MECHANICAL BEHAVIOUR OF CONCRETE PRISMS STRENGTHENED BY NANO GRAPHENE FIBERS

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ABSTRACT

Recently Nano-technology is considered to be used in many applications and it has received an increasing attention in building materials. More experimental studies are required for understanding the real behaviour of modified concrete with Nano-graphene. In this paper, fifty-two tested specimens with different Nano-graphene types and different ratios were tested to study the behaviour of modified concrete specimens containing Nano-particles at various water-cement ratios. The specimens' dimensions were 100 mm ×100 mm ×400 mm. twelve tested specimens are control. In the first group, twenty tested specimens were prepared by adding Graf Pro nano graphene particles with ratios equal to 0.5% and 1% of cement weight. In the second group, ten specimens were prepared by adding (Graf Pro + Graf Max (9:1)) nano graphene particles with ratio equal to 0.50% of cement weight. In the third group, ten tested specimens were prepared by adding Graf Max nano graphene particles with ratio equal to 0.50% of cement weight. All these specimens at w/c=0.35 and 0.4. Comparison between the tested control specimens and results of tested specimens containing Nano-particles was done. The flexural and compression testing were recorded. The results showed that the use of Nano-particles enhances the microstructure of concrete by filling the harmful pores and dandifying the microstructure of cement paste. Finally, the Nano-particles resulted in significant increase in the flexural and compressive strength of concrete.

Keywords: Nano-graphene, Cement, Compressive strength and Flexural strength.

1. INTRODUCTION

The new dimension in the construction world is nanotechnology. The development in the field of nanotechnology gives an advantage of developing cementitious materials at nanoscale [(1)]. Cement-based concrete is a widely used material for a great variety of constructions. Although, cement has great properties and high performance, its intrinsic brittleness is a weakness that requires further investigation for improvement. Graphene demonstrates a number of excellent properties, such as high flexibility, 1TPaYoung's Modulus, 130GPa tensile strength, high electrical and thermal conductivity [(2)]**.** P. Sudheer and Abhinay (2017) [(3)] studied the effect of replacement of nano-graphene particles respect to cement in mortar cubes mixture casted for various proportions (including 1%, 2%, 3%, 4% and 5%). A slight increase in compressive strength up to 12% was observed using graphene when compared to conventional mortar cubes.

Mallikarjuna and Sreenivas (2018) [(4)] studied the performance of graphene cement concrete as incorporation of graphene nanoparticles in concrete showed interested modifications in mechanical and micro structural properties. Results of this study showed that Nanoparticles of graphene (of 1% to 3% by weight of cement) improved the mechanical properties of the concrete, both compression and flexural strength. Results of this study indicated that concrete specimens with 2% graphene are the most effective in improving the mechanical properties of concrete.
In another study of graphene, Wang et al. (2015[)] [(5)] was investigated that addition by 0.05% has remarkably increased the compressive and flexural strength by 46.5 % and 68.5 % respectively at the age of 7 days in the cement paste due to modification of its pore structure with increased nucleation effect of graphene oxide
Dimov et al. (2018) [(6)] was studied the performance of multifunctional nanoengineered concrete showing an unprecedented range of enhanced properties when compared to standard concrete. These include an increase of up to 146% in the compressive and 79.5% in the flexural strength, whilst at the same time an enhanced electrical and thermal performance is found decrease in water permeability by nearly 400% compared to normal concrete makes this composite material ideally suitable for constructions in areas subject to flooding. The unprecedented gamut of functionalities that are reported in this paper produced by the addition of water stabilized graphene dispersions, an advancement in the emerging field of nanoengineered concrete which can be readily applied in a more sustainable construction industry.

2.1. Material Properties

The materials used in this paper are the same used for normal concrete. Three types of nano materials were added as the following:
The Graf Pro Nano graphene particles used was a powder with black color, the Graf Plus Nano graphene particles used was a powder with black color and the Graf Max Nano graphene particles used was a powder with black color
The cement was used Portland cement CEM-I 52.5N; it was tested according to ESS 2421-1/2005[(6).] Properties of Ordinary Portland cement are shown in Table 1.

Table 1: Physical and mechanical properties of cement

Property	Description	Test Results	Limits
Setting time (min)	Initial	115 min	Not less than 45 min
	Final	190 min	Not more than 10 hrs.
Compressive strength (MPa)	2 days	21.2	Not less than 10
	28 days	54	42.5≤ x ≤ 62.5

Siliceous sand was used with 4.75mm maximum particle size in this research. Crushed aggregate of 20 mm maximum particle size was used in this research according to ESS 1109/2021. Polycaboxilate-based super plasticizer was used in the concrete mixes. The mix proportions for all experimental specimens were presented in Table 2.

Table 2: Proportions of used concrete mixes

Materials	**Aggregate**	**Cement and water**	**Admixture**	**Nano-particles content by weight**
	Coarse: Fine	Water: Cement	Polycaboxilate-based super plasticizer	Graf Pro-Graf Plus-Graf Max
Ratio %	0.54:0.46	0.35-0.4	1.5% *C	C*V_f%
C: Cement, W: Water, V_f: Fiber weight ratio as percentage of cement weight				

2.2. Mixing and Curing

Mix the cement, fine and coarse aggregate together for 1 minute, then add 50% of the mixing water and admixture to the mix. The rest 50% of mixing water and admixture is added to the Nano-particles (such as Graf Pro & Graf max as showed in figure 1a,) and the admixture. Mix together to ensure dispersion of the Nano-particles, then add to the automatic mixer for 2 min as shown in figure 1b.

(a) (b)

Fig.1: (a) The Nano Graphene particles and (b) The mixing procedure

Figure 2 shows the concrete specimens during casting and compacting to insure the homogeneity of concrete mix into the wooden forum and at successive stages.

Fig. 2: The tested specimens during casting and curing

After the specimens were compacted, the specimens were left to harden for 24 hours, then the sides of the form were stripped away and the tested specimens were totally submerged in water up to 7&28 days.

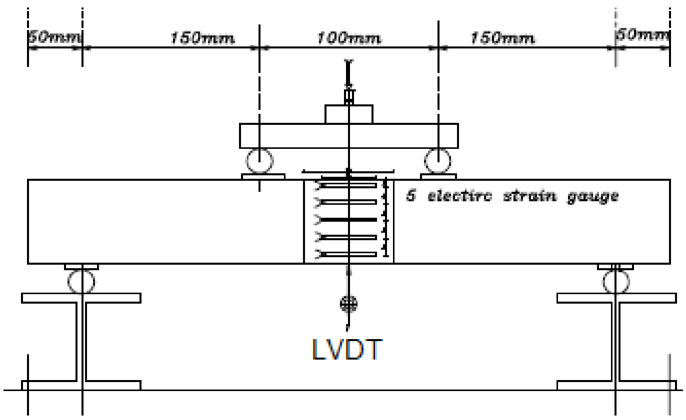
2.3 Testing Procedure

Fifty-Two tested prisms of concrete which are the control and the three groups with different types of Nano-fibers were tested as shown in Table 3. In the first group, twenty tested

specimens were prepared by adding Graf Pro nano graphene particles with ratios equal to 0.5% and 1% of cement. In the second group, ten specimens were prepared by adding Graf Max nano graphene particles with ratio 0.50% of cement. In the third group, ten tested specimens were prepared by adding (Graf Pro+ Graf Max (9:1)) nano graphene particles with ratios equal to 0.50% of cement. All results of tested specimens containing Nano-particles were compared with control tested specimens and were discussed.
The set-up for specimens tested to study the behaviour of concrete containing nano-graphene particles (100×100×400mm) is shown in Figure3. The bearing surface of the supporting and loading rollers are wiped clean, and loose sand or loose materials are removed from the surface of the specimens. The tested specimens are then placed in the machine in such a manner that the load is applied to upper most surface as cast in the mould, along one line, the axis of the specimen is carefully aligned with the axis of loading device. According to ESS1658-5/2018 & ESS1658-6/2018The load is applied without shock and increased continuously at a rate of 0.1 KN/S for flexural and 11.25 KN/S for compression, and data were automatically recorded during the test. The load increased until failure of the tested specimen.

Table 3. Parameters of tested specimens

Group	Beam Code	Type of Fiber	W/C
G1	Control 1	-	0.40
	Control 2	-	0.35
G2	B1	Graf Pro 1%	0.40
	B2	Graf Pro 0.5%	0.40
	B3	Graf Pro 1%	0.35
	B4	Graf Pro 0.5%	0.35
G3	B5	Graf Pro+ Graf Max (9:1)	0.40
	B6	Graf Pro+ Graf Max (9:1)	0.35
G4	B7	Graf Max0.5%	0.40
	B8	Graf Max0.5%	0.35



3(a)

3(b)

Fig. 3: Test set up, two electric strains gauges and two LVDTs at mid-span section of tested specimens

Fig. 4: Failure mode of tested specimens containing different Nano particles

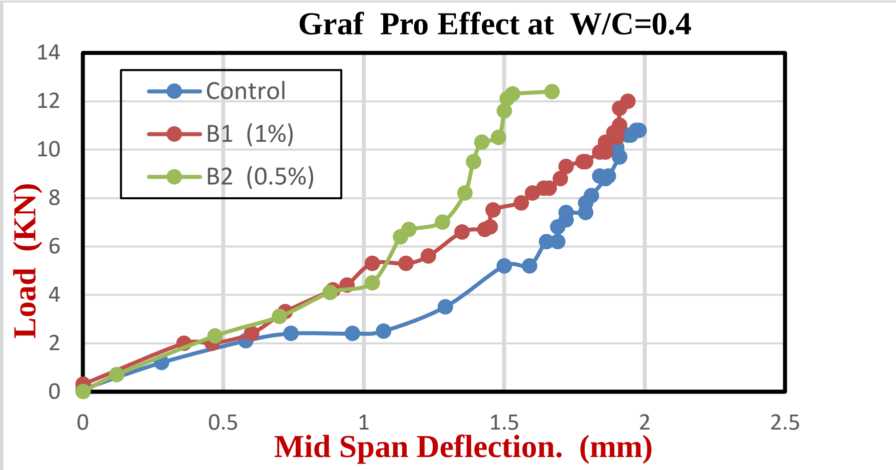
3. EXPERMENTAL RESULTS AND ANALYSIS

The analysis of test results of Nano particles concrete specimens, compared with control ones were studied in this part. The load deflection curves, flexural strength and compressive strength for tested specimens were presented.

3.1. Load Deflection Curves

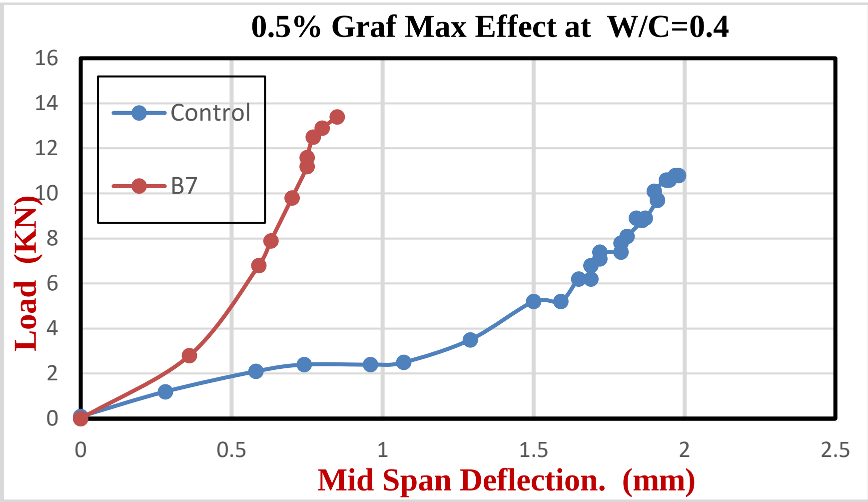
Figure 5 shows the load deflection curves of tested specimens at W/C =0.4.

Figure 5a shows the relation between load and deflection for the prisms of w/c =0.4 and strengthened by 0.5% ,1% Graf pro nano particles, the energy absorbed by the material using Graf pro 0.5%,1% increased by 22.4%, 5.4% compared with control. The modulus of elasticity increased by 12.9%, 47.7%. Finally adding Graf pro by 0.5%,1% decreased the ductility of concrete by 2%, 15.6% compared with control.



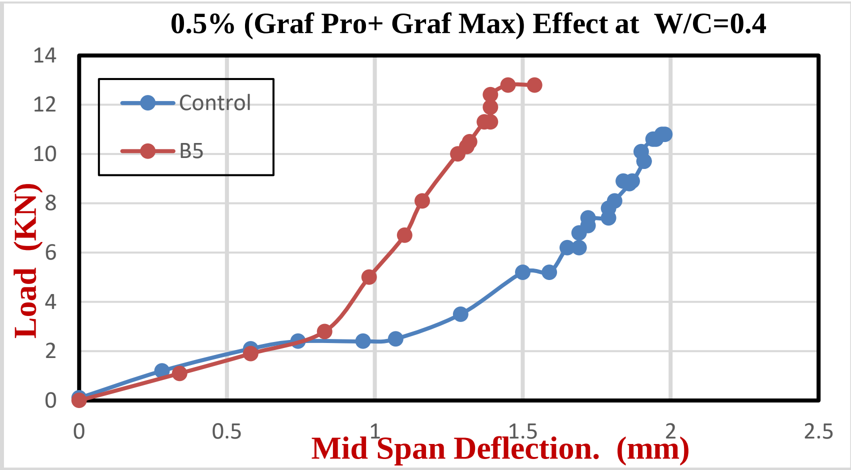
5(a)

Figure 5b shows the relation between load and deflection for the prisms of w/c =0.4 and strengthened by 0.5% Graf max nano particles, the energy absorbed by the material using Graf max 0.5% increased by 38.4% compared with control. The modulus of elasticity increased by 211.8%. Finally, adding Graf max by 0.5% decreased the ductility of concrete by 57% compared with control.



5(b)

Figure 5c shows the relation between load and deflection for the prisms of w/c =0.4 and strengthened by 0.5% (Graf pro+ Graf max) (9:1) nano particles, the energy absorbed by the material using Graf pro 0.5% increased by 8.8% compared with control. The modulus of elasticity increased by 72.9%. Finally, adding (Graf pro+ Graf max) (9:1) by 0.5% decreased the ductility of concrete by 22.2% compared with control.

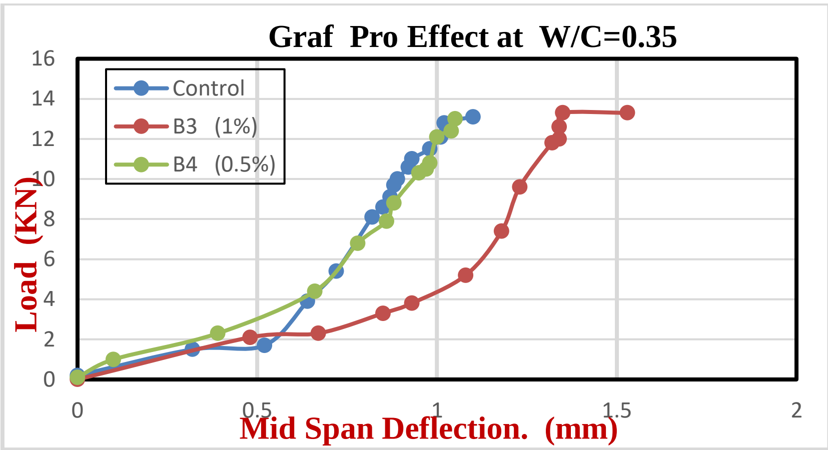


5(c)

Fig. 5: Load deflection curves for tested specimens with different Nano-particles at w/c =0.4

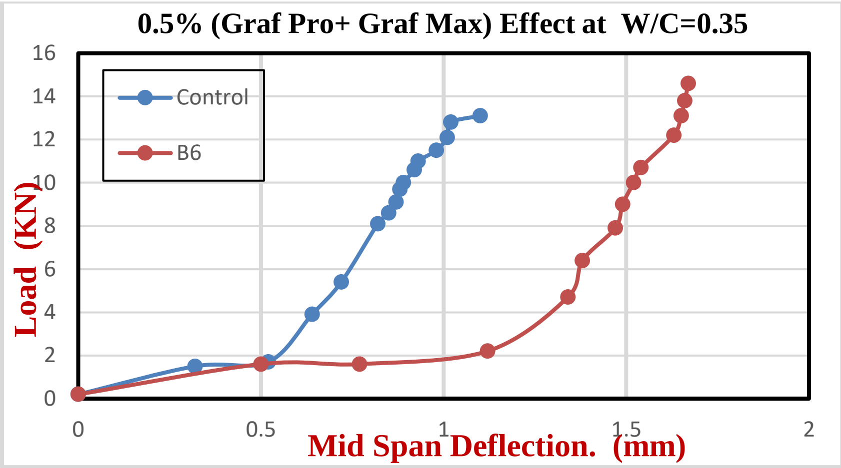
Figure 6 shows the load deflection curves of tested specimens at W/C =0.35.

Figure 6a shows the relation between load and deflection for the prisms of w/c =0.35 and strengthened by 0.5% ,1% Graf pro nano particles, the energy absorbed by the material using Graf pro 0.5%,1% increased by 3.3%, 38.9% compared with control. The modulus of elasticity increased by 8.2% using 0.5% of Graf Pro while it decreased by 23.8% in case of 1% of Graf Pro. Finally, adding Graf pro by 0.5%decreased the ductility of concrete by 4.5%, while adding 1% of Graf Pro increased the ductility of concrete by 39% compared with control.



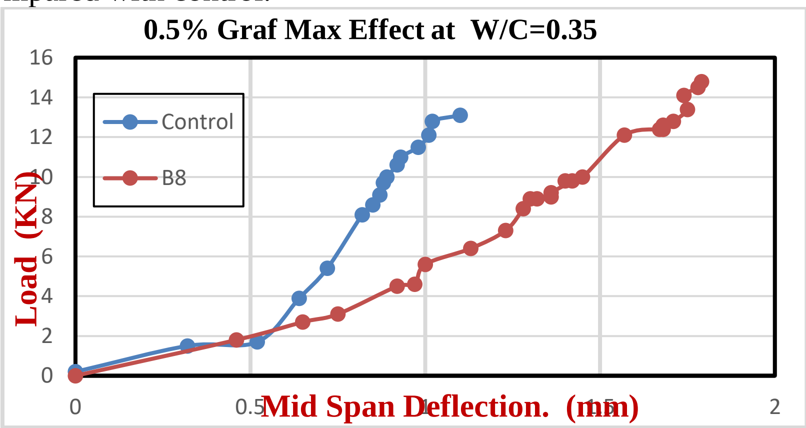
6(a)

Figure 6b shows the relation between load and deflection for the prisms of w/c =0.35 and strengthened by 0.5% (Graf pro+ Graf max) (9:1) nano particles, the energy absorbed by the material using Graf pro 0.5% increased by 40.7% compared with control. The modulus of elasticity decreased by 36.4%. Finally, adding (Graf pro+ Graf max) (9:1) by 0.5% increased the ductility of concrete by 51.8% compared with control.



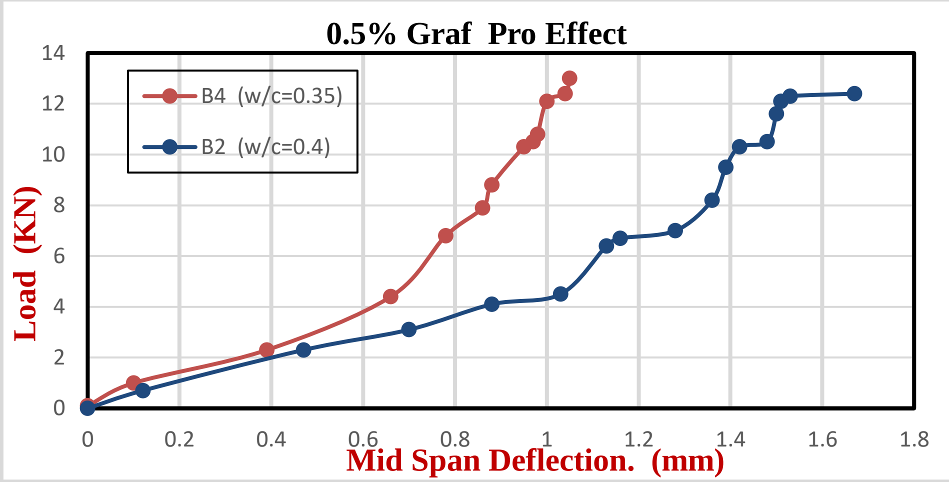
6(b)

Figure 6c shows the relation between load and deflection for the prisms of w/c =0.35 and strengthened by 0.5% Graf max nano particles, the energy absorbed by the material using Graf max 0.5% increased by 89.15% compared with control. The modulus of elasticity decreased by 28.9%. Finally, adding Graf max by 0.5% increased the ductility of concrete by 62.7% compared with control.

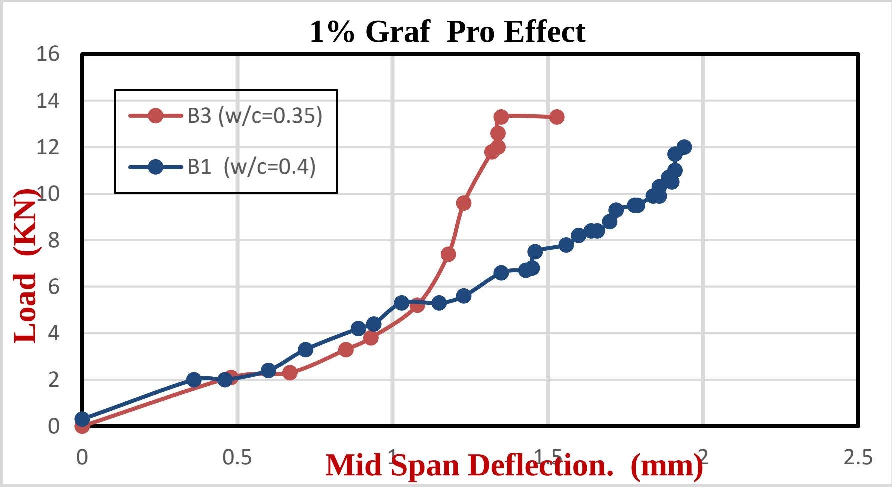


6(c)

Fig. 6: Load deflection curves for tested specimens with different Nano-particles at w/c =0.35

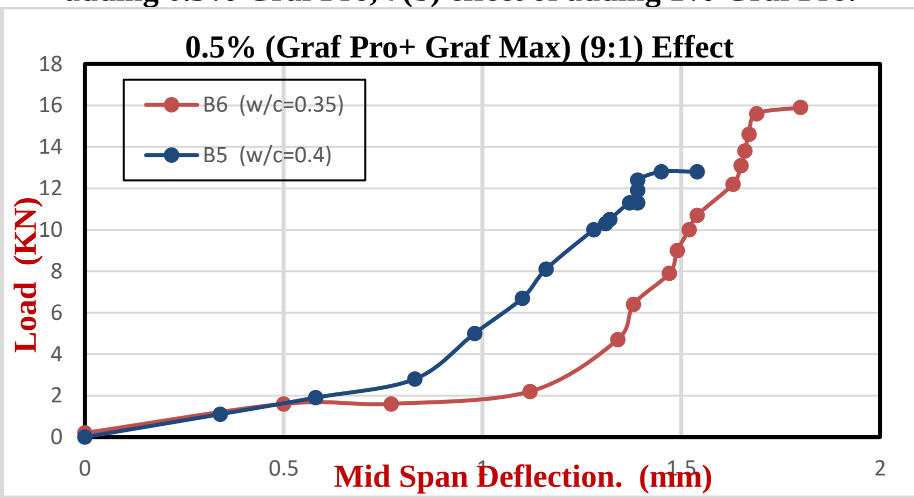


7(a)

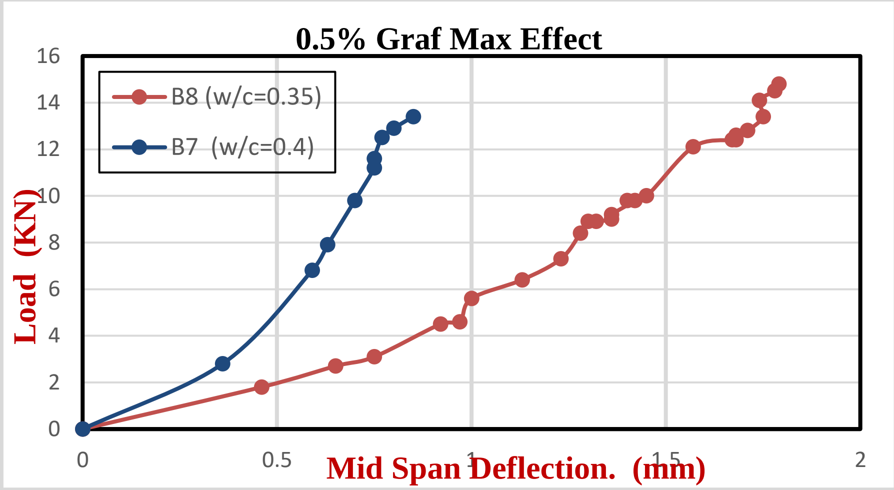


7(b)

Fig. 7: Comparative curves for tested specimens at different w/c ratios: 7(a) effect of adding 0.5% Graf Pro, 7(b) effect of adding 1% Graf Pro.



8(a)



8(b)

Fig. 8: Comparative curves for tested specimens at different w/c ratios: 7(a) effect of adding 0.5% (Graf Pro + Graf Max) (9:1), 7(b) effect of adding 0.5% Graf Max.

Fig. 9: The crack patterns of tested specimens containing different nano particles

3.2.1 Effect of Nano-Particles on Compressive and Flexural Strength at w/c=0.4

The compressive strength of control concrete tested specimens at 28 days was equal to 24.75MPa. By adding Graf Pro with ratios equal to 0.5% and 1%of cement, the compressive strength of concrete was equal to 30.74MPa and 23.4MPa respectively. By adding Graf Max with ratios equal to 0.5% of cement, the compressive strength of concrete was equal to 31.44MPa. Finally, by adding (Graf Pro + Graf Max) (9:1) with ratio equal to 0.5 of cement, the compressive strength was equal to 22.5MPa. From the results shown in figure 8, it was found that adding Nano-particles enhanced the density of concrete by increasing the ratios of Nano-particles regardless the type of Nano- particles. The addition of nano-particles increased the compressive strength of concrete specimens over the case where no such materials were used. However, increasing the content over a certain threshold started to reduce the gain.

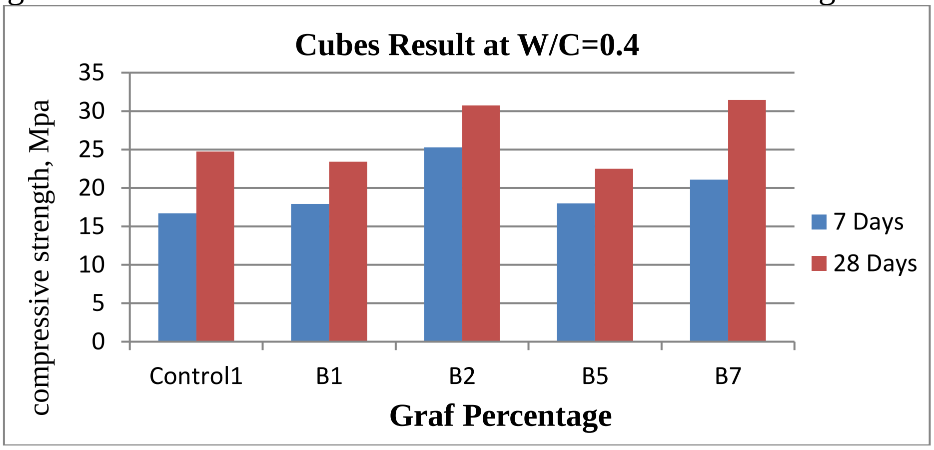


Fig. 10: Compressive Strength of Tested specimens at w/c=0.4

Figure11 presents the experimental flexural strength results of the tested specimens. Comparison between the flexural strength of the tested specimens without particles (G1) and the flexural strength of tested specimens having Nano-particles was done in figure 10.

As shown in table 4 and figure 10, the results at 28 days indicated that by adding the Nano-particles, the flexural strength increased.

Mixing Graf pro with Graf max has negative effect in increasing compressive strength while it increased flexure strength.

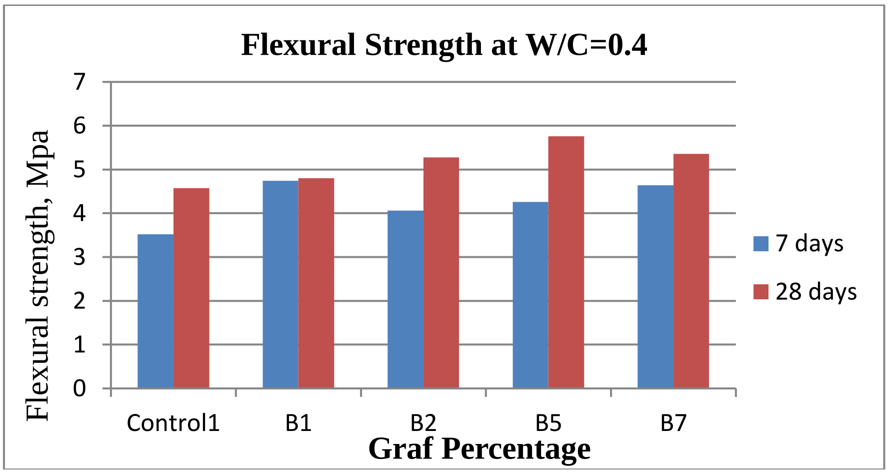


Fig. 11: Flexural Strength of Tested specimens at w/c=0.4

3.2.2 Effect of Nano-Particles on Compressive and Flexural Strength at w/c=0.35

The compressive strength of control concrete tested specimens at 28 days was equal to 23.58MPa. By adding Graf Pro with ratios equal to 0.5% and 1%of cement weight, the compressive strength of concrete was equal to 30.26MPa and 30.23MPa respectively. By adding Graf Max with ratios equal to 0.5% of cement weight, the compressive strength of concrete was equal to 32.38MPa. Finally, by adding (Graf Pro + Graf Max) (9:1) with ratio equal to 0.5% of cement weight, the compressive strength was equal to 31.15MPa.

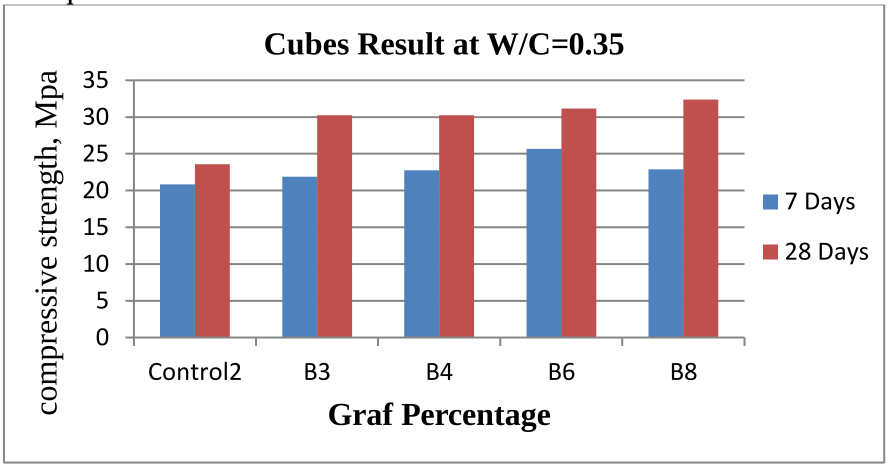


Fig. 12: Compressive Strength of Tested specimens at w/c=0.35

Figure 12 presents the experimental compressive strength results of the tested specimens. As shown by adding any type of used Nano-particles to concrete, the compressive strength increased comparing by control samples.

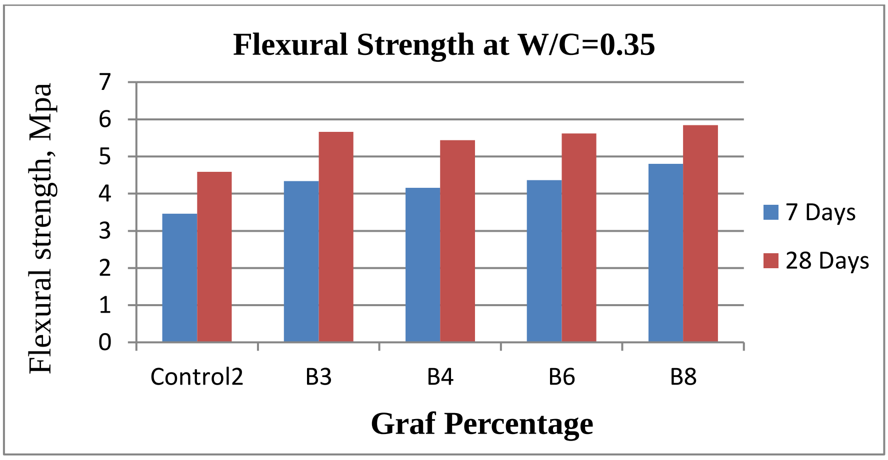


Fig. 13: Flexural Strength of Tested specimens at w/c=0.35

Figure 13 presents the experimental flexural strength results of the tested specimens. Comparison between the flexural strength of the tested specimens without particles (G1) and the flexural strength of tested specimens having Nano-particles, the results at 28 days indicated that by adding the Nano-particles, the flexural strength increased. From load-Deflection curves the value of the stiffness of each beam were taken into account, the stiffness is calculated as the slope of the straight part of the load-deflection curve at value of load less than the observed cracking load.
Also, Ductility as the ability of material to undergo large deformations without rupture before failure. Finally, the energy absorption, based on displacement, is calculated as the area under the load-deflection curve till ultimate failure load.

4. CONCLUSION

From experimental test results of concrete using Nano-particles, the following was concluded.

1. From analysis of tested results for using nanoparticle on the mechanical properties of concrete, the following was concluded:
   i. Adding Graf Pro Nano graphene with ratio 1% and 0.5%, the compressive strength of concrete (w/c=0.4) after 7days and 28days increased by about (7%and 51%), (-5%and 24%) respectively.
   ii. Adding Graf Max fibers with ratio 0.5%, the compressive strength of concrete (w/c=0.4) after 7day and 28day increased by about (26.75% and 27%) respectively.
   iii. Adding Graf Pro and Graf Max (9:1) fibers with ratio 0.5%, the compressive strength of concrete (w/c=0.4) after 7day and 28day increased by about (8% and -9%) respectively.
   iv. Adding Graf Pro fibers with ratio 1% and 0.5%, the compressive strength of concrete (w/c=0.35) after 7day and 28day increased by about (5%and 9%), (28.1%and 28.3%) respectively.
   v. Adding Graf Max fibers with ratio 0.5%, the compressive strength of concrete (w/c=0.35) after 7day and 28day increased by about (37% and 30.8%) respectively.
   vi. Adding Graf Pro and Graf Max (9:1) fibers with ratio 0.5%, the compressive strength of concrete (w/c=0.35) after 7day and 28day increased by about (23% and 32%) respectively
2. From load deflection curves, it was found that using w/c =0.4 the Nano graphene particles increased the initial stiffness of tested plain concrete prisms. Also, the deflection of prisms at the maximum load decreased.
3. By adding Nanographene particles, the maximum load increased at least about 10 % than the control prism.

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