EXPERIMENTAL INVESTIGATION ON THE MECHANICAL PROPERTIES OF CEMENT MORTAR INCORPORATED WITH GRAPHENE AND C&D WASTE

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Abstract

Concrete is one among the essential materials utilized in engineering works.The two main properties which attribute to the reliability of concrete as a universal choice are strength and durability. Despite its remarkable properties, it has few shortcomings, namely, low tensile strength, low ductility, and unavoidable cracks. All of these inadequacies are the result of the relatively porous microstructure of concrete. The use of nanomaterials is the most influential and powerful alternative to overcome these limitations. In this paper, a comparative study of the mechanical properties of normal strength mortar over the mortar reinforced with graphene has been presented. Making use of the construction demolition waste in different proportions, namely, 25% and 50% as the partial replacement for fine aggregate, graphene was incorporated in the cement mortar of 1:3 grade in the proportion of 0.1%, 0.4%, 0.7%, and 1% by weight of cement respectively. The proportion of construction demolition waste and graphene were consequently varied and the corresponding change in mechanical properties, namely, compressive strength, tensile strength, and flexural strength of cement mortar was observed on the 7th day, 14th day, 21st day, and 28th day respectively and the same was compared with the result of normal mortar. It was observed that these mechanical properties increased with an increase in the proportion of graphene up to a certain limit after which it decreased. However, the optimum percentage of graphene varied along with the variation in the percentage of C&D waste.

Keywords: *Concrete, Nano Materials, Graphene, C&D Waste, Mechanical Properties*

1. INTRODUCTION

Cement concrete is one of the fundamental building and construction material used worldwide. It is durable and has outstanding properties to supplement the construction field under docile environments. Although highly durable, the porous internal structure of the cement concrete greatly limits the tensile strength of the concrete. Various conventional methods considered to overcome this weakness are to incorporate concrete with fibers such as steel fibers, polymer fibers, carbon fibers etc. However, these fibers have their own limitations. Steel fibers are prone to corrosion whereas polymer fibers even by providing good tensile strength lack consistency. Moreover, the addition of these fibers significantly affects the workability of concrete. All these fibers mainly focus on improving the macrostructure of the concrete which is not enough to resolve the limitations regarding the concrete.

The microstructure of the concrete is the major area where the focus needs to be concentrated as the strength of the concrete is mainly attributed to its microstructure. The main hydration product of cement-based materials, the CSH-gel, is a nano-structured material (Quercia et al. 2014). The adhesive property of the CSH gel formed after hydration process is the source of the mechanical strength of the concrete. Thus, to improve the mechanical properties of the concrete, one needs to improve the microstructure of the concrete. This has led to increased research in the field of Nano science which is seen as the most powerful alternative to solve the problem.

Nano science relates to the study of properties of particles in the Nano scale. Nano as the name suggests refers to the magnitude of 10^{-9}. Nano Science deals with every particle in molecular or atomic scale. The various properties of the material significantly come into light at this scale. This application of

Nano science in the field of construction has already begun in recent times. Due to exceptional mechanical properties and signs to revolutionize the construction industry, the interest to study the Nano materials for the construction field has increased among the researchers.

2. LITERATURE REVIEW

Antonio et al. (2016) described the advancement of researches in the field of nanomaterial graphene for the improvement of the mechanical properties and durability of concrete. Similarly, Nandhini et al. (2016), investigated the effect of addition of graphene oxide in fly ash concrete while Ming-li et al. (2016) studied the effect of addition of functionalized graphene (FGN) on the mechanical properties, fluidity and microstructure of cement mortar and Hassani et al. (2014) studied the effect of graphene oxide on the mechanical properties and durability of concrete pavement. All these studies focused on incorporating mainly functionalized graphene to improve the mechanical properties of cement mortar and concrete. Although the results seemed favourable, functionalized graphene being very reactive are not stable in physiological solution. Thus, it is very difficult to control the properties as per our requirement.

Another Nano material under research is Graphene. The mechanical properties of Graphene exhibit its potential to be used in the construction industry as reinforcements. Graphene having extremely high aspect ratio in the range of 1000:1 to 2,500,000:1 can be used to significantly improve the microstructure of the concrete thus avoiding considerable cracks (Makar et al. 2005).

With the advancement in technology, modernization and urbanization is spreading rapidly throughout the world. This has resulted in frequent changes in building design and orientations. The materials, debris and rubble resulting from these frequent modelling and construction due to design changes known as the construction demolition waste has added further burden to the construction industry and environment as whole as the disposal mechanism of these wastes are not well established. It is in this light; researches are going on to recycle these wastes to be used again in the construction industry which will not only solve the disposal problems but also supplement in the construction field.

Cement based concrete mainly consist of cement, fine aggregates, coarse aggregates, admixtures and water (S Sanju et al. 2016). Recycled construction demolition waste can be used as a full or partial replacement of coarse and fine aggregates which will ease out the pressure on the environment and will also economise the construction industry. Many researches have been done to replace fine aggregate with construction and demolition waste. Monish et al. (2012) carried out an experimental investigation to study about the effect of the replacement of the fine aggregate by demolition waste on the workability and the compressive strength of concrete while Raman et al. (2017) studied the replacement level of the natural river sand by demolished waste in concrete. Most of these studies have focused on replacing fine aggregates compared to coarse aggregates. However, these wastes do not have the same strength as the materials they have replaced. The general problems faced are increased moisture content and low strength concrete. To overcome the cons faced by using recycled construction demolition waste, appropriate additives are to be introduced. Nano materials in this case can solve this problem. Thus, in this research an experimental investigation was conducted to study the mechanical properties of cement mortar by incorporating graphene as additive to strengthen the mix after replacement of coarse aggregate by construction and demolition waste in various proportions.

3. EXPERIMENTAL PROGRAMME

3.1. Materials

Ordinary Portland Cement (OPC) 43 Grade was used as binding material in the mortar. The sand used was Manufactured Sand (M-sand) which was sieved in a proper manner so as to achieve Zone II gradation. The Construction and Demolition Waste (CDW) was used as a partial replacement to fine aggregates in the cement mortar. The CDW was sieved though 4.75mm sieve and zoning was done to achieve the grade requirements of Zone II. The sand was replaced by 25% and 50% CDW. Industrial graphene purchased from United Nanotech Innovations Pvt. Ltd., Bangalore was used. The physical properties of the materials used has been presented in Table 1 to Table 3.

Table 1. Physical properties of cement

Physical Properties	Test Results	IS 8112-1989 Standards
Fineness	6.8%	10%
Specific gravity	3.1	3.15
Standard consistency	30%	25-35%
Initial setting time	90 minutes	Minimum 30 minutes

Table 2. Physical properties of sand

Zone	Specific gravity	Loose density (kg/m^3)	Bulk density (kg/m^3)
II	2.42	1496	1634

Table 3. Physical properties of graphene

Physical properties	Range of values
Tensile modulus	>1000 GPa
Tensile strength	>5 GPa
Bulk density	0.30 gm/cc
Average diameter	10-15µ
Average thickness	10-15nm
Purity	>98%
Number of layers	10-15
Surface area	112 m2/gm

3.2. Mix Proportion

Several trial mixes were carried out on cube moulds of size 7.07cm as per the Indian Standards with the variation in water cement ratios ranging from 0.35 to 0.7 for cement: sand ratio of 1:3. The ratio of cement: sand of 1:3 with water cement ratio of 0.5 yielded the optimum strength with good workability. Henceforth, 1:3 (cement: sand) ratio by weight and 0.5 water cement ratio was adopted for further investigations. The various mix proportion used has been presented in Table 4.

Table 4. Varieties of mortar mixes

S.No.	Mix type	Cement	Sand (kg)	CDW	Graphene	Water (ml)
1	Conventional Mortar	1.8	5.4	Nil	Nil	900
2	M-C25	1.8	4.05	1.35	Nil	900
3	M-C50	1.8	2.7	2.7	Nil	900
4	M-C0 (G-0.1%)	1.8	5.4	Nil	1.8	900
5	M-C0 (G-0.4%)	1.8	5.4	Nil	7.2	900
6	M-C0 (G-0.7%)	1.8	5.4	Nil	12.6	900
7	M-C0 (G-1%)	1.8	5.4	Nil	18	900
8	M-C25 (G-0.1%)	1.8	4.05	1.35	1.8	900
9	M-C25 (G-0.4%)	1.8	4.05	1.35	7.2	900
10	M-C25 (G-0.7%)	1.8	4.05	1.35	12.6	900
11	M-C25 (G-1%)	1.8	4.05	1.35	18	900
12	M-C50 (G-0.1%)	1.8	5.4	2.7	1.8	900
13	M-C50 (G-0.4%)	1.8	5.4	2.7	7.2	900
14	M-C50 (G-0.7%)	1.8	5.4	2.7	12.6	900
15	M-C50 (G-1%)	1.8	5.4	2.7	18	900
Total Quantiy		27	71.55	20.25	118.8	13500

3.3. Fabrication of Mould

The mould used was rectangular in shape with cast iron frame resting on a wooden board with 12 compartments spaced by granite blocks so as to form prisms of size 160mm×40mm×40mm as per the standards of BS EN 1015-11. Fig 1 shows the mould specimen.

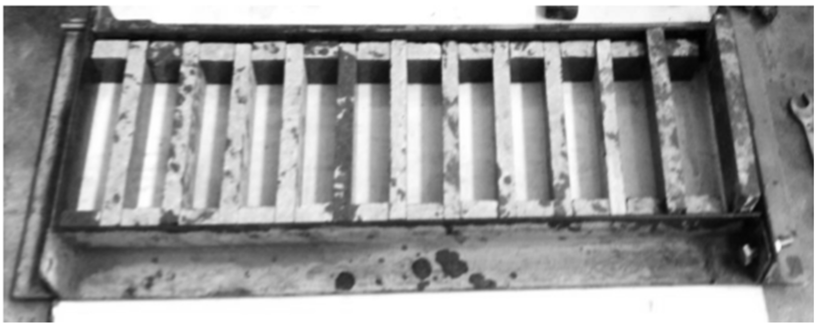

Figure 1. Mould with prism compartments

3.4. Dispersion of Graphene

In cement-based materials, the Graphene molecules tend to agglomerate due to strong Vander Wall's force of attraction resulting in poor dispersion. In order to ensure the proper dispersion of Graphene in cement mortar, ultrasonic process was adopted. The ultra sonicator was employed to disperse the Graphene. 20 KHz frequency and 50% amplitude of ultrasonic pulse was applied.

A predetermined quantity of Graphene was weighed in a weighing balance sensitive to 0.001gm and mixed with calculated volume of water in a beaker. Not more than 3gms of Graphene was mixed in one shift to assure homogeneous dispersion. Graphene and water were poured in a glass beaker and stirred well. The probe of the ultra sonicator was inserted inside the beaker and sonication process was allowed to take place for 20 minutes time. The dispersed mixture was then carried to concrete laboratory where it was added to mortar at the time of mixing.

3.5. Test Methodology

3.5.1. Flexural Strength Test

The cured specimen was taken out from water and allowed to lose its dampness. After those suitable markings were made in the specimen to conduct the flexural strength test. The test was carried out as per BS-EN 1015-11. Suitable markings were done as shown in the figure 2.

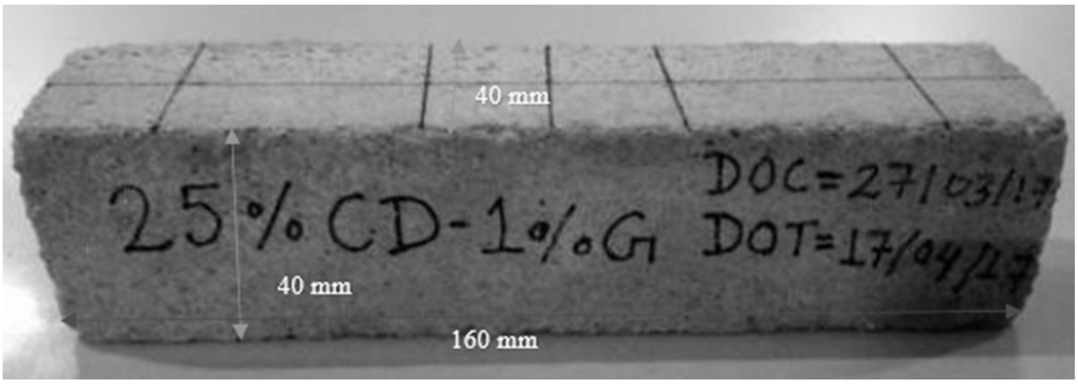

Figure 2. Flexural strength test specimen

In flexural strength testing machine, the three-point loading of the prism specimen was carried out till it failed. The dial gauge reading was converted to kg force and ultimate load carried by the specimen was noted down and flexural strength was computed by using the formula given belowin Eq. (1).

$$\sigma f = \frac{Pl}{bd^2} \quad (1)$$

where, σ_f= flexural strength in MPa, P= load applied in Newton, l= span of the specimen in mm, b= breadth of the specimen in mm, d= depth of the specimen in mm

Three specimens were tested at every 7, 14, 21 and 28 days from the day of curing and the average value was taken as the flexural strength of the specimen of a particular mix. Out of the two broken halves of the flexural strength testing specimen, one halve was used for determination of compressive strength and the next halve was used for the determination of split tensile strength.

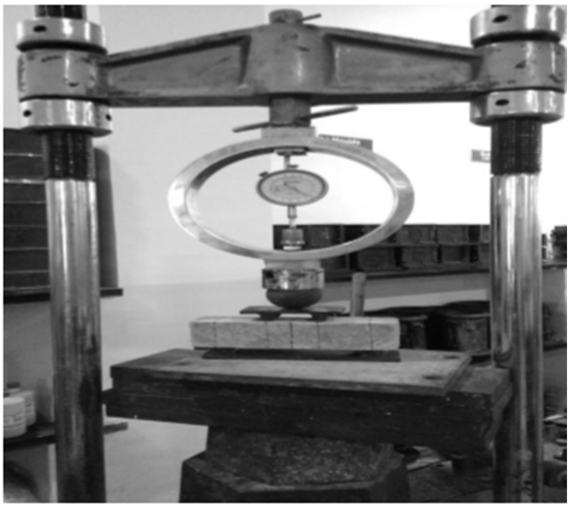

Figure 3. Flexural strength test set up

Figure 4. Flexural strength test specimen at failure

3.5.2. Compressive Strength Test

One half of the broken specimens were tested on 7, 14, 21 and 28 days from the day of curing. Compressive strength test was carried out confirming to BS EN 1015. Uniformly distributed load was applied on the specimen on the cross-section area of 40mm×40mm till the specimen failed under crushing load. Three halves of the broken specimen of a particular mix were tested and the average value was taken as the compressive strength of the particular mix. Compressive Strength was calculated using the formulae given below in Eq. (2).

$$\sigma c = \frac{P}{A} \quad (2)$$

Where, σ_c = compressive strength in MPa, P= load applied in Newton, A= cross section area of specimen in mm^2

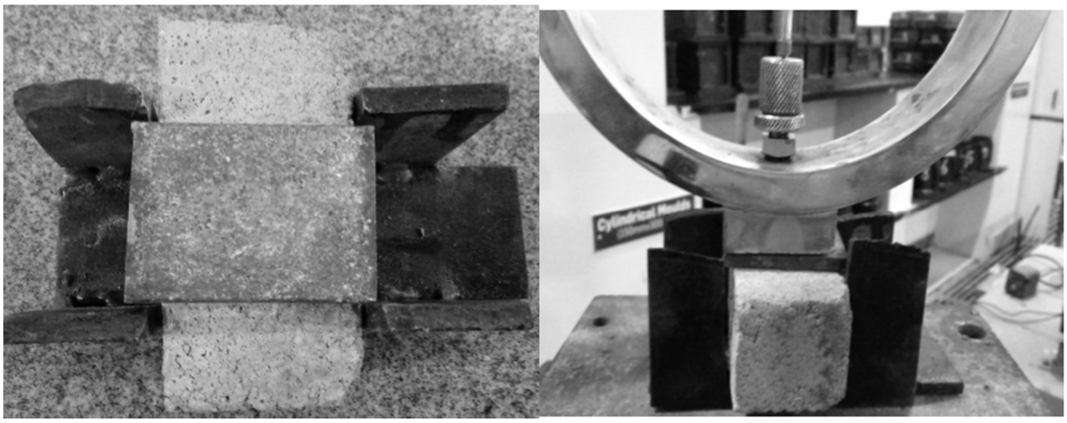

Figure 5. Compressive strength test specimen in zig and test setup

3.5.3. Split Tensile Strength Test

Other halve of the broken specimen of the flexural strength test was tested for split tensile strength test on 7, 14, 21 and 28 days from the day of curing. Line load was applied on the specimen on the section of 40mm till the specimen failed. Three samples from a particular mix were tested and average value was taken as the split tensile strength of the particular mix. Split Tensile Strength was calculated using the formulae given below in Eq. (3).

$$\sigma t = 2P/\pi bd \quad (3)$$

Where, σ_t = split tensile strength in MPa, P= load applied in Newton, b= breadth of the specimen in mm, d= depth of the specimen in mm

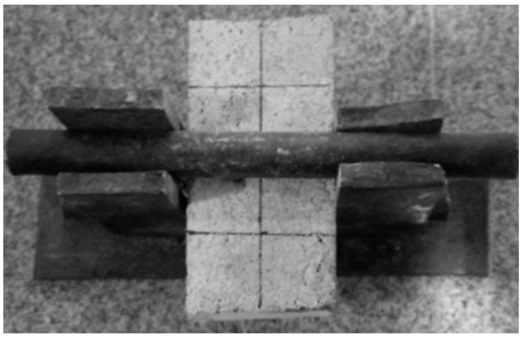

Figure 6. Tensile strength test set up

4. RESULTS AND DISCUSSIONS

The table 5 below indicate the 28-day compressive strength, flexural strength and split tensile strength for various tested samples.

Table 5. Strength of Specimens

Mix Type	Flexural Strength	Compressive Strength	Tensile Strength
NORMAL	5.58	24.83	3.00
25% CD	5.32	19.01	2.45
50% CD	5.09	17.78	2.16
NORMALWith 0.1% G	6.79	25.75	3.62
NORMAL 0.4% G	6.56	28.20	4.06
NORMAL 0.7% G	7.65	28.81	4.46
NORMAL 1% G	6.90	32.50	4.04
25% CD With 0.1% G	5.94	21.46	3.20
25% CD With 0.4% G	7.24	27.59	3.83
25% CD With 0.7% G	6.67	22.07	3.18
25% CD With 1% G	5.66	21.46	3.76
50% CD With 0.1% G	5.83	18.39	2.45
50% CD With 0.4% G	6.22	22.99	2.90
50% CD With 0.7% G	5.32	18.39	2.77
50% CD With 1% G	6.11	19.31	3.77

All measurements are in MPa

4.1. Compressive Strength

The results of compressive strength values for cement mortar with varying percentage of construction and demolition waste and varying percentage of graphene are shown in figure 7.

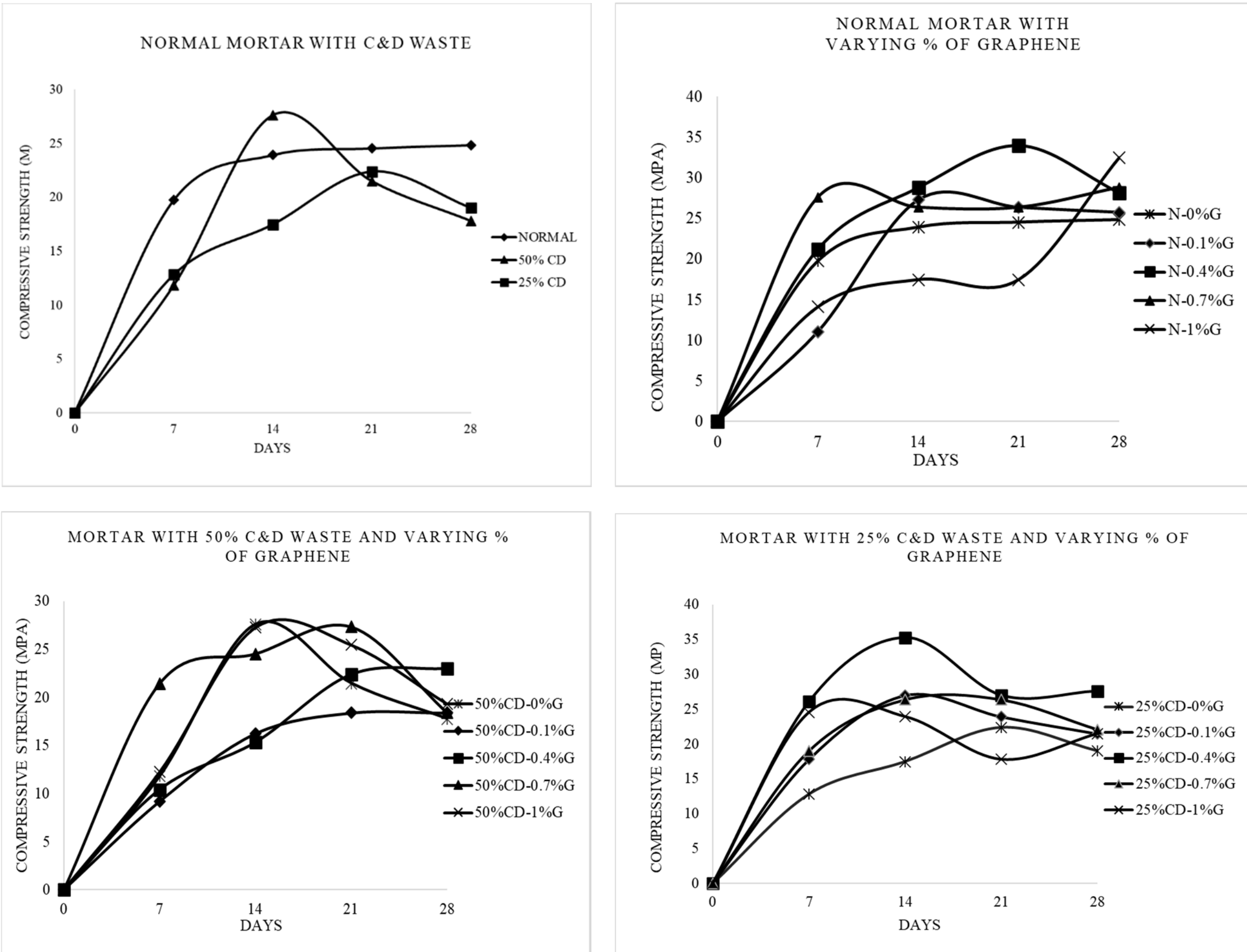

Figure 7. Compressive Strength Test Results

From the above graphs, it is seen that there is decrease in compressive strength of mortar incorporated with 25% and 50% construction and demolition waste compared to the normal cement mortar. This may be because of the formation of transition zone between C&D waste and sand, forming the weak zone in mortar. Moreover, C&D waste being more porous in nature results in increased porosity thus decreasing the compressive strength of cement mortar.

Also, there is increase in compressive strength of mortar with the incorporation of graphene in different proportions. This is because graphene is a nanoparticle which fills the nano voids decreasing the porosity thus reducing the transition zone in mortar leading to the increase in compressive strength.

It is seen that the incorporation of graphene in varying percentage in mortar with 25% C&D waste has led to increase in the compressive strength where in addition of 0.4% graphene by weight of cement has shown the optimum result. This is because with the increase in % of graphene, the graphene molecules tend to come close to each other leading to their re-agglomeration thus resulting in poor distribution of graphene molecules in the mortar.

It is seen that the incorporation of graphene in varying percentage in mortar with 50% C&D waste has led to increase in the compressive strength. The addition of 0.4% graphene by weight of cement has shown the optimum result. The curve of varying percentage of graphene has shown the greater values of compressive strength in 14th day and later decrease in 28th day, this is because the hydration product increases with the day and so does the Ca(OH)2 thus increasing the alkalinity of the mortar.

4.2. Flexural Strength

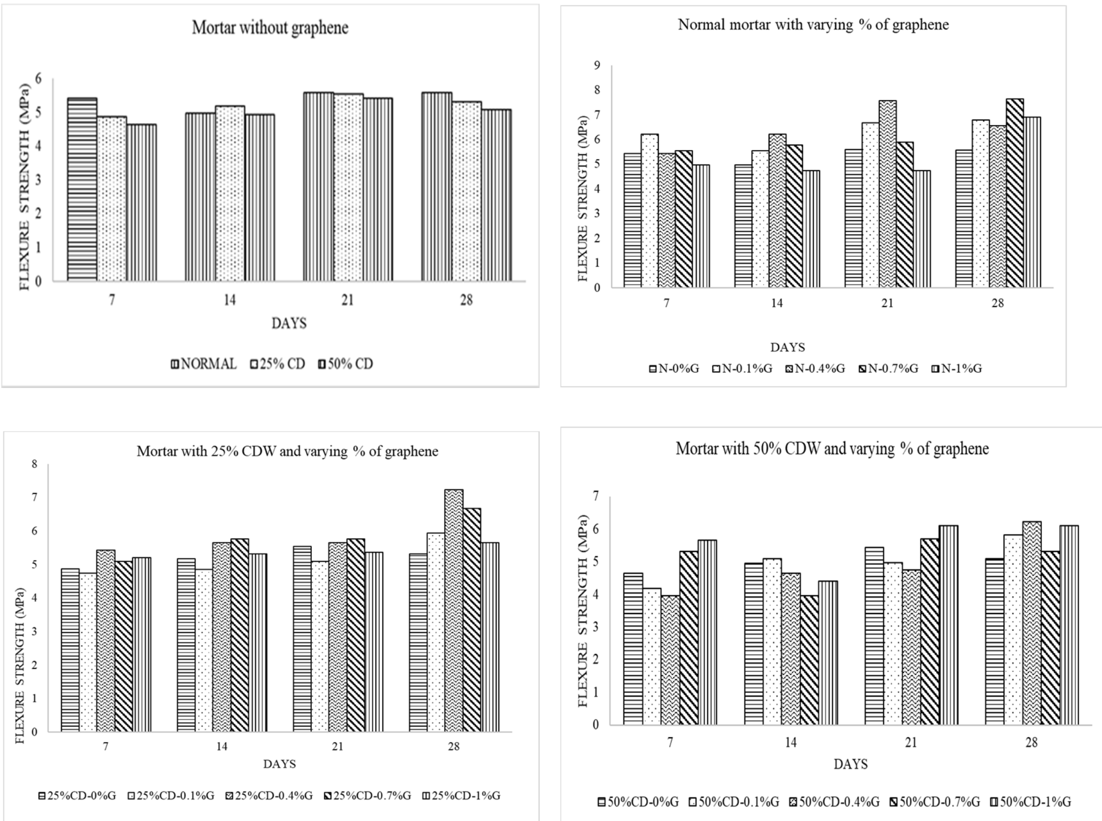

Figure 8. Flexural Strength Test Results

Figure 8 shows the flexural strength test results. It is seen that there is decrease in flexural strength of mortar incorporated with 25% and 50% construction and demolition waste compared to the normal cement mortar. This is due to the formation of transition zone between C&D waste and sand particles and also due to the increase in porosity of mortar. This weak zone initiates the cracks in the bottom fibers where tensile stress is developed when the flexural load is applied. These cracks propagate to the compression zone and the specimen fails under lesser flexural load.

There is increase in flexural strength of mortar with the incorporation of graphene in different proportions. This may be due to the fact that graphene fills the nano voids and reduces the transition zone between C&D waste and sand particles. So, when the flexural load is applied, there are not enough weak points to initiate the cracks thus improving the flexural strength. The incorporation of graphene in varying percentage in mortar with 25% and 50% C&D waste has led to increase in flexural strength of mortar with the addition of 0.4% graphene by weight of cement showing the optimum result.

4.3. Split Tensile Strength

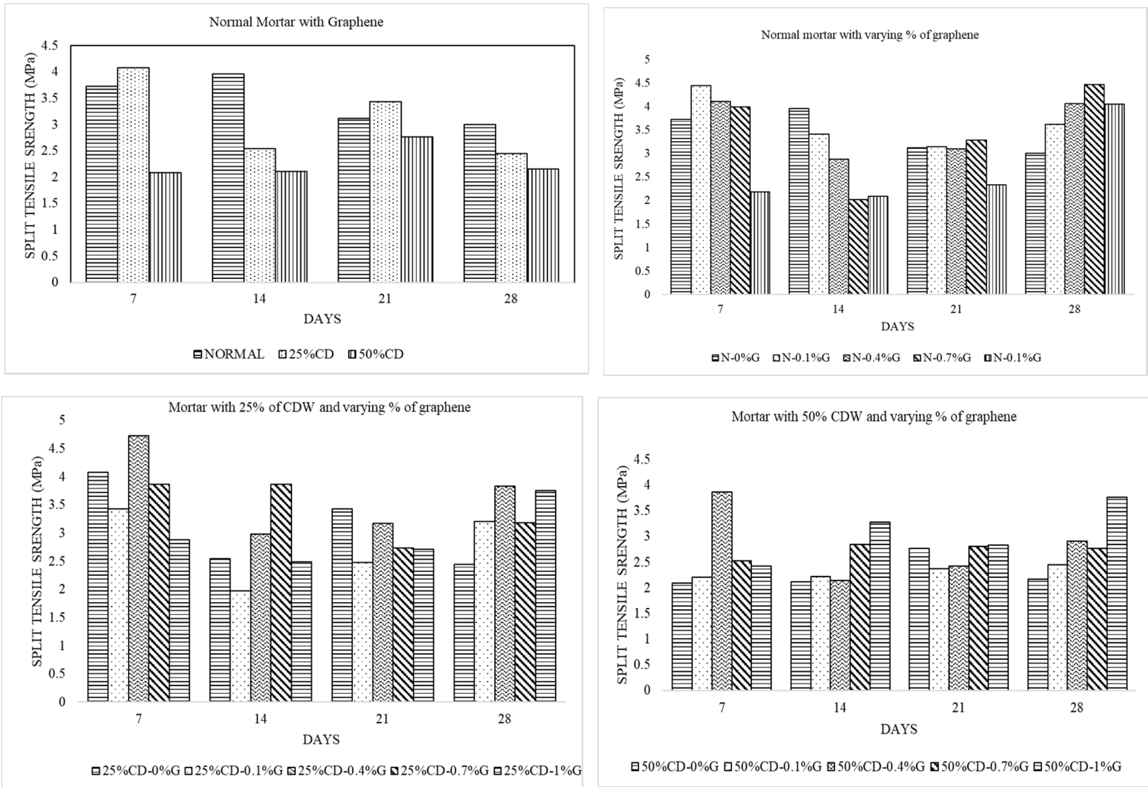

Figure 9. Split Tensile Strength Test Results

Figure 8 shows the split tensile strength test results. The incorporation of graphene in varying percentage in mortar has led to increase in split tensile strength of mortar. The addition of 0.4% graphene by weight of cement has shown the optimum result for mortar with 0%, 25% and 50% construction and demolition waste.

5. SUGGESTION AND RECOMMENDATION

The results obtained from the analysis gives us the fair level of idea that with the increment of proportion of Graphene, there is considerable increase in the flexural, compressive and tensile strengths up to a certain limit. The increasing trend ceases after a specific proportion which varies with the variation of C&D waste replaced and the flexural, compressive and split tensile strength decreases with the use of C&D waste. For the future work more samples with different mix proportion is recommended for the testing inorder to obtain a optimal mix ratio.

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