

Performance Characteristics of Silica fume based concrete made with Graphene Oxide

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Abstract. Concrete is a strong and durable material with serviceability and long-lasting properties demand for concrete is increasing with the growth in the infrastructure globally, concrete is more robust in compression than tension, and lesser tensile strength can lead to reduced crack formation resistance. The utilization of concrete using nanoparticles is starting to show promise as a modern development to improve concrete's properties, these materials range from 1-100 nm in size, can occupy a larger surface area, and play a significant role in the hydration process, the nanomaterials were available in various shapes, forms and dimensions, graphene oxide (GO) is an output from the oxidation process of the graphene material, graphene is one of the strongest material globally. The present study mainly focuses on the impact of GO on the M25 grade concrete's strength and workability, made with Silica fume (SF) as the partial replacement for cement with the proportion of 5, 7.5, and 10% along with the addition of GO with 0.02%, 0.05%, 0.1%, and 0.2% to the weight of cement, test results obtained were indicated that the 0.05% addition of GO shown optimum values.

1 Introduction

Nano materials can improve the material properties, as they are minimal in size they occupy a larger surface area as a result voids were reduced greatly, they play a crucial role in the hydration process of the concrete reducing the voids in the cement aggregate paste (interfacial zone), helps concrete to be denser and obtain the uniform interlocking structure with increased resistance against the stresses developed and the increased bonding capacity, there are 4 types of nano materials carbon-based, metal-based, composites, dendrimers, these materials have salient application across various fields including construction industry as well. Graphene oxide is a two-dimensional material obtained in the process of oxidation of graphite, The dimension of the particle is less than 200nm, often used in the electronics sector as sensors, but in the construction field it can be used as an additive in concrete it acts as nano reinforcing material, it is twice stronger, and four-time lesser permeable than the concrete, it improves the toughness and flexibility of the concrete by exhibiting

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significant resistivity against the crack formation Li X et al. (2017) [7], the preparation of GO powder made with modified hummer method as mentioned by Chandra Sekhar Reddy (2019) et.al [8] with the use of solvents, the combination of the GO with the cementitious materials could be effective to improve the concrete's characteristics.

Graphene oxide (GO) is often produced by oxidising graphene with a strong acid. This happens because GO contains active groups that are hydrophilic, like hydroxyl (-OH) and carboxyl (-COOH), which modify the non-hydrophilic properties of graphene. GO is a nanoparticle having a two-dimensional structure resembling a vast surface area sheet whose thickness is significantly less than its width and length. The unique structure of GO allows for the refinement of the characteristics of the cement-WCP composite with the inclusion of GO. Concrete's qualities can be enhanced by GO, which has a positive impact on cement-based materials' mechanical qualities in specifically. Young's modulus, flexural strength, compressive strength, and toughness are all increased by more than 30% in the initial stages of cement production by adding 0.022 percent by weight of GO.

Silica fume is the finer material, it is an iron industry by-product, the particle size is much finer on comparing with average cement particle size, it used in concrete as the strength enhancer, with the increased surface area the products formed in the process of hydration are calcium silicate hydrate (CSH) gel, helps the concrete to attain high early and ultimate strengths with improved mechanical properties, and durable parameters as well Vikas et al. (2013) [9], with its functionalities in concrete SF used in the preparation of the high performance concrete Mehmet Gesoğlu et al.(2007) [10] examined the properties of plain and rubberized concretes with and without silica fume in terms of strength development and chloride permeability. In order to do this, two varieties of tyre rubber—tire chips and crumb rubber—were utilised as coarse and fine aggregate, respectively, in the creation of rubberized concrete mixtures. The impact of 0.05% and 0.1% GO-reinforcement on cementitious composites' slump, 7- and 28-day compressive and flexural strength, and 28-day rapid chloride permeability test (RCPT) characteristics were examined by Bayer (2023)[11]. In this case, three distinct binder mixtures had been developed into the mixtures: a control, a silica fume (SF) substitute, and a fly ash (FA) substitution.

Roy R et al. [12], GO amalgamated mixes were lesser permeable, resistance against the sulphate attack observed from the study conducted by Shriram Marathe et.al [13] still lot of research going on as the technology progressing to find and utilizing the alternative materials, the combination of cementitious materials along with the nano materials. Mallikarjuna Reddy et.al (2020) [14] utilised the recycled coarse aggregate and recycled fine aggregate as replacement of natural aggregate in concrete mix required to find the percentage of recycled coarse aggregate and recycled fine aggregate, as the strength of concrete cannot be achieved by using higher percentages. Using a moisture sensor, the smart concrete curing system is designed to produce an autonomous mechanism that will deliver water for curing based on the moisture content of the concrete and the ambient temperature by Mallikarjuna Reddy et.al (2020)[15] .

FRP bars are superior to steel bars in a number of ways, including their excellent resistance to corrosion and the high mechanical strength, stiffness, and longevity of the polypropylene fibres used in concrete. With the kind of FRP bar and fibre that have been selected to improve research on the flexural performance of RC beams constructed using a mix of FRP and steel bars by Sai Chandra et.al (2023)[16]. The hc-sr04 sensors are placed at the corners of the glass column for determining the concrete filled into the box and monitor through Arduino.ide software by Nagaashwini et.al (2023)[17]. In order to replace natural aggregate (NA) in the concrete mix, Vivek Kumar et al. (2022) used recycled coarse aggregate (Rca) and recycled fine aggregate (Rfa). It was necessary to determine the proportion of Rca and Rfa because a larger percentage could not be used to increase the strength of the concrete. Ground Granulated Blast Furnace Slag (GGBFS) and Viscosity

Modifying Admixture (VMA) were added to Self Compacting Concrete (SCC) to study its strength characteristics and behaviour at the external beam-column connection experimentally by Vittalaiah et al. (2020) [28]. According to studies by Vivek Kumar et al. (2020) [29], the surface zone will be negatively impacted by inadequate curing and increased permeability. The amount of shrinkage that concrete improves depends on how quickly it loses moisture. When concrete is correctly cured, water kept in the mixture will allow for continued hydration and an increase in compressive and tensile strength to withstand contraction forces.

The current study highlights on the behaviour of concrete under freshly mixed state and under compressive strength loading for the combination of SF and GO obtained results were compared with conventional concrete(CC) results. With its greater surface area and capacity to fill the cement paste's nano pores, nano fine particles can enhance the qualities of concrete. Since nanotechnology in cement-based materials is still in its preliminary stages of study, there are opportunities for using recently produced nano materials. One such pure carbon nanomaterial is graphene, which consists of carbon atoms organized in a single, one-atom-thick layer. Considering that carbon is the basic building block of all known life on the planet, graphene has the potential to be an environmentally benign and sustainable alternative for an infinite range of uses, including the building industry.

2 Materials and Methodology

2.1 Cement

OPC 53 grade was employed for this study confirming to IS: 12269- 2013 [18], tests were intended on cement by following IS: 4031-2019 [19] to obtain its properties with specific gravity as 3.15, fineness as 4 %, Consistency as 32 %, Initial and final setting time as 40 and 260 mins, respectively. The cement from a well-known cement manufacturing company that ensured the chemical composition of the cement and produced high-quality cement. The supplier's cement was the subject of an initial study and laboratory testing to determine the physical standards.

2.2 Fine and Coarse Aggregates

Natural sand confirming to IS: 383-2016 [20], assessed for its properties by IS 2386-1963[21], the properties like specific gravity as 2.75 and fineness modulus as 7.4. For 20 mm coarse aggregate the impact value test and crushing value test have been performed and the results shown as 17.24 % and 27.38 % respectively. Its specific gravity is 2.64 and fineness modulus as 2.97 which is taken from local quarry.

2.3 Silica Fume

Finer material in size, spherical confirming to IS: 15388-2003 [22], and amorphous, the average particle size is 0.15 μ m, available in powder form as depicted in Fig. 1, chemical properties were placed in Table 3. The micro material incorporation in concrete mix results in the reduction in the porosity by reduced voids, and it absorbs water that resists the free water movement in the mix and opposes the bleeding with the higher surface area covered by micro-particles with a high increased particle density, the cohesiveness insist the bonding capability of the mix that endures the strength with a reduction in the permeability values.



Fig. 1 Silica Fume

2.4 Graphene oxide

Graphene oxide (GO) is a powder composed of carbon atoms arranged in a hexagonal lattice structure, with a purity value of more than 98% carbon in Fig.2. GO is the most difficult material, having a higher Young's modulus of 1TPa and exhibiting great tensile strength, accessibility, and heat conductivity, as well. Enhanced dispersion results in a homogeneous concrete mix and the material's water-retention capability reduces the permeability and improves resistance towards segregation in a reduced risk of shrinkage cracking.



Fig. 2 Graphene oxide

Table 1. Properties of Silica Fume and Graphene Oxide

Property	Value (%)	Property	Value
Diameter	0.1-0.2 micron	Size	150 nm
Colour	Dark grey	Surface area	2600 m ² /gram
Surface Area	21000 m ² /kg	Carbon Purity	>98%
Density	550 kg/m ³	Density	2.5 g/cm ³
Specific Gravity	2.2	Tensile strength	>120 GPa

2.5 Water

Water with a pH value over 6.5 was used to mix and cure concrete and remains free of other chemicals and organic contaminants as per IS: 456- 2000 [24].

2.6 Superplasticizer

A naphtha-based chemical conforming to IS: 9103-1999 [23] was used for the experimental investigation which is liquid, and contains an iron content of less than one percent, helps fresh concrete to retain the workability property, reduces the permeability and bleeding.

3 Design Mix and Testing

3.1 Mix Proportions

M25 mix design was done with the help of IS:10262:2019 [25], a sample of 8 mixes was prepared with and without GO, materials were chosen as per weigh batching, the fresh properties of concrete ascertained by conducting slump cone test, concrete in freshly mixed state observed for any segregation and bleeding, the concrete mix was seen to be cohesive, the proportionating of the materials by weight of cement the SF content was kept constant 7.5% then GO was added as mentioned below in Table 2.

Table 2 Proportions of Mix

Designation	Cement (%)	Silica Fume (%)	GO (%)
CC	100	-	-
SF1	95	5	-
SF2	92.5	7.5	-
SF3	90	10	-
GO1	92.5	7.5	0.02
GO2	92.5	7.5	0.05
GO3	92.5	7.5	0.1
GO4	92.5	7.5	0.2

3.2 Mixing and Casting

The materials were added uniformly, and then water and chemical admixture was added, the action of mixing was done before the concrete was set, and the mixed concrete was transferred in the moulds of sizes 150mm as depicted in Fig. 3, and placed at room temperature for 24 hours.



Fig. 3 Casting of Cubes with GO

3.3 Curing of concrete

Casted cube specimens were placed in the curing tank as displayed in Fig. 4, after removal from the moulds, the curing process is vital as results in a hydration process and harden the concrete.



Fig. 4 Curing of cube specimens

3.4 Workability test

Slump cone test was conducted on the freshly mixed state of concrete with the help of steel slump cone apparatus of dimensions 10,20, and 30 cm, concrete was filled in four layers, with tamping each layer, and the cone lifted gradually as shown in Fig. 5. The w/c ratio is calculated with the necessary workability as well as strength in consideration. According to IRC: 44-2017, the mix design has been completed. To achieve the ideal workability of 25–50 mm and the desired strength, a variety of test mixtures using different w/c and super plasticizer doses were carried out.

The workability is verified using the slump test. 0.38 w/c had been employed at first for testing purposes and to determine the dosage capacity of Super plasticizer. To achieve the necessary concrete grade, a w/c of 0.35 was chosen, and the slump was examined. The resulting result is displayed in Figure 6. This testing is conducted considering the matrix's void-filling property is crucial for achieving the necessary strength. The maintained weight-to-cash ratio of 0.35 was used for choosing the aggregate ratio.



Fig. 5 Slump cone test

3.5 Compressive strength test

For every curing age of seven days, fourteen days, and 28 days, the compressive and splitting tensile strength of 150 mm cubes was evaluated using a compression testing machine (CTM) by following IS: 516-1959 [26]. A constant rate of 3.5 N/mm²/min was applied to increase the load without causing any shocks until the cube collapsed. Compression and split tensile strength differences in hardened concrete are shown in Figures 3 and 4. The strength test is performed using a 2000 kN compression testing machine. Cubes were evaluated utilizing a compression test apparatus in the dried state as depicted in Fig. 6.



Fig. 6. Testing of cubes under Compressive loading

4 Results and discussions

4.1 Workability Test on fresh concrete

Intended on the freshly mixed state of concrete, to ascertain the workability property, the mixes were more cohesive due to the early setting property of the silica fume, as the proportion of silica fume increased slump value reduced, mixes were cohesive without segregation and bleeding phenomenon. A similar phenomenon was noted for the mixes that contained GO dosages, the control mix (CC) indicated higher slump value of 104mm, the inclusion of SF content increment increased the cohesiveness as well as in GO inclusion however, the slump values of mixes were in the range of 50-100 mm as represented in Fig 6, without any bleeding as the water retained by both micro and nano particles.

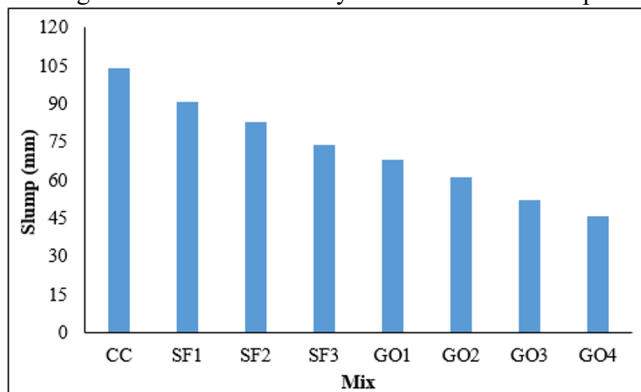


Fig 7. Slump values of concrete

4.2 Compressive strength test

Compressive strength under uniform compressive loading, the concrete mixes were cohesive hence more dense sustained more load, and the bonding capacity greatly improved, the chemical response among formed calcium hydroxide solution in the hydration process, and silica resulted in the formation of CSH gel paste due to which the voids percentage is reduced significantly, the concrete mix's inclusion of SF resulted in concrete to gain high early strength, the 7.5% dosage of SF content exhibited the optimum strength value of 48 MPa, that proportion kept constant for rest of other blends and GO was

added, the addition of 0.05% GO with 7.5 % SF content exhibited ultimate strength values for testing after 28 days, noted reduction in the strength values for the mixes with the GO dosages values of 0.1%, and 0.2% as shown in Fig. 8.

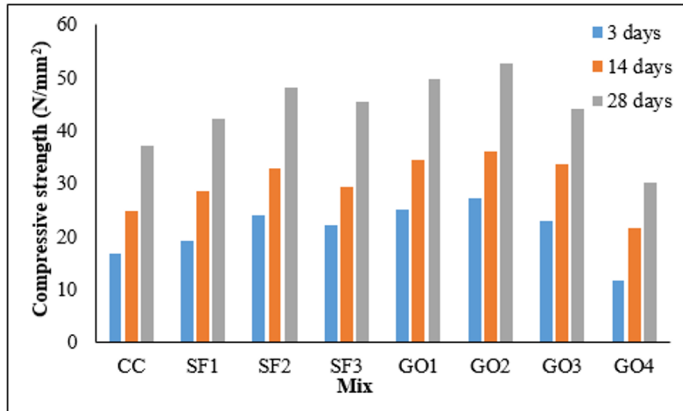


Fig. 8. Graph showing values of Compressive strength with SF and GO

The combination of the nano and micro-particles in the concrete mixes increased the particle-packed density GO incorporation improved toughness and reinforcing property of the concrete density, the resistance against the water penetration opposed the segregation and bleeding along with the reduced heat of hydration, early strength gain in concrete mixes were noted 0.05% level dosage of GO exhibited higher strength of 27 MPa, similarly after 14, and 28 days with the strength values of 36.22 and 52.74 MPa respectively.

5 Conclusions

The combination of SF and GO in the concrete mixes showed impacts on the properties of concrete, the design mix and proportionating of materials indicated no bleeding in a freshly mixed state, and mixes were more cohesive, by conducting tests on mixes the following conclusions were made.

1. The inclusion of SF and GO showed high cohesiveness and slump cone test data revealed that incorporating more finer materials reduced slump values.
2. With SF, GO has improved the concrete's overall strength, especially its compressive strength with different ages. When concrete is formed using more water and less cement, or with a smaller water-to-cement ratio, it has reached its maximum strength.
3. Silica fume incorporation in the concrete mixes improved the strength characteristics, concrete mixes gained high early strength up to the limit of 7.5%, compared with CC mix.
4. GO addition of 0.05% exhibited the optimum values under the compressive loading, the percentage of rise in the strengths are 62%, 45%, and 42% after 3, 7, and 28 days of testing respectively.

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