An experimental study on influence of graphene oxide in silica fume blended concrete

T. Navya Charitha* M. Anil Kumar, K. Shyam Chamberlin

P.G. Student, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, India – 522502

Assistant Professor, Department of Civil Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, India – 522502

Abstract:

Micro cracks in concrete is a prevalent problem which contributes to the deterioration of concrete over the course of time. Considering the micro scale of size that these cracks possess, many developments were made in recent days where nano particles like nano-silica and other carbon nano materials like graphene which is a wonder material used to make a stronger, greener concrete are being employed in the manufacture of concrete to build resistance against these cracks and their further propagation. This paper reports the influence of graphene oxide incorporated in silica fume blended concrete at different doses the dosage of graphene oxide was 0.03% and 0.05%. Two types of mixes are developed by the inclusion of graphene oxide (GO) and silica fume (SF) which are named as SF concrete, GO in SF blended concrete; these results were compared with the conventional concrete. The current study focuses on the influence of GO Mechanical properties, XRD analysis, and Rapid Chloride Permeability Test (RCPT) is performed to measure the chloride resistance of silica fume-based graphene oxide concrete. The mechanical properties and chloride ion permeability with inclusion of 0.03% GO have shown better results compared to the other mixes. From the XRD analysis it has been noticed that the peak intensity at 26° for 0.03% GO concrete mix is higher than silica fume induced concrete mix.

Keywords: Nano Material, Graphene Oxide, Silica Fume, RCPT, XRD, Eco-friendly

Email: navyacharan@gmail.com
1. Introduction and Literature

The most used material in civil infrastructure in cement-based concrete. Although cementitious material has impressive properties, they are also semi-weak and have low tensile strength. Mean while fibers are utilized in concrete named as FRC, they improve ductility, toughness, and decrease the propagation of micro-cracks. Still, they fail to resist the initiation of micro cracks [1].

Graphene is an allotrope of carbon and the basic structural element of other allotrope, such as graphite[2]. Graphene is single layer of carbon atoms tightly bond in hexagonal honey comb lattice this formation results in the lightest material known and strongest compound discovered with its exceptional mechanical stiffness, elasticity, surface area is High and great conductive electrical and thermal[3][4]. The production of GO is environmentally friendly compared to other cement supplementary nano materials[5]. The inclusion of GO can lead to reduction in workability of the cement paste[6]. The variations in thermal and electrical conductivity properties were also improved[7]. The mineralogical analysis of graphene-based cement was carried out using an X-ray diffraction pattern, which revealed that the cement produced more heat of hydration than other graphene-based cement[8]. In cement mortars holding fine recycled aggregates, graphene is being used in an innovative way. The optimum graphene concentration was found to be 0.05% by weight of cementitious content improved mechanical properties and has a high resistance to sulphate attack[9][10][11]. Self-compacting concrete results in porosity GO gave positive impact[12]. The charge transferred from the RCPT and the chloride in the specimen have a linear relationship. To assess the chloride profile, a new approach employs the RCPT charge and surface chloride[13].

The aim of this research is, to assess the chloride ion permeability of the silica fume-based graphene oxide concrete.

- To investigate the properties of GO induced in SF blended concrete and to find out the mechanical efficiency of Nano based concrete.
- XRD analysis was performed to analyze the phase detection of selection GO-SF based concrete mixes.
- To measure the Chloride Ion permeability of silica fume-based graphene oxide concrete.

2. Material and Methodology

2.1 Materials

Cement:

According to IS 12269-2013, the cement used in the analysis was 53-grade Ordinary Portland cement. It was purchased from a reputed cement manufacturing company that focuses on high-quality production and chemical composition.
Aggregates:
There are no impurities in the aggregates used. Crushed angular type coarse aggregate that are well-graded according to IS 383-2016 are used. River sand is used in the fine aggregates.

Silica fume (SF):
Corniche India Pvt Ltd. Produced the silica fume. The preferred dosage of silica fume is 3-10 percent by weight of cement. For the current project, silica fume dosage of 7% by weight of cement was utilized.

Graphene oxide (GO):
“Ad Nano Technologies Private Limited” is a source of graphene oxide. The appropriate process of graphene inclusion into concrete is taken as a powder form. For the current project, Graphene oxide dosage of 0.03% and 0.05% by weight of cement was utilized.

Fig 1 Graphene oxide

2.2 Methodology of work:
The material properties are investigated in accordance with Indian codal determinations. The major materials used in this study are the fine and coarse aggregate, cement, graphene oxide and silica fume. The design for M40 grade concrete was evaluated and mixed according to IS 10262-2019 and Is 456-2000 guidelines.

Preparation of graphene oxide solution:
Powdered graphene oxide is used in this research which is then made as an aqueous solution mixing with water which is convenient to mix it in concrete mix. The graphene oxide solution is excluded from the overall amount of water required for the mixture of concrete.

2.3. Detailing of Mix proportion design:
To assess the effect of graphene oxide, two types of concrete mixes were investigated: silica fume concrete and graphene oxide blended with silica fume concrete, both the mixes were compared to conventional cement concrete. The main aim of this research is to investigate the effect of graphene oxide in the presence of silica fumes to assess the chloride ion resistance of the developed mixes.
Conventional concrete mix: The specification for M-40 grade concrete was achieved using a total binder content of 418.965kg/m$^3$, a water/binder ratio of 0.40, a super plasticizer dosage of 2.09kg/m$^3$, and fine aggregate: coarse aggregate ratio of 0.36:0.64 are used in this research.

Silica fume concrete mix: The weight of OPC 7% is substituted for silica fumes (SF) in the mix.

Mix design containing both Graphene oxide and silica fumes: GO is used in different proportion of 0.03% and 0.05%.

2.4. Mixing of materials, casting and curing:

The specified mixes were batched in required quantity. After thoroughly mixing of cement and aggregate the superplasticizer was poured into the mixer.

To make graphene oxide blended silica fume concrete, the aggregate cement silica fume water is place into the mixer and the mixer is allowed to mix for few minutes and then the remaining water containing the superplasticizer and GO solution is poured into the mixer and the mixture was blended for few more minutes to make sure that there is uniform mixing and dispersion of the graphene oxide.

In the suitable mould, the mixed specimens were casted, compacted and vibrated and top layer is finished to smooth after the specimens are dried, they are demoulded and cured in water.

Table 1

| Property            | Material specifications |
|---------------------|-------------------------|
| Loss of Ignition    | 1.8%                    |
| Moisture            | 0.2%                    |
| Bulk density        | 678                     |
| Specific gravity    | 2.2                     |
| Pozzolanic Act Index| 127%                    |
| SiO$_2$             | 92.3%                   |

Table 2

| Property             | Material specification |
|---------------------|------------------------|
| Surface Area        | 200m$^2$/gm            |
| Average Thickness(Z)| 1-4nm                  |
| Average Lateral dimension(X&Y) | 5-10 µm          |
| Bulk density        | 0.1g/cc                |
Table 3
Mix Proportion details of concrete mixes kg/m³

| Mix Designation | Cement in kg/m³ | Graphene Oxide % | Graphene Oxide (gm) | Silica Fume % | Silica fume (kg) | Fine Aggregate Kg/m³ | Coarse Aggregate kg/m³ 20mm | Coarse Aggregate kg/m³ 10mm | Water Kg/m³ |
|-----------------|----------------|------------------|---------------------|---------------|-----------------|----------------------|-----------------------------|-----------------------------|-------------|
| M1 Conventional Concrete | 27.5 | 0 | 0 | 0 | 0 | 45.686 | 53.694 | 35.796 | 11.001 |
| M2 7% Silica Fume Concrete | 25.57 | 0 | 0 | 7 | 1.925 | 45.686 | 53.694 | 35.796 | 11.016 |
| M3 0.03% GO 7% SF (GO-SF) | 28.05 | 0.03 | 9.0503 | 7 | 2.111 | 19.666 | 49.443 | 32.962 | 10.129 |
| M4 0.05% GO 7% SF (GO-SF) | 28.05 | 0.05 | 13.073 | 7 | 2.111 | 19.666 | 49.443 | 32.962 | 10.129 |

2.5. Testing of concrete mixes

**Hardened properties test:** The tests like compressive strength, split tensile strength and flexural strength are performed according to respective Indian standards and in addition, the chloride ion resistance of graphene oxide blended silica fume concrete is evaluated with the control mixes.

Fig 2 Compressive strength test setup.
XRD Analysis:
The XRD patterns was carried out and recorded on “PANalytical EMPYREAN diffractometer” Diffraction patterns were collected at room temperature in the scattered angular range between 10° and 90°. XRD data of 0.03% GO induced concrete mix (M3) is compared with silica fume induced concrete mix (M2).

Rapid Chloride Penetration:
A Rapid chloride penetration apparatus was used with ASTM C 1202 as the standard rapid method for evaluating concrete chloride penetrability. When the specimen is placed in the cell, to prevent the chemical solution leakage the edges are coated with silicon sealant. sodium hydroxide in positive terminal and sodium chloride in negative terminal and 60V is supplied to the apparatus.
Results and Discussions:

Mechanical strength on GO-SF Mix:

The GO-SF mix (M3) has shown better improvement in strength at 7 and 28 days. The mix (M3) gave a compressive strength 49.775 MPa at 28 days.

Flexural strength:

The GO-SF mix (M3) has shown better improvement in strength at 7 and 28 days. The mix (M3) gave a flexural strength 8.2158 MPa at 28 days.
The GO-SF mix (M4) has shown better improvement in strength at 7 and 28 days. The mix (M4) gave a split tensile strength of 3.607 MPa at 28 days.

**Split Tensile Strength**

The GO-SF mix (M4) has shown better improvement in strength at 7 and 28 days. The mix (M4) gave a split tensile strength of 3.607 MPa at 28 days.
Table 4:
Test results for mechanical properties

| Mix Name                          | Mix constituents | Cubes Compressive strength (MPa) | Cylinders Split Tensile strength (MPa) | Prisms Flexural strength (MPa) |
|-----------------------------------|------------------|----------------------------------|---------------------------------------|-------------------------------|
|                                  |                  | 7  28                            | 7  28                                 | 7   28                        |
| (M1) Conventional Concrete        | 0%               | 27.325 40.7                      | 2.1925 2.8995                        | 6.128 6.37                    |
| (M2) Silica Fume Concrete (SF)    | 7%               | 27.775 43.33                     | 2.4755 3.0415                        | 6.128 7.8484                  |
| (M3) Graphene oxide (GO) blended Silica Fume (SF) Concrete | 0.03%GO 7%SF | 34.215 49.775                    | 2.829 3.3241                        | 6.6185 8.2158                |
| (M4) Graphene oxide (GO) blended Silica Fume (SF) Concrete | 0.05%GO 7%SF | 30.55 45.579                     | 3.184 3.6070                        | 6.348 8.012                  |

Rapid Chloride Penetration Test:

The percentage reduction in chloride ion permeability of Graphene oxide and silica fume blended were contrasted to mix without graphene oxide as shown in table 5.
Table 5:
Result of Chloride Ion Permeability

| Sample                                         | RCPT value in coulombs | Permeability |
|------------------------------------------------|------------------------|--------------|
| Control Mix                                    | 1075.9                 | LOW          |
| Silica Fume Concrete (7%)                      | 1312.1                 | LOW          |
| Silica Fume (7%) Graphene Oxide (0.03%) Concrete | 247.23                 | VERY LOW     |
| Silica Fume (7%) Graphene Oxide (0.05%) Concrete | 235.8                  | VERY LOW     |

XRD Analysis:
It has been observed that the Peak Intensity at 26° for Cement+0.03% GO mix is higher than Cement+Silica fume mix which indicates the formation of C₃S.

It has also observed that along with C₃S it is also detected such as Ca(OH)₂ and C₂S.
Conclusions:
The silica fume blended graphene oxide concrete attained enhancement in Mechanical properties and Low chloride permeability values compared to control mixes from the results
- The utmost Compressive strength and flexural strength was noticed at 0.03% Graphene oxide when compared with the other mixes.
- On increasing the percentage of graphene oxide, the split tensile strength was increasing so the maximum strength attained 0.05% graphene oxide.
- It is observed that chloride ion penetration is reduced with add-on of graphene oxide dosage in cement.
- XRD Data of 0.03% GO induced Concrete mix is compared with Silica fume induced Concrete mix and has been observed that the Peak Intensity at 26° for Cement+0.03% GO mix is higher than Cement+Silica fume mix which indicates the formation of C₃S.

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