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Utilizing recycled nanomaterials as a partial replacement for cement to create high-performance concrete

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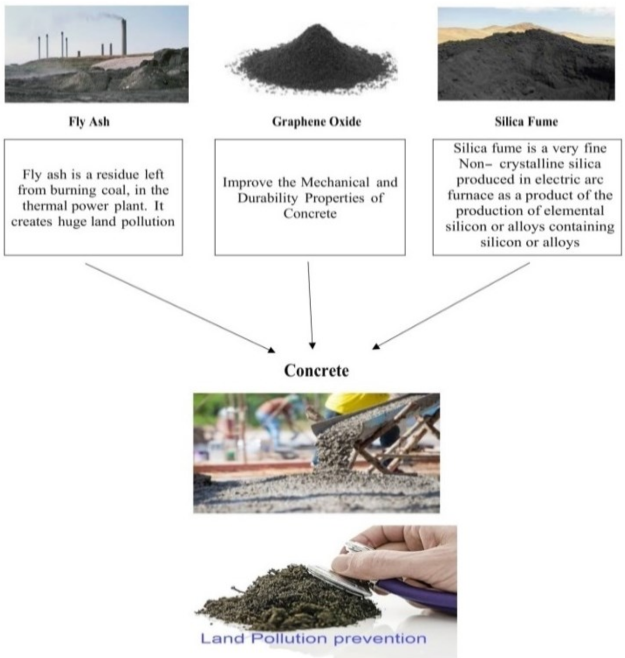
Graphical abstract



Abstract

The world is witnessing a boom in construction industry due to urbanization which leads to over-exploitation of primary resource to match the demands and also increase the land pollution. The advent of nano engineering technology has a significant impact on cementitious materials, particularly graphene oxide which has piqued the interest of several researchers. Because graphine oxide not only provide strength, but it also makes the material more robust and weather resistant. Perhaps more crucially we can minimise the quantity of material necessary to build concrete by incorporating graphine oxide. The macro level workability strength behaviour flexural behaviour and water absorption test of the inclusion of graphene oxide in cement will be explored in this research. Graphene oxide is often available in powder form and it should be combined with water to make a paste before being mixed with concrete for best effects. In this study varied percentages of GO from 0% to 0.05% are employed to determine the optimal proportion of GO by weight of regular portland cement to achieve high strength. Polycorboxylate ethers will be employed as a super plasticizer in this study.

Keywords: Land pollution, flyash, silica fume, graphene oxide

1. Introduction

Graphene oxide has a property of expanding in cold environment and contract in hot environment which will reduce the expansion and contraction cracks in concrete. The challenges to the application of cement like low fracture toughness, vulnerability to harmful penetration, low tensile strength can be reduced to a great extent. Physical methods were used to create graphene, which had a purity of above 95%. The graphene was made up of 1–5 layers with a thickness of 1.0–1.77 nm and a diameter of 2–10 nm. It had a specific surface ratio of 360 m^2/g to 450 m^2/g (Gökçe *et al*., 2019; Golewski and Gil, 2021).

The most significant aspect impacting correct mixing of fresh concrete is its workability. This facilitates transportation, placement, and compaction. When you add extra components to concrete, it loses its workability, and when you add nanoparticles to cementitious composites, the features of cement pastes alter (Somasri and Kumar, 2021; Konsta-Gdoutos *et al*., 2010). This might be due to a decrease in free water, which is essential for lubricating, making the cement mortar or concrete mixtures much more difficult to work with. Super-plasticizers were added to freshmix to keep it flowing at a certain water-to-cement ratio necessary to wet the nanomaterials and enhance their surface area (Birenboim *et al*., 2019; Suo *et al*., 2020; Sukontasukkul *et al*., 2020). It has been observed that superplasticizers based on polycarboxylate ethers are an effective addition for maintaining cementitious matrix workability (Konsta-Gdoutos *et al*. 2010).

Because of its huge surface area and hydrophilicity, graphene oxide absorbs excess water in the mix, diminishing the lubrication with cement pastes, concrete, and GO sheets and rendering pastes and mortars less workable (Mohammed *et al*., 2018; Gong *et al*., 2015; Sanchez and Sobolev, 2010).

When compared to normal concrete there is a 141 percent increase in compressive strength, 125 percent increase in split tensile strength and a 117 percent increase in flexural strength. It also reduces the drying shrinkage cracks as a result the size of the structural parts is reduced resulting in lower construction costs (Devi and Khan, 2020; Das *et al*., 2020; Bajpai *et al*., 2020).

By incorporating nano particles into concrete fibres have shown to regulate nano and micro scale fractures in the early stages, improving the quality of cement-based composites. Methods for producing nano particles fibres and sheets based on nanotechnology as an example consider graphene oxide nano alumina carbon nano tubes can be used as alternative for reinforced materials in concrete structures (Jeong *et al*., 2020).

In a minor slump test the slump diameter was reduced by 41.7 percent when compared to the reference sample at a GO dose of 0.05 percent and slump was reduced by 34.6 percent because GO requires more water to wet their enormous surface area a 0.2 percent polycarboxylate superplasticizer applied to the cementitious matrix increased flow by 34 percent indicating that it is an important additive for protecting the workability of new mixes by reducing water usage (Lv *et al*., 2013).

2. Experimental programs

2.1 Materials

2.1.1. Cement

OPC of grade 53 with a specific gravity of 3.15 in accordance with IS 12269:2013 the normal cement consistency was determined to be 28.4 percent with initial and final setting times of 145 minutes and 285 minutes respectively. IS 383:2016 confirms river sand in zone III with a specific gravity of 2.65. The strength test for OPC grade 53 was found to be 37.20 N/mm^2, 47.40 N/mm^2 and 60.60 N/mm^2 in 3, 7 and 28 days respectively. Sound test for OPC grade cement was found to be 1 mm by using Le-Chatelier Expansion. Table 1 illustrates the cement properties.

Table 1. Physical properties of Cement

Test on material	Result
Specific gravity	3.15
Fineness test (90 micron)	2.9 %
Consistency Test	28.4 %
Initial Setting Time	145 mins
Final Setting Time	285 mins
Strength test	3 days – 37.20 N/mm^2
7 days – 47.40 N/mm^2	
28 days – 60.60 N/mm^2	
Soundness test	
(Le-Chatelier Expansion)	1 mm

2.1.2. Flyash

Flyash is used in concrete to increase the durability of concrete. IS 3812:2003 part 1 and part 2 covers the physical and chemical properties of flyash to be used in concrete.

2.1.3. Silica fume

Silica fume is used in concrete to increase the initial strength in concrete. IS 15388:2003 covers the physical and chemical properties of silica fume to be used in concrete. The bulk density of silica fumes various from 150 to 350 kg/m3 (Akshana *et al*., 2020).

2.1.4. Graphene oxide

The modified hummers method is used to create graphene oxide and-nano technologies provided graphene oxide water dispersion of graphene oxide is an oxidized version of graphene that has been laced with O_2 groups because of the presence of oxygen functions it disperses readily in water and other organic solvents it has a specific surface area of 200 m^2/g a purity of 99 percent and a thickness of 1-4 nm on average. Table 2 Represents the properties of graphene oxide.

Table 2. Graphene oxide properties

Graphene oxide	Description
Purity	99%
Thickness	0.8-2 nm
Average Lateral	
Dimension (X & Y)	5- 1 0 µm
Layers	1 - 3 l a y e r s
C Content	60–80%
O_2 Content	15-32%
H_2 Content	1-2%
N_2 Content	1-2%
Colour	Black Powder
Surface Area	110 - 250* m^2/g
Bulk Density	0.5 g/cm^3
Chemical Formula	C
Physical Form	Fluffy, Very Light Powder
Odour	Odourless
S Content	<1%

2.2 Mix proportions and casting

Six distinct mixtures were created, and test has been carried out on both fresh and hardened concrete at various curing ages. With a w/c ratio of 0.3, the binder, fly ash, micro silica, fine and coarse aggregate water and super plastizer were held constant at 427.73, 53.5, 53.5, 589, and 1211 kg/m3 (1:0.125:0.125:1.377:2. 831:0.3:0.009), respectively. GO was added in various percentages by weight of cement, ranging from 0 to 0.05 percent with a 0.01 percent rise. Table 3, illustrates the proportions of the blend. After that, fresh concrete was poured into greased moulds of various shapes and sample sizes. After 24 hours, water was cured for 1 week, 2 weeks and 4 weeks in a temperature (27 + 2 + C and 90% humidity) controlled curing tank until the age of testing.

2.3 Test on concrete

2.3.1 Workability test

The capacity of a concrete to mix, transport, and put materials with little loss of homogeneity, such as segregation or bleeding, is referred to as workability. The workability was verified using IS 6461 part VII- 1973. The control mix's slump value was set at 79 mm. The slump cone test was used to estimate the slump value, which required pouring fresh concrete in four 14-inch-high layers, disturbing each layer 25 times, then raising and measuring the height of the coned concrete. The influence of GO on the fluidity of concrete composites, as well as the slump value for various mixes, was investigated. Figures 1 and 2 Shows the variations of slump and compaction factor.

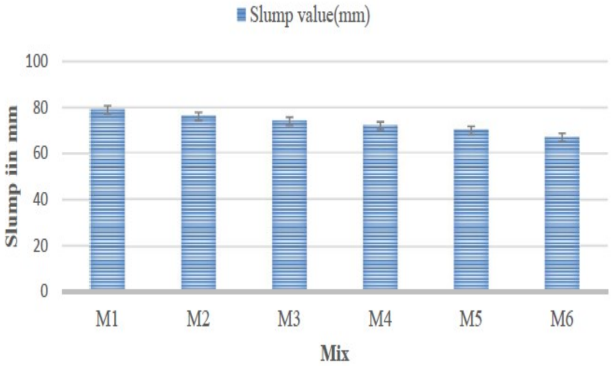


Figure 1. Slump test

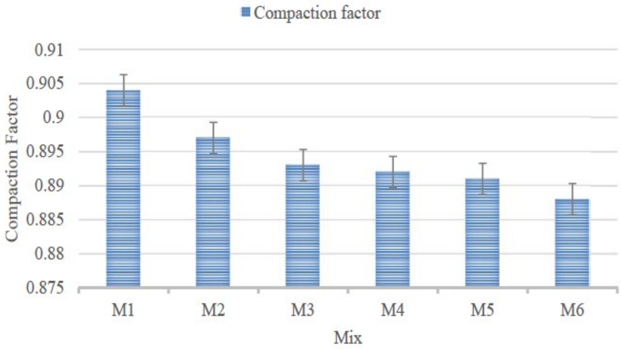


Figure 2. Compaction factor

2.3.2 *Hardened properties of concrete*

The compressive and splitting tensile strength of 150 mm cubes was tested on a Compression Testing Machine according to IS: 516–1959 and IS: 5816–1999 codes for each curing age of 1 week, 2 weeks and 4 weeks (CTM). The load was steadily raised without shock until the cube failed, at a steady rate of 3.5 $N/mm^2/min$. Figures 3 and 4 represents the variation of compressive and split tensile strength of hardened concrete. 100 ton compression testing machnice is used to test the strength test.

Table 3. Quantity of materials used in kg/m^3

Mix	Description	Cement (Kgs.)	GO(Gms)	Fly ash(Kgs.)	SF(Kgs.)	Water(Kgs.)	FA(Kgs.)	CA(Kgs.)	SP(Lits)
M1	Conventional	427.73	0.00	53.5	53.5	141	589	1211	3.86
M2	0.01 % GO	427.73	0.01	53.5	53.5	141	589	1211	3.86
M3	0.02 % GO	427.73	0.02	53.5	53.5	141	589	1211	3.86
M4	0.03 % GO	427.73	0.03	53.5	53.5	141	589	1211	3.86
M5	0.04 % GO	427.73	0.04	53.5	53.5	141	589	1211	3.86
M6	0.05 % GO	427.73	0.05	53.5	53.5	141	589	1211	3.86

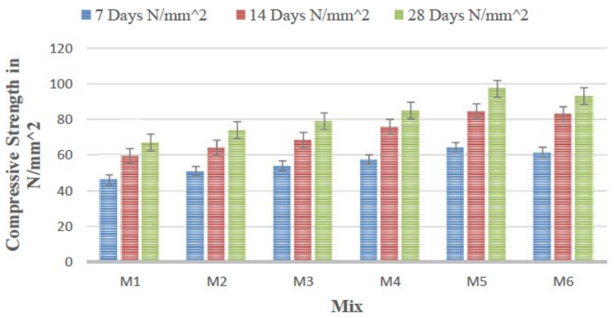


Figure 3. Comparison of compressive strength

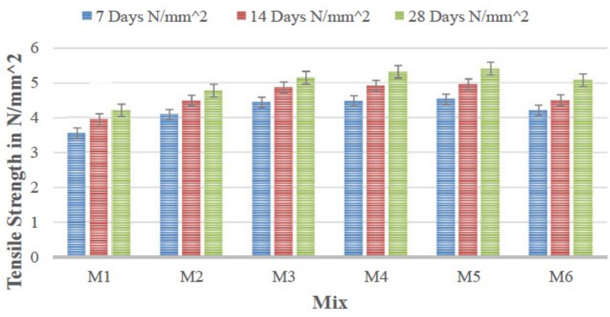


Figure 4. Comparison of split tensile strength

2.3.3 *Test on permeability*

To estimate the rate of water flow into the concrete surface per unit area at a certain interval, the initial surface absorption test (ISAT) was performed on 150 mm cubes, in accordance with BS 1881: Part 208:1996, on 150 mm cubes. The specimens were dried in an oven at 105°C until they weighed less than 6% of their original weight. A 78 mm diameter cap was connected to the cube surface, allowing for a minimum of 5000 mm2 of water contact with the test surface. The water was allowed to flow via a 150 mm reservoir and a faucet to a scale-attached exit for the test. The water head was held between 180 and 220 mm, the tap was opened, and measurements were taken every 10 minutes, 30 minutes, and 60 minutes from the start of the test. After 1 week, 2 weeks, and 4 weeks of cure, tests were conducted.

3 Physical properties

At 1 week, 2 weeks, and 4 weeks of cure, compressive and splitting tensile tests were performed on CTM. The GO-containing mixtures outperform the control mix, M1, in both compressive and tensile strength. M5 had the greatest improvement with 0.04 percent GO, followed by M4 (0.03 percent GO), M3 (0.02% GO), and M2 (0.01% GO). The progressive improvement in strength with increasing

GO content in concrete mixtures at various hydration times may be noticed. After 4 weeks of curing, the mixes with 0.04 percent GO had the highest compressive strength, up 32 percent from the control mix. The mix containing 0.01 percent GO had a minimum improvement in compressive strength of 8 percent.

4 Conclusion

The current study found that including GO at various percentages by weight of cement in the development of concrete reduced workability while significantly increasing compressive strength (26–32%), tensile strength (24–32%), and initial surface absorption during a 28-day curing period. The results are unaffected by the increase in GO content; the mix created with 0.04 percent has the longest curing time of all the mixes when compared to the control and other mixes.

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