive strength of 0.1%, 0.2% and0.3% addition of GO increased by 13.4%, 6.6% and 7.6% respectively at 28 days and17.4%,4.1%and -14.3%respectivelyat 56 days.

In comparison with the control specimen, the compressive strength of 0.06%, 0.08%and 0.1% addition of rGO increased by 59.6%, 53.8% and 40% respectively at 7 days. However only 2% increase in strength is observed at 56 days for 0.08% addition of r-GO. This enhancement in strength is mainly boosted due to high physical strength of rGO.

For GO, with an increase in the percentage of GO, flexural strength also increased. The maximum strength is achieved forGO-M3 mix, which showed 27% enhancement in flexural strength when it is being compared it with the specimens of control mix at 28days and10% increase at 56days.

In case of r-GO, maximum increase of 27% in flexural strength is observed for r-GO-M1mix with0.06%addition of r-GO, followed by21%forrGO-M2mix and 8.5% of rGO-M3 mix at 28 days.

For same percentage of addition of GO as well as r-GO i.e., in case of GO-M1 and rGO-M3mix, GO showed more strength. Though comparing with the best mixes of GO and r-GO i.e.GO-M1and rGO-M1 mix, both GO-M1 mix achieved slightly higher compressive strength than r-GO specimens.

The main reason for decrease in compressive strength at higher dosage of GO is poor dispersion of GO in the cement matrix, leading to agglomeration. This is mainly attributed to presence of high functional group content in GO forms an organic bond with the hydration of cement products leading to increased strength and pore filling mechanism. Despite of r-GO stronger physical properties, random pore filling nature of r-GO resulted in slightly lower flexural strength compared to GO mixes.

For precise electrical resistivity measurements, it is essential to create a solid and consistent connection among the matrix of cement as well as the steel plates. An accurate current flow is guaranteed by this connection, giving accurate information regarding the specimens' resistance.

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