Effective Role of Graphene Oxide Nanostructured Materials in Enhancing the Physico-Mechanical Characteristics of Concrete Structures

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Abstract

Nanostructured graphene oxide (GO) materials have been studied world-wide for various technological applications now-a-days. Due to its good dispersability in water, this can exhibit high aspect ratio. In this research work, a detailed experimental study has been carried out on concrete with addition of GO in appropriate levels (0, 0.03 and 0.06 wt%). The addition of GO after sonication in water was carried-out in the concrete at the time of mixing the cementitious material along-with other conventional additives. The prepared concrete cubes, cylinders and prisms with / without GO were studied for the compressive strength, flexural strength, elastic modulus and ductility index. The hydration process in concrete were enhanced effectively with the presence of GO and enhanced the concrete properties to a greater level.

Keywords: concrete, nanostructured graphene oxide, physico-mechanical properties, advantages

1. Introduction

Concrete is a heterogeneous material which consists of cement, aggregate and water. As the concrete is densely compacted, it acts as a homogeneous material [1]. The concrete is good in compression because of the interlocking effect as it is densely packed. But the adherence of the cement phase and the aggregate phase may lead to cracks at the interface result in the formation of cracks [2]. Also, the voids in the concrete may result in the reduction in the durability property which may further lead to low the concrete tensile strength [3]. The voids in the concrete may be due to poor compaction, lack in the quality of raw materials and use of excess water-cement ratio in the mix [4]. `

Even when there are 5% voids in the concrete, it leads to 30% reduction in the strength [5]. Presence of any salts in water can easily intrude into the voids of concrete which may affect the long term performance characteristics of the concrete [6]. Therefore, these voids in the concrete should be filled by suitable materials, viz, fillers, fine particles, etc. in order to make as a dense concrete compact which may further enhance its mechanical behaviour [7]. Variety of additive materials, such as, fly ash, silica fume, fibre reinforced plastics (FRP),metakaoline, slag, etc. have been added to concrete to improve its physico-mechanical characteristics. Even though the use of fly ash has a lot of advantages, problems may arise during mixing, setting time, strength development, and durability properties of concrete [8]. Silica fume is an inorganic filler, however, its presence in concrete is found to enhance shrinkage rate and its workability is also reported to be very poor [9]. Fiber reinforced composite materials [10] are extensively used now-a-days in many structural applications. The externally bonded FRP composites enhanced the load carrying capacity of the structural members, however, FRP composites may result in unpredictable ultimate mode of failure (e.g. peeling, delamination) [11]. Metakaolin is a pozzolanic material of small particle size with high surface area that reacts quickly and reduces the diffusion coefficient and changes the microstructure of the hydrated cement paste [12].However, the usage of metakaoline in concrete is still under consideration in construction industries [13]. Slag the by-product from steel production that are similar to volcanic rocks character. This has been widely used in construction industry as the steel slag concrete had good workability and improved the mechanical properties of the concrete [14]. However, steel slag concrete is greater prone to poor curing conditions than OPC concrete [15]. Attempts were made to study the behaviour of nanoparticles in the concrete especially to improve its quality characteristics[16]. With the incorporation of metal oxide nanoparticles in the concrete, there was no significant reduction in the pores of concrete [17]. Recent advances in processing techniques and improved material performance have led to new high-performance construction materials [18-22]. In this research work, attempts are made to prepare and incorporate graphene oxide nanostructured materials to enhance the physico- mechanical behaviour of concrete. The prepared concrete specimens with graphene oxide (GO) nanostructured materials are tested for physico-mechanical characteristics, like microstructure, strength, elastic modulus and ductility index. The obtained results are discussed in this research article.

2. Materials and Method

2.1 Materials used for the preparation of graphene oxide

The chemicals such as graphite (Merck, India), potassium permanganate, sulphuric acid, hydrogen peroxide and hydrochloric acid were used in the experiment without any further purification.

2.2. Synthesis of graphene oxide nanostructured materials[23]

The oxidation and exfoliation of graphite sheets were made by thermal treatment in order to synthesize nanostructured graphene oxide. The preparation of GO is indicated in the flow chart as shown in Fig.1

In a volumetric flask of 1000 ml, 100 ml of concentrated H2SO4 (98%) was prepared with the Graphite powder (2 g) and kept in the ice bath (0 – 5 ºC) with continuous stirring for 4 hours, then potassium permanganate (6 g) was added slowly to the suspension. The reaction temperature was kept lower than 15ºC. The mixture was diluted slowly with the addition of 150 ml distilled water hours the mixture was stirred at 35 °C. The which colour changes to bright yellow with solution is finally treated with 40 ml H2O2 by and kept under stirring for 2 hours and then removed from the ice bath. For about 2 the addition of 150ml of double distilled water and stirred for 2 hours and kept still for 3 – 4 hours for the particles to settle down at the bottom and the remaining water was filtered. By centrifugation method the residue was washed with 10% HCl repeatedly and then deionized (DI) with water for several times till gel like substance (at neutral pH) obtained. For more than 6 hours the gel like substance was dried in vacuum at 60°C to obtain GO nanostructured materials.

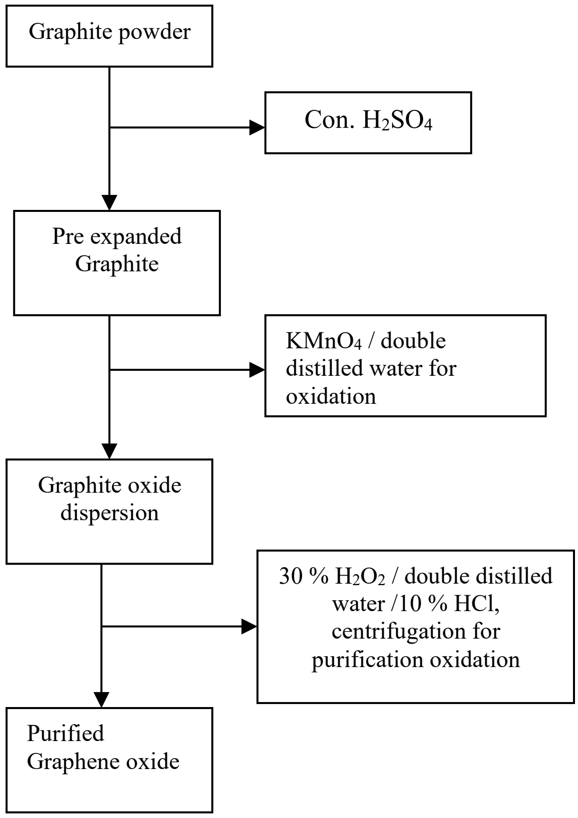

Fig. 1: Synthesis of Graphene oxide by Modified Hammer's method

2.3 Physicochemical characterization of GO

The X-Ray Diffraction Analysis (XRD) of the synthesized sample was studied by Shimadzu XRD6000 X-ray diffractometer using CuKα radiation model. The microstructures of the samples were studied by JEOL model JSM-6360 scanning electron microscope.

2.4. Fabrication of concrete specimens

2.4.1. Exfoliation of GO powder in water

At the concentration of 4 mg/ml, the prepared GO powder was dispersed in water. The GO dispersion was carried-out in a sonicator with continuous stirring with an ultrasonic frequency of more than 20 kHz to exfoliate the GO and to blend it thoroughly in water medium.The sonicator instrument used in this study is shown in Fig. 2.

Fig. 2: Sonicator apparatus used for the exfoliation of GO powder in water

2.4.1 Preparation of concrete mix with exfoliated GO dispersion

The Ordinary Portland Cement (OPC) was used throughout the study. The river sand was sieved through a set of sieves as per the sieve analysis procedure prescribed in IS 383 code. The fineness modulus of the sieved grade II sand was found to be 2.64. Based on the soil texture, presence of organic matter and their packing arrangement, the voids in the aggregate were indirectly determined by bulk density of the fine aggregate as 1.922 g/cc. The cement, fine aggregate and water were mixed along-with exfoliated GO dispersion as per the procedure indicated in ASTM C1738-11 a. M_{25} grade concrete with 0.5 as the water-cement ratio were used to cast concrete beams. For better workability, 0.5 wt.% of super plasticizer (Polycarboxylate, Melflux 2510 L/ 45% N.D., BASF, India) was added to the concrete mix. The above ingredients were mixed thoroughly before casting. The composition of GO in the concrete mix was kept as 0 %, 0.03 wt.% and 0.06 wt.% of cement respectively.

2.4.3. Casting of concrete specimens

The concrete mix was transferred to the set of cylindrical steel moulds (two sizes: 150 x 300 mm and 150 x 64 mm respectively) and steel beam prism moulds (100 x100 x 500 mm) and the specimens were demoulded after 24 hours. The photograph of the concrete specimens in different moulds is shown in Fig. 3.

The cast specimens were immersed in potable water for 28 days in the laboratory curing tank in the open atmosphere without any interference. After this curing period, the concrete specimens were subjected to further studies.

Fig. 3: The cast concrete specimens in different moulds

2.5 Physico-mechanical properties of GO incorporated concrete Specimen

The physico-mechanical properties of GO incorporated concrete specimens were studied for their strength, elastic properties as per ASTM C 78 standard and compared with the control concrete specimen.

3. Results and discussion

3.1. XRD studies of GO nanostructured materials

The crystallographic properties of the GO nanostructured materials were studied using X-ray diffraction technique. The XRD pattern of GO prepared by Modified Hammer's method is shown in Fig. 4. Due to the chemical oxidation and exfoliation of graphite the diffraction peak mainly appeared at $2\theta = 11.31^{\circ}$ with the d-spacing at 0.78 nm.

No impurity peaks appeared which shows the ultrafine purity of the prepared GO. The obtained results are in line with the reported data [23].

3.2. SEM studies of GO nanostructured materials

The morphology and the microstructure of nanomaterials were studied using SEM studies. The SEM photographs obtained on GO nanostructured materials with different magnification are presented in Fig. 5 (a-d). The SEM photographs revealed the layered like sheets in all the samples. Fig. 5 (d) revealed the presence of GO sheets were stacked one above the other as reported in literature [23].

3.3. Studies on compressive strength of concrete specimens

The compressive strength of the concrete specimens with GO (0 wt.%, 0.03 wt.%, 0.06 % wt.

%) (150 x 300 mm) were carried out in the compressive strength machine as per the schematic diagram shown in Fig. 6 (a,b). The load was applied gradually at a rate of 140kg/sq.cm/min. on the specimens until the specimens undergo failure. The compressive strength of specimens was found to be 20.27 N/mm^2 (0 wt. % GO), 31.63 N/mm^2 (0.03 wt. %) and 34.03 N/mm^2 (0.06 wt.%).

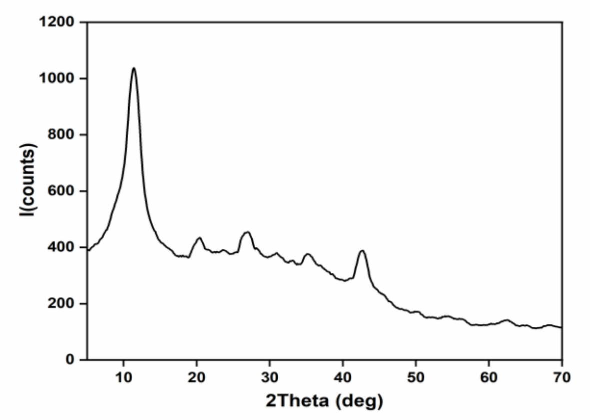

Fig. 4: XRD pattern obtained on GO nanostructured material prepared by Modified Hammer's method

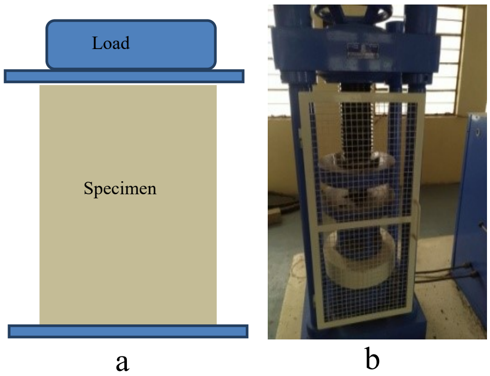

Fig. 6: (a, b): Schematic representation of measurement of compressive strength in concrete specimens

The bar chart depicting the compressive strength of concrete specimens (with incorporation of 0 wt.%, 0.03 wt.% and 0.06 wt.% of GO) is shown Fig. 7.

The compressive strength of specimens was increased gradually with respect to the increase in the weight GO % in concrete. As the pores in the concrete were filled by the effect of GO, the compressive strength of the concrete was enhanced as reported in the literature [24].

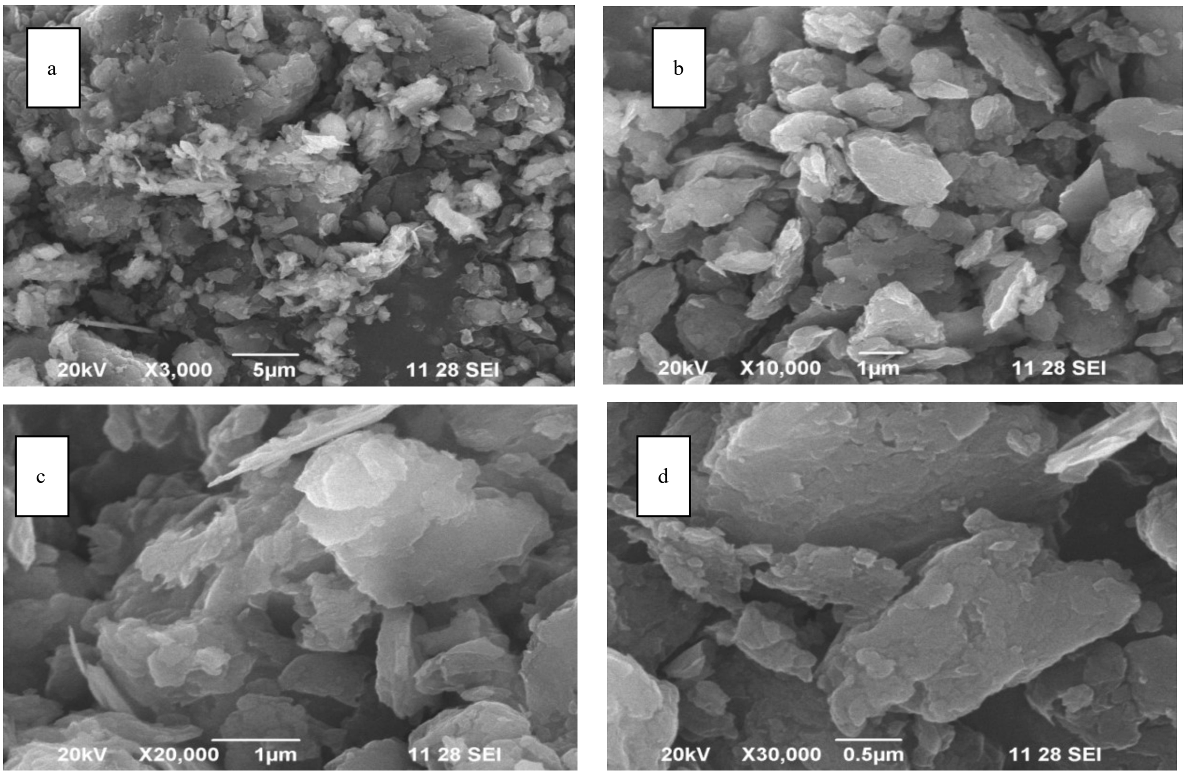

Fig. 5: SEM photographs obtained on GO nanostructured materials prepared by Modified Hammer's method (a) 3000x magnification, (b) 10000x magnification, (c) 20000x magnification, (d) 30000x magnification

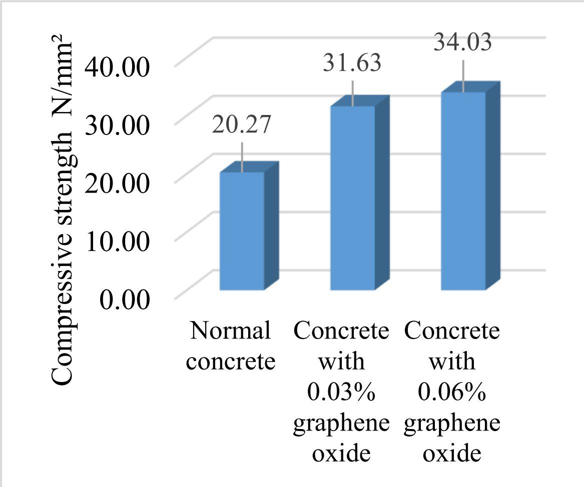

Fig. 7: Compressive strength of concrete specimens (with incorporation of 0 wt.%, 0.03 wt.% and 0.06 wt.% of GO)

3.4. Studies on flexural strength of concrete specimens

In the concrete pavement design, the flexural strength of the concrete referred as the modulus of rupture play a major role [25]. The flexural strength of the concrete were performed on 100 x 100 x 500mm prisms as per IS 516 [26] as shown in Fig. 8 (a, b). The modulus of rupture of specimens was found to be 5.82 N/mm^2 (0 wt. % GO), 7.58 N/mm^2 (0.03 wt. %) and 6.87 N/mm^2 (0.06 wt.%).

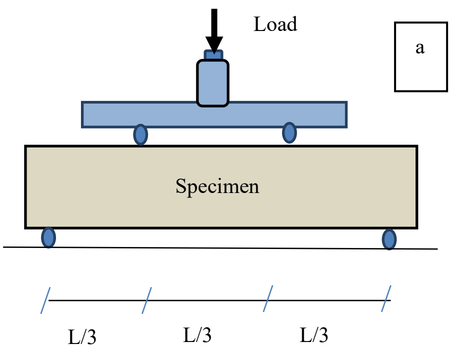

Fig. 8: (a, b): Schematic representation of measurement of flexural strength in concrete specimens

The bar chart depicting the flexural strength of concrete specimens with incorporation of 0 wt.%, 0.03 wt.% and 0.06 wt.% of GO as shown Fig. 9.

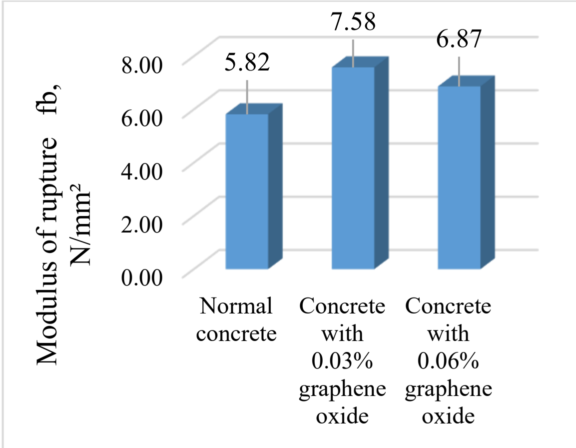

Fig. 9: Flexural strength of concrete specimens (with incorporation of 0 wt.%, 0.03 wt.% and 0.06 wt.% of GO)

The flexural strength of concrete specimen (incorporated with 0.03 wt.% of GO) has shown 1.3 times higher than that of control specimen and 1.10 times more than that of specimen (incorporated with 0.06% wt. % of GO). This may be due to the elongation effect of concrete specimen with the optimum level of GO (i.e., 0.03 wt.% of GO) [27].

3.5. Studies on elastic modulus of concrete specimens

The elastic modulus of the concrete specimens (150 x 300 mm) were studied to understand the compression behaviour and load carrying capacity of the specimens. The measurement of elastic modulus of the concrete specimens with GO (0 wt.%, 0.03 wt.%, 0.06% wt. %) was carried out in an universal testing machine as per the schematic diagram shown in Fig. 10 (a,b).

The bar chart depicting the elastic modulus of concrete specimens with incorporation of 0 wt.%, 0.03 wt.% and 0.06 wt.% of GO is shown Fig. 11.

The elastic modulus of the specimens was found to be 44447 N/mm^2 (0 wt. % of GO), 34531 N/mm^2 (0.03 wt. % of GO) and 48706 N/mm^2 (0.06 wt.% of GO). Based on this, it was found that the specimen with 0.03 wt. % of GO can accommodate more strain when compared with the other two specimens (i.e., control and specimen with 0.06 wt.% of GO). This peculiar mechanical behaviour has resulted in low elastic modulus for the concrete specimen having 0.03 wt.% of GO.

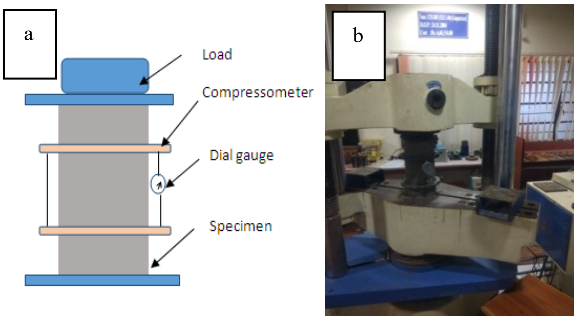

Fig. 10: (a, b): Schematic representation of measurement of elastic modulus in concrete specimens

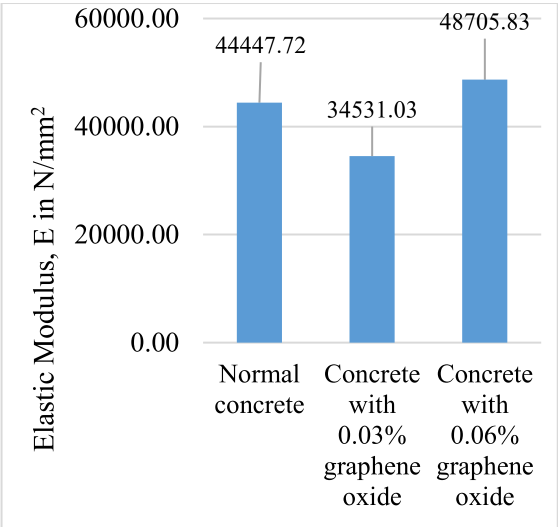

Fig. 11: Elastic modulus of concrete specimens (with GO)

3.6. Studies on ductility index of concrete specimens

The ratio of the maximum load deformation to the elastic limit deformation is the ductility index which is a very important parameter in understanding the mechanical characteristics of the solid blocks. The measurement of ductility index of the concrete disc specimens (150 x 64 mm) with GO (0 wt.%, 0.03 wt.%, 0.06% wt. %) was carried out in an impact testing machine as per the schematic diagram shown in Fig. 12 (a,b) and as per IS 2386 (Part 4).

The 45 N hammer was dropped at the centre of the disc specimen at a height of 30.48cm with the 64 mm steel ball repeatedly. The number of blows required to cause the first visible crack at the top surface in the specimen was the initial failure and the ultimate failure was the number of blows after which the disc specimen failed fully.

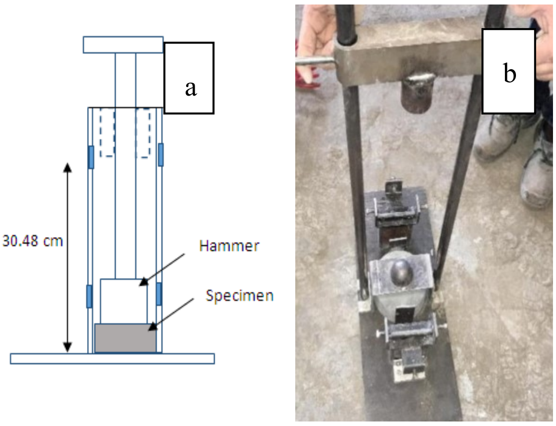

Fig. 12: (a, b) Schematic representation of measurement of ductility index in concrete specimens with impact testing machine.

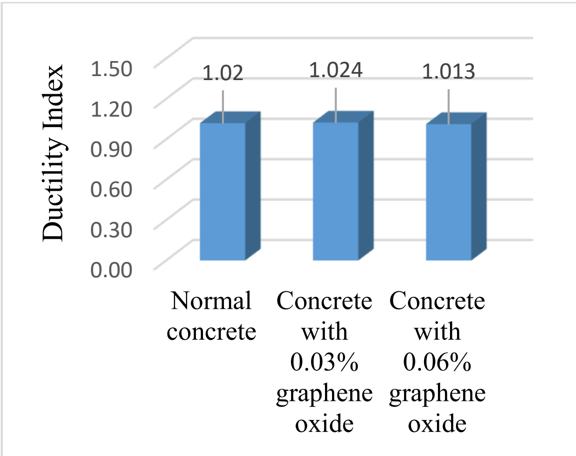

Fig. 13: Ductility index of concrete specimens (with incorporation of 0 wt.%, 0.03 wt.% and 0.06 wt.% of GO)

The average ductility index of the specimens was found to be 1.02 (0 wt. % of GO), 1.024 (0.03 wt. % of GO) and 1.014 (0.06 wt.% of GO). The bar chart depicting the ductility index of concrete specimens with the incorporation of 0 wt.%, 0.03 wt.% and 0.06 wt.% of GO as shown Fig. 13. The ductility index of the specimen (incorporated with 0.03 wt.% of GO) was found to be marginally higher than that of other specimens. This may be due to the enhancement of impact energy of the specimen because of GO.

4. Conclusion

The graphene oxide nanostructured materials thus prepared by Modified Hammer's method in this work show a simple technique. The XRD studies confirm the formation of graphene as reported in the literature. The exfoliation behaviour of graphene was confirmed by SEM analysis. In this research work, adetailed experimental study has been carried out on concrete with addition of GO in appropriate levels (0, 0.03 and 0.06 wt%). The compressive strength of concrete specimen with incorporation of 0.06 wt.% GO resulted in an enhancement of 68 % in comparison with control. However, the flexural strength of concrete specimen with 0.03 wt% GO exhibited an enhancement of 34.2% when compared with control. Similarly, the elastic modulus of specimen with 0.06 wt. % of GO resulted in the enhancement of 4.34% than control. The impact strength of the concrete specimen with 0.03 wt.% of GO resulted in the enhancement of 36 % than that of control. Therefore, the physico-mechanical behaviour of concrete specimens was greatly influenced by the incorporation of GO.

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6. References

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