STUDIES ON FRESH AND MECHANICAL PROPERTIES OF HIGH STRENGTH FIBER REINFORCED CONCRETE INCORPORATING GRAPHENE OXIDE AS A NANO MATERIAL

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ABSTRACT

Nano materials have recently been employed in cement composites to increase their mechanical and durability characteristics. One such nano material is graphene oxide (GO). Adopting this nano material not only improves current features but also introduces new ones. Because of its exceptional mechanical capabilities and active functional groups, graphene oxide has sparked a lot of interest in making it suitable for use as a nano-reinforcement material. In this study total of five mixes were made by adding Graphene Oxide in various dosages (0 percent, 0.025 percent, 0.05 percent, 0.075 percent, and 0.1 percent by weight of cement) with optimal steel fibre (0.25 percent by volume of concrete). All five mixes were subjected to rheological (slump test), mechanical (compressive, split tensile and flexural strength). In comparison to all other mixtures, the one with 0.075 percent GO dose with the 0.25% steel fiber yielded good results in compressive, flexural, and split tensile strength. When compared to control concrete, the concrete with only 0.075 percent GO addition of 0.25% steel fiber had a higher quality.

Keywords: graphene oxide, steel fibre, compressive, split tensile and flexural strength..

I INTRODUCTION

One of the most important building materials is concrete and its use has been ever increasing in the entire world. The reasons being that it is relatively cheap and its constituents are easily available, and has usability in wide range of civil infrastructure works. However, concrete has certain disadvantages like brittleness and poor resistance to crack opening and spread. Concrete is brittle by nature and possess very low tensile strength and therefore fibres are used in one form or another to increase its tensile strength and decrease the brittle behaviour. With time a lot of experiments have been done to enhance the properties of concrete both in fresh state as well as hardened state. The basic materials remain the same but superplasticizers, admixtures, micro fillers are also being used to get the desired properties like workability, Increase or decrease in setting time and higher compressive strength.

The main area of FRC applications are as follows

- Runway, Aircraft Parking and Pavements &Tunnel lining and slope stabilization
- Blast Resistant structures
- Thin Shell, Walls, Pipes, and Manholes
- Dams and Hydraulic Structure
- Different Applications include machine tool and instrument frames, lighting poles, water and oil tanks and concrete repairs.

In the production of concrete, among the materials which are used to make the concrete, ordinary Portland cement plays an important role and which has recognized to be the mostly used construction material all over the world. Now a day's, the demand for improving the mechanical properties of concrete has been increased, in order to satisfy the advanced structural requirements. Hence the demand for the usage of Nano particles in cement has been increasing and, it drew an attention of the researchers because the nano particles are interacted directly with the bond of the cement particles. Earlier and in present days also, firstly used micro scale particle in cement was fly ash, it has shown an interesting advancement in the mechanical properties of concrete. Recently, another type of carbon Nano particle was found by two scientists i.e., Graphene. It has revealed its excellence in enhancing the various advanced properties as well as desired mechanical properties, and showing a path way to the formation of high strength concrete structures.

Graphene is a 2-dimensional nano material and atomically thin layer of carbon, it has a large specific surface area, high Young's modulus, high thermal conductivity and excellent electrical conductivity. These properties make the graphene as one of the most prominent nano material for applications in concrete.

The production of purely one atom layer thick of graphene in large quantities is a highly costliest and time taking process. Hence, scientists were concentrated on the production of alternatives or derivatives of graphene from graphite flakes in large quantities. Those are,

a) Graphene Oxide (GO)
b) Graphene Nano Platelets (GNPs)
c) Reduced Graphene Oxide (rGO)

Graphene Oxide (GO) : Graphene oxide is a compound made up of carbon, hydrogen and oxygen molecules. It is artificially created by treating graphite with strong oxidizers such as concentrated sulfuric acid (H_2SO_4, 98%), Potassium permanganate ($KMnO_4$), Sodium nitrate ($NaNO_3$), Hydrogen peroxide (H_2O_2, 30%), Hydrochloric acid (HCL, 5%) and Distilled water (H_2O) which were all analytical grade chemicals used. It is produced in the form of water dispersed aqueous solution. Generally, it is produced with 1.5 – 2 nm thickness per single layer of GO nano particles.

Graphene Nano Platelets (GNPs) : GNPS with an average thickness between 5 to 15 nanometers are obtained in variable sizes up to 50 microns.

Reduced Graphene Oxide (RGO) : It is processed by the lessening of oxygen content from GO, by using chemical and thermal methods.

Graphene and its extractions such as GO, GNPS and RGO etc. are ensuring the enhancement of more compressive, flexural and tensile strength, strain and damage sensing, impermeability to water absorption, electrical and thermal resistivity. The main differences of graphene derivatives from graphene are, at first graphene oxide (GO) can present more reaction with the cement paste and it is a very good scattering material in the cement paste due to these improved properties GO is used as an attractive material to cement mixtures. And the reduced graphene oxide showing average attributes in between graphene oxide and graphene, majorly due to less usable chemical groups in its structure and graphene nano platelets are possessing the thickness of <100nm and diameter in some micrometres and these graphene nano platelets could be preferred as structural composites. Figure 1 shows the structure of graphene and its derivatives.

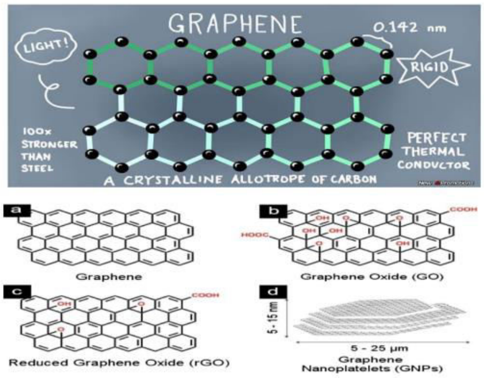


Figure.1: Structure of graphene and its derivatives (B.P. Vinayan (2016))

Mechanism of GO in cement composites:

- The nucleation of cement hydrate and C-S-H gel on GO nano sheets results in the creation of flower-like crystals, Pore structure refinement.
- The generation of cement hydrate and the thickening of gels both contribute to increased strength.
- When GO is incorporated in cement, GO absorbs more heat and has high resilience to high temperatures.
- This improvement in strength is due to the adherence of GO nanosheets to cement paste
- because of the huge specific surface area of the nanoparticles, the rate of pozzolanic reaction, and as an activator to promote the pozzolanic reaction.
- The filling action of microparticles in the transition zone increases compressive, flexural, and split strength.
- Cement hydrate reacts with GO functional groups, forming strong chemical interactions such as ionic or covalent bonds.

II SURVEY OF RESEARCH

Vyshnavi et al (2020): In this study, they were conducted slump flow, compressive strength, and split tensile strength tests on silica fume and fly ash-based self-compacting mortar. In this work instead of cement 6% silica fume and 24 % fly ash were used in the self-compacting mortar. At 0.025% GO dosage in self-compacting mortar, the compressive strength increased by 15%. At 0.05% GO dosage the split tensile strength increased by 23%. With the incorporation of VMA’s in self-compacting mortar the slump flow value shows 702 mm at 0.064% GO dosage.

P.K Akarsh et.al (2020): The research revealed that the effective usage of GO in silica fume-based high-strength concrete as a mineral additive was investigated. The current research tells on the applicability of SF-based concretes with GO intended for use in pavements. Initially, the concrete mix was planned to achieve a pavement quality concrete with a compressive strength of 50 MPa utilizing traditional OPC concrete, as per Indian Standard requirements. To determine the precise effect of GO, three types of concretes were constructed, namely Silica Fume Concrete, Graphene Oxide Concrete, and Blended Concrete containing both GO and SF, the results of which were compared to normal concrete. After conducting workability, mechanical strength tests as trial mixes, the optimum mixture was chosen. Mechanical, durability, and microstructure experiments were performed on chosen concrete mixes. The results of the tests suggest that a 7 percent SF and 0.15 percent GO i.e., CS3G3 mix achieves a compressive strength of roughly 77 MPa and flexural strength of 8 MPa, resulting in good results. When compared to other mixes, the microstructure of the CS3G3 mix showed greater bonding. GO infused silica fume based mostly used for pavement applications.

Chandra Sekhar indukuri et.al (2020): In this study, the properties of fresh and Hardened cement paste such as flowability, microstructure, strength, and durability were studied after the addition of GO. He has performed fresh properties such as workability, fluidity, and setting time and concluded that decrease in the workability &setting time by increasing in the viscosity of cement mix. Regarding the Hardened properties performed on the hardened samples and noted that at 0.04% wt of Go got maximum mechanical strength. To determine the microstructure and crystalline nature of concrete SEM and XRD tests were performed.

S.C Devi et.al (2019): In this study They were prepared five mixes with various dosages of GO (0%,0.02%,0.04%, 0.06% and 0.08% by weight of cement). They have conducted tests on the hardened and permeability characteristics of concrete samples. The conclusion was that adding GO to concrete at various percentages by weight of cement reduced workability, at 0.08 percent GO mix got higher compressive and tensile strength. The increasing compressive strength was around 21to 55%, tensile strength 16 to 38% as compared with control mix, The water flowing properties As the GO dose was increased, the sorptivity and permeability of the nano-reinforced concrete mixes with GO decreased. SEM/EDX microstructural analysis was performed on 90-day-old concrete mixes. The condition of the concrete samples was determined using the UPV test. The 0.08 percent mix had the highest quality for all curing ages compared to the control mix, homogeneity of the GO reinforced concrete composite was maintained.

Chandrasekhar et.al (2019): In this study, the impact of GO on fly ash and silica fume-based cement paste was evaluated through mechanical and microstructure techniques (SEM, XRD). By SEM analysis it is found that the microstructure of cement composite mix changed from porous nature to dense pore filled nature after the addition of GO. By XRD analysis it is clear that it has helped in demarketing the crystalline structure and phase composition in cement paste. The addition of silica fume (3% wt, 5% wt) is mainly due to avoiding the reaction between calcium ions and graphene oxide nano-sheets to break the agglomeration formation.

Instead of cement if we add 15 % of fly ash, the workability of cement paste increased and fluidity was recorded as 265 mm. After 28 days no. of curing days of GO reinforced cement paste, it has shown at 0.03 % of GO the improvement of the flexural strength 65.4% more whereas in compressive strength improvement was found to be 46.8%.

A. Sanjayan et.al (2018): He has studied that the hygroscopic nature of GO structure due to the presence of functional groups at different planes (Epoxy, Carboxyl, and Hydroxyl). The hygroscopic nature tends to absorb water molecules is present in the voids of GO cement composite. This has shown a significant effect on GO structure, mechanical and electrical characteristics.

Lingchao Lu et.al (2018): According to the research, the quantity of GO utilized is calculated, and considerably less GO may be used to provide more or similar to mechanical augmentation. With the integration of sustainability, multifunction, and durability, GO would be a viable candidate for reinforcing binding materials. The toughness of hardened cement composites can be greatly improved by altering the microstructure of cement paste.

A.Mohammad et.al (2017): In this investigation, the effects of graphene oxide (GO) incorporation in standard and high-strength concrete at high temperatures were studied experimentally. Comprehensive thermal evaluations of heat transfer, residual mechanical strength, pore structure, mass loss, and dilatometry were used to investigate the behavior of concrete specimens. according to the test results, Mechanical strength improved significantly the following exposure to 800 °C in both normal and high strength specimens with GO. The control specimens lost around 70% of their initial mechanical strength, while the GO specimens lost roughly 35%. This is attributable to a change in the pore structure of GO specimens, which increased gel porosity while decreasing the number of capillary pores. As a result, the thermal deformation of GO specimens was consistent with the results of pore structure investigations, and no early negative expansion was seen. As a result, GO mixtures showed higher resistance to forming cracks, allowing them to retain the majority of their initial strengths. When compared to severe spalling in the reference specimens, the high-strength specimens containing GO displayed anti-spalling behaviour.

Song et al (2005) have studied the statistical variations in impact resistance of high-strength FRC with 1% fibre volume fraction using hookend fibres of aspect ratio 40. They have reported that the first crack strength of HSFRC was about 3.9 times that of HSC and failure strength about 4.2 times. Two reliable regression models were also developed to predict the failure strength through first-crack strength. From statistical studies, it was found that the impact resistance of concrete exhibited large variations.

Yao et al (2003) have investigated the mechanical properties of FRC containing different fibre combination at the same volume fraction of 0.5%. It was reported that among the three types of hybrids (steel-carbon, PPcarbon, and steel-PP) steel-carbon combination gave concrete of highest strength and toughness. Among the three types of fibres, steel fibre gave the highest MOR and carbon fibre gave the highest compressive strength while PP gave the lowest MOR, split tensile strength and compressive strength.

III OBJECTIVES

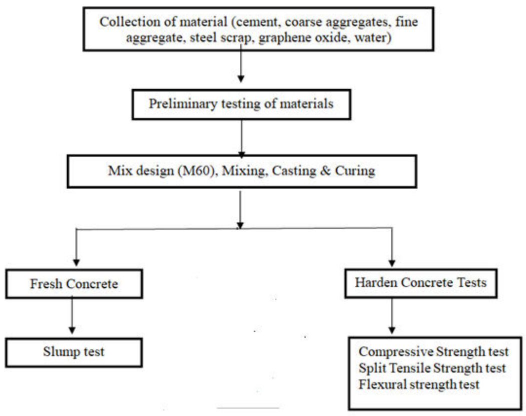
i) To develop mix design methodology for mix 60MPa

ii) To study the effect of adding different percentages (0%, 0.025%, 0.05%, 0.075%, 0.1%) of graphene oxide by the weight of cement with 0.25%of steel fiber in the preparation of concrete mix.

iii) To find out the workability of freshly prepared concrete by Slump test.

iv) To find out the mechanical properties of concrete by compressive strength, flexural strength and split tensile strength of concrete samples.

IV METHODOLOGY



V EXPERIMENTAL WORK

The materials used in this investigation are

- OPC (53 Grade)
- Sand
- Coarse aggregate
- Water
- steel fiber
- Graphide oxide

A. Material properties

Cement used in the investigation was found to be Ordinary Portland Cement (53 grade) confirming to IS : 12269 – 1987.

Table.1: Physical Properties of cement

Property	Result
Standard Consistency	32%
Initial Setting Time	38min
Final Setting Time	310min
Specific gravity	3.12

The coarse aggregate used is from a local crushing unit having 20mm nominal size. The coarse aggregate confirming to 20mm well-graded according to IS: 383-1970 is used in this investigation.

The fine aggregate used was obtained from a near-by river course. The fine aggregate confirming to zone II according to Is 383-1970 was used.

Table.2: Physical Properties of Fine aggregates & Coarse aggregates

Property	CA	FA
Water absorption	0.8%	0.5%
Specific gravity	2.68	2.54
Impact value	12.1%	-

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Water cement ratio used in the mix is 0.45.

Steel fibres were used in this work, specifically hooked-end fibres with aspect ratios of 25. Steel fibres are 25 mm long, 1 mm in diameter, and have a tensile strength of 1150 MPa. The ideal steel percentage, according to the cost analysis and economic index, is 0.25 percent steel fibers with a 25-aspect ratio.

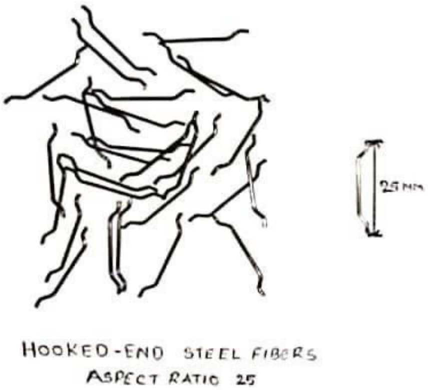


Figure.1: Steel fibers

Graphene oxide is a 2D layered nanomaterial, it is important to determine the particle size because nanomaterials should be less than 100 nm. To check if the material falls under nanomaterialcategory or not, SEM analysis was done.

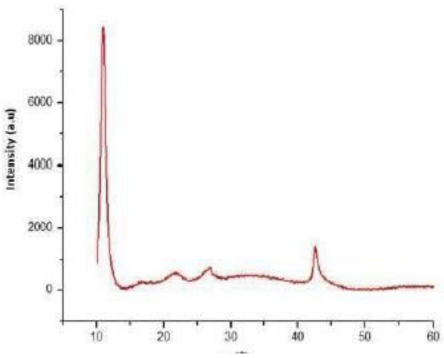


Figure.2: XRD of GO nanosheets

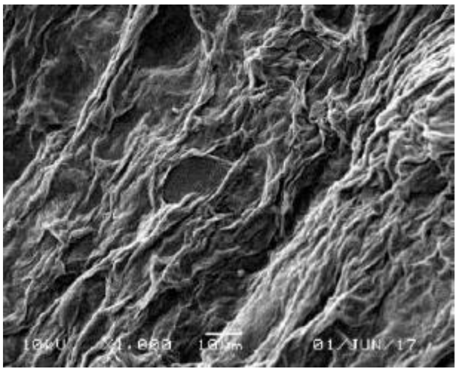


Figure.3: SEM of GO nanosheets

Super plasticizer named Conplast SP-430 from local construction site was used in the experimental work. Super plasticizers are added to concrete to improve the flow characteristics without majorly altering their strengths

In this experimental work Fly ash which has grade of high calcium or ASTM class F has taken but usually two types of grades available high calcium i.e. ASTM class C and low calcium i.e.ASTM calss F. The specific gravity of flyash uptained is 2.2.

B. Mix design

Table.3: Designed Values of Materials

S.No	Item name	As per mixed design(kg/m^3)	Per unit
1	Cement	450	1
2	Flyash (cementious)	76	-
3	Fine aggregates	592.044	1.3156
4	Coarse aggregates	1179.39	2.620
5	water	158	-
6	Super plasticizer	39.6	-
Ratio of M60 Designed Mix=1:1.3156:2.620 with water/binder ratio=0.45			

Table.4: Mix proportions

Graphide oxide (%)	Cement (kg/m^3)	Flyash (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)	water (kg/m^3)	Super plasticizer (kg/m^3)	Graphide oxide (kg/m^3)
0	450	76	592	1179	158	39.6	0
0.025							**0.11**
0.05							**0.22**
0.075							**0.33**
0.1							**0.45**

C. Fresh properties of concrete

Slump cone test is most simple and common test conducted to determine the workability of concrete mix. According to the IS 1199-1959, Slump test is carried out for every batch of mix. The apparatus is shown in the below.

Figure.4: Slump cone apparatus

A sample of prepared concrete mix is taken for the test. The internal surface of the frustum of cone is cleaned and greased to avoid the adhesion of concrete. A non-porous base plate is placed on a uniform surface and the slump cone mould is fixed on it. Concrete mix is filled in three equal layers in the mould. The excess concrete is removed and evelled. Now, the cone is lifted in upward direction and the concrete slumps down. The slump (Vertical settlement) is measured in mm.

D. Casting and curing

In the present work cubes, beams and cylinder specimens were cast to conduct various tests. For the preparation of cube specimens, the mixed concrete is poured into the cube moulds made of steel of dimensions of 150 X 150 X 150mm. The moulds are cleaned and greased to avoid sticking of concrete to the moulds and tighten the bolts to prevent leakage of concrete. The concrete is put in layers into the moulds till the surface and leveled. The specimens are allowed to dry up for 24hrs. The specimens are prepared by pouring the mixed concrete in the moulds of 150mm dia X 300mm height. The specimens are de-moulded after 24hrs. The specimens are prepared by pouring the mixed concrete in the moulds of 100mm X 100 X 500 mm. The specimens are de-moulded after 24hrs.

E. Curing

The next stage is curing of the specimens. It is an important phase as the water for hydration is to be maintained in the specimens. Proper curing gives good strength to the concrete. So, after removing from the moulds the specimens are transferred to the curing tank containing water free from impurities and cured for 28 and 56days.

F. Mechanical properties of concrete

Compressive strength of concrete is the most important characteristic and it is an indexing property as concrete is designed to carry compressive loads. This test is conducted to determine the variation of strength of the specimens with varying ratios of coarse aggregate and reduction in fine aggregate content. Compressive strength test machine (CTM) with 2000KN capacity is used to conduct the test on cubes. After placing the cube between the plates in the CTM, load is applied until the crack is observed on the specimen. The load at the point of cracking is considered as failure load and it is noted. The compressive strength is calculated by

Compressive Strength (σ) = Failure load / Cross sectional area of specimen

The cylinder specimens were tested on compression testing machine to create a tensile cracking. Align the specimen so that the lines marked on the ends are vertical and centered over the bottom plate. Apply the load continuously without shock at a rate of approximately 14-21 kg/cm^2/minute (Which corresponds to a total load of 9.9 ton/minute to 14.85 ton/minute).

Tensile strength = $2P / \pi L D$

Here; P = peak load

L = length of cylinder = 300mm

D = diameter of cylinder = 150mm

The beam specimens were tested on universal testing machine for two-point loading to create a pure bending. The bearing surface of machine was wiped off clean and sand or other material is removed from the surface of the specimen. The two point bending load applied was increased continuously at a constant rate until the specimen breaks down and no longer can be sustained. The maximum load applied on specimen was recorded. The modulus of rupture depends on where the specimen breaks along the span. Beam dimensions are 500mm×100mm×100mm. if the specimen breaks at the middle third of the span then the modulus of rupture is given-by,

$$f_{rup} = \frac{Pl}{bd^2}$$

Where; P = load, d = depth of the beam, b = width of the beam.

VI RESULTS AND DISCUSSIONS

A. Workability of concrete (Slump cone test)

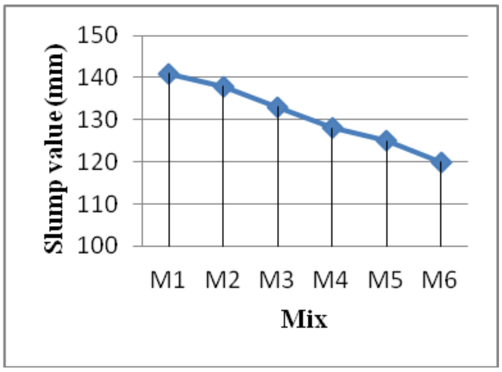


Figure.5: Slump test results

The above figure shows the slump results. It was observed that, the slumps increase as the GO content were increased in the mix. From M1 mix to M6 mix the workability is increases.

B. Mechanical properties of concrete

a. Compressive Strength of Concrete (in N/mm^2)

The compressive strength value highly gained for $SF_{0.25}G0_{0.075}$ (M5) mix, the compressive strength for 28days was 68Mpa. The compressive strength increases from M1 to M5 after that decreases. The least compressive strength gained for conventional concrete (without adding any steel fiber and graphene oxide).

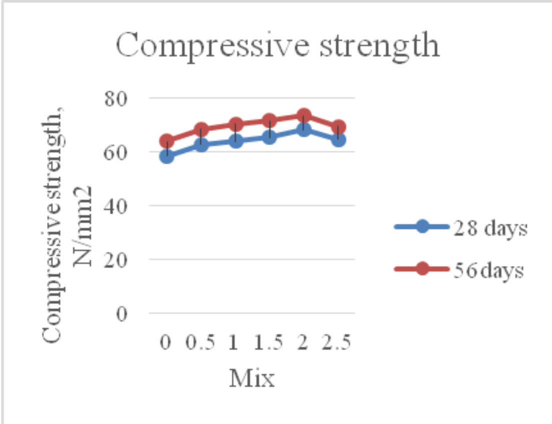


Figure.6: Effect of GO on 28 and 56 days compressive strength

b. Tensile Strength Test

The Tensile test was performed on the beams of size 15 x 30 cm to check the split tensile strength of the fibre reinforced concrete and the results obtained while performing the tension test on CTM.

The split tensile strength value highly gained for $SF_{0.25}G0_{0.075}$ (M5) mix, the Tensile strength for 28days was 5.53Mpa. The tensile strength increases from M1 to M5 after that decreases. The least tensile strength gained for conventional concrete (without adding any steel fiber and graphene oxide).

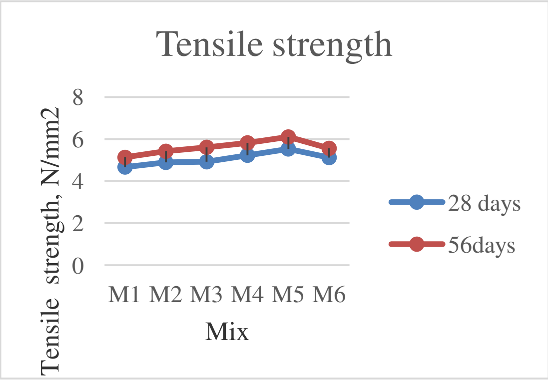


Figure.7: Effect of GO on 28 and 56 days split tensile strength

C. Flexural Strength Test

The flexural strength value highly gained for $SF_{0.25}G0_{0.075}$ (M5) mix, the Tensile strength for 28days was 5.53Mpa. The flexural strength increases from M1 to M5 after that decreases. The least flexural strength gained for conventional concrete (without adding any steel fiber and graphene oxide).

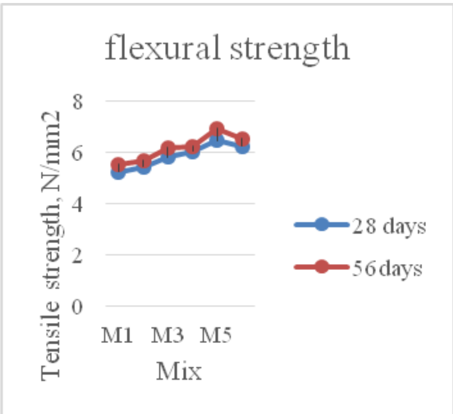


Figure.8: Effect of GO on 28 and 56 days flexural strength

CONCLUSIONS

- When Graphene oxide is added to High Strength Concrete, its workability is diminished. The huge surface area of graphene oxide aids which reduces workability. Also the fluidity of the GO cement composite was increased due to the incorporation of fly ash. This was achieved mainly due to the effective properties of fly ash such as very fine particle size, less water requirement and ball effect that played a crucial role.

- At 28 and 56 days of curing, the compressive strength of the $SF_{0.25}G0_{0.075}$ mix appears to be raised by 16 and 15 percent respectively, compared to the control mix (SF_0G0_0). Because of the creation of hydration crystals, we can see a reduction in micropores, nano cracks, and an improvement in concrete density.

- When compared to control concrete (SF_0G0_0), the flexural strength of the $SF_{0.25}G0_{0.075}$ mix increased by 23 percent and 25 percent at 28 and 56 days.

- In comparison to the control concrete (SF_0G0_0), the split tensile strength of the $SF_{0.25}G0_{0.075}$ mix increased by 18% and 19% at 28 and 56 curing days.

- Since GO integrated concrete has high split tensile and flexural strength, it may be employed in high-rise building construction. Most importantly toughness of cement composite was increased due to the modification of micro structure of hydration crystals in cement composite by incorporation of graphene oxide (GO).
- As compared to the control mix, the graphene oxide dose 0.075 percent contained mix has higher strength values.
- Finally, it was observed that, the incorporation of GO offered an effective modification of hydration crystals and improved toughness by reducing the brittleness nature of the cement Concrete composites; and it can be believed that GO aqueous solution has an ability to create a strong barrier in cement composites for reducing the transport of aggressive chemicals.

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