BEHAVIOUR OF MORTAR 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 behavior of modified concrete with Nano-graphene. In this paper, one hundred-eighty 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 40 mm× 40 mm ×160 mm. eighteen tested specimens are control. In the first group, one hundred-eight tested specimens were prepared by adding Graf Pro nano graphene particles with ratios equal to 0.03%, 0.05%, 0.1%, 0.5%, 1% and 2.5% of cement. In the second group, fifty-four specimens were prepared by adding Graf Plus nano graphene particles with ratios equal to 0.25%, 0.50% and 1% of cement. In the third group, fifty-four were prepared by adding Graf Max nano graphene particles with ratios equal to 0.25%, 0.50% and 1% of cement. All these specimens at w/c=0.3,0.4 and 0.5. 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 cement mortar by filling the harmful pores and dandifying the microstructure of cement mortar. Finally, the Nano-particles resulted in significant increase in the flexural and compressive strength of cement mortar.

Keywords: Nano-graphene, Cement, mortar, 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 to12%is 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) 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) 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 are 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 cement mortar. 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, The Graf Max Nano graphene particles used was a powder with black color.

The cement used was 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

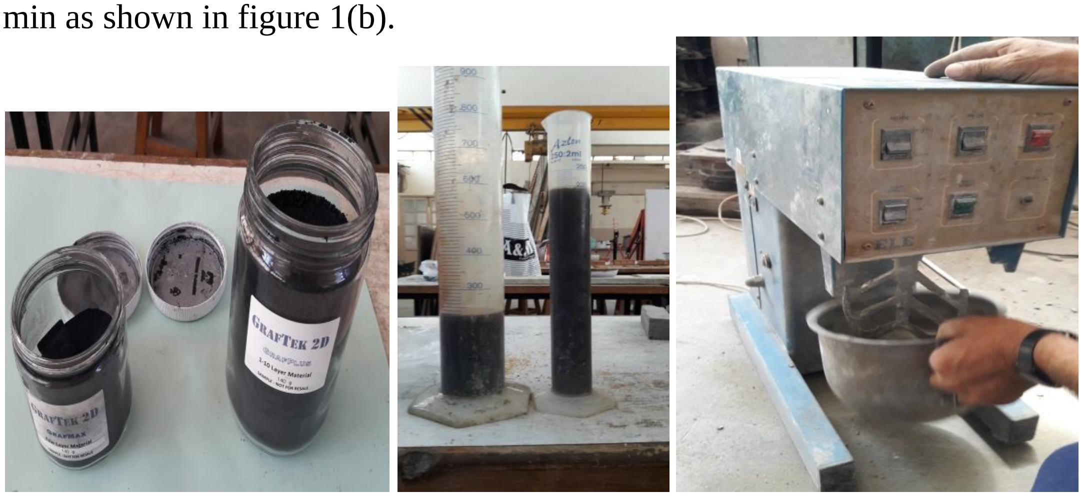
Siliceous sand was used with 4.75mm maximum particle size in this research. Polycaboxilate-based super plasticizer was used in the cement mortar mixes. The mix proportions for all experimental specimens are presented in Table 2.

Table 2: Proportions of used cement paste mixes

Materials	**Aggregate: cement**	**Cement and water**	**Admixture**	**Nano-particles content by weight**
	Fine: Cement	Water: Cement	Polycaboxilate-based super plasticizer	Graf Pro-Graf Plus-Graf Max
Ratio %	3:1	0.3-0.4-0.5	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 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 plus& Graf max as showed in figure 1(a) and the admixture. Mix together to ensure dispersion of the Nano-particles, then add to the automatic mixer for 1 min as shown in figure 1(b).



(a) (b)

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

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

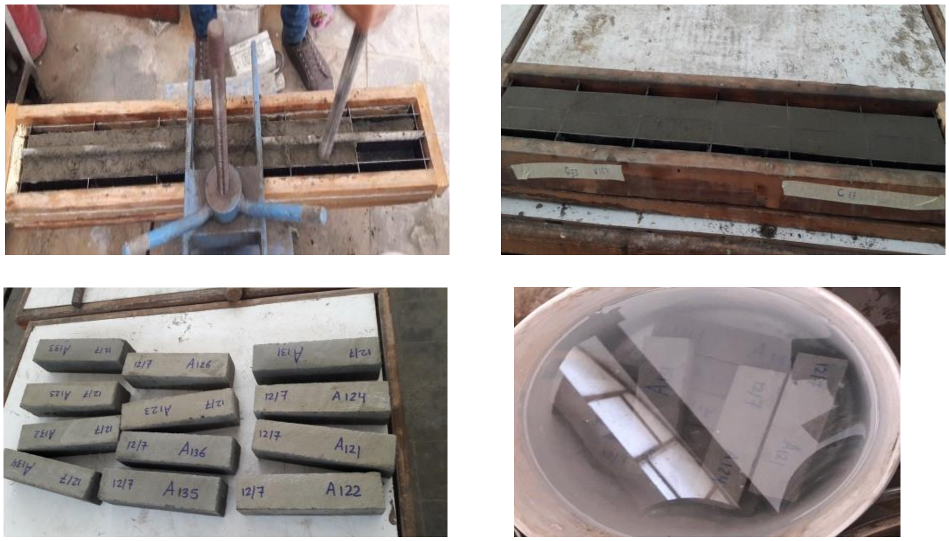


Figure 2: The tested specimens during casting and curing

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 28&56 days.

2.3 Testing Procedure

Two hundreds thirty-four tested specimens 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, one hundred-eight tested specimens were prepared by adding Graf Pro nano graphene particles with ratios equal to 0.03%, 0.05%, 0.1%, 0.5%, 1% and 2.5% of cement. In the second group, fifty-four specimens were prepared by adding Graf Plus nano graphene particles with ratios equal to 0.25%, 0.50% and 1% of cement. In the third group, fifty-four tested specimens were prepared by adding Graf Max nano graphene particles with ratios equal to 0.25%, 0.50% and 1% 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 cement mortar containing nano-graphene particles (40×40×160mm) 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 ESS 2421-7/2005, Iso 679/1989[(7).] The load is applied without shock and increased continuously at a rate of 0.05 KN/S for flexural and 2.4 KN/S for compression, and data were automatically recorded during the test. The load increased until failure of the tested specimen.

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Table 3. Parameters of tested specimens

Group	Beam Code	Type of Fiber	% of Fiber, Vf%
G1	Control	-	0.0
G2	A14	Graf Pro	0.03%
	A15	Graf Pro	0.05%
	A16	Graf Pro	0.1%
	A13	Graf Pro	0.5%
	A11	Graf Pro	1%
	A12	Graf Pro	2.5%
G3	B13	Graf Plus	0. 25%
	B12	Graf Plus	0. 5%
	B11	Graf Plus	1%
G4	C13	Graf Max	0. 25%
	C12	Graf Max	0. 5%
	C11	Graf Max	1%

Figure 3: Test set up for flexural & compression of tested specimens According to ESS 2421-7/2005

Figure 4: Failure mode of tested specimens containing different nano particles

3. EXPERMENTAL RESULTS AND ANALYSIS

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

3.1. Effect of Graphene Nano-Particles on Compressive and Flexural Strength at W/C=0.3

As shown in Figure 5, The compressive strength of control mortar tested specimens at 56 days was equal to 10.10MPa. By adding Graf Pro with ratios equal to 0.5%, 1%, and 2.5%, the compressive strength of concrete was equal to 14.6MPa, 16.88MPa, and 12.9MPa respectively.

With admixtures ratio of 3% of cement weight instead of 1.5%, The compressive strength of control mortar tested specimens at 56 days was equal to 10.52MPa. By adding Graf Pro with ratios equal to 0.03%, 0.05% and 0.1%, the compressive strength of concrete was equal to 14.63MPa, 13.05 and 11.83 respectively.

Also, the flexural strength of Samples to which small percentages are added, the results are almost the same as the samples with larger percentages. Samples with 0.1% added Graf Pro almost behave as samples with 0.5% and samples with 0.03% as samples with 1%.

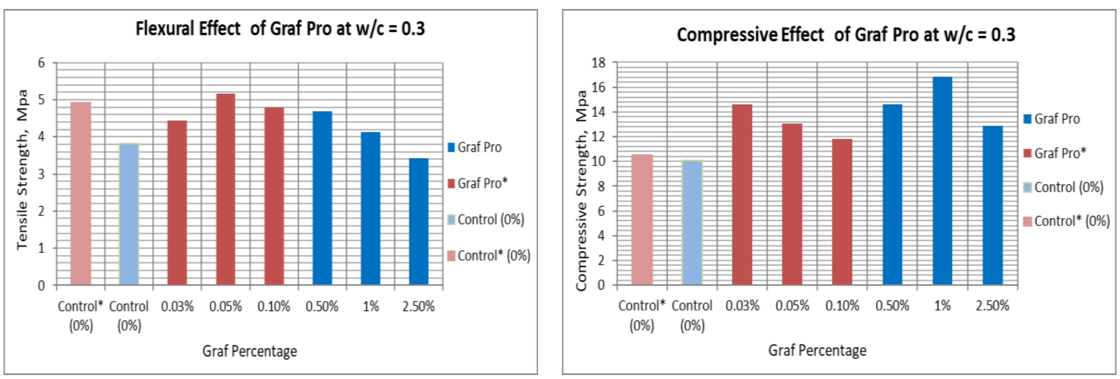


Figure 5: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Pro at w/c=0.3

As shown in Figure 6, increasing percentage of Graf Pro particles added leads to low efficiency of specimens. So, no need for using higher ratios and to save nano particles we should use lower ratios and get appropriate strength.

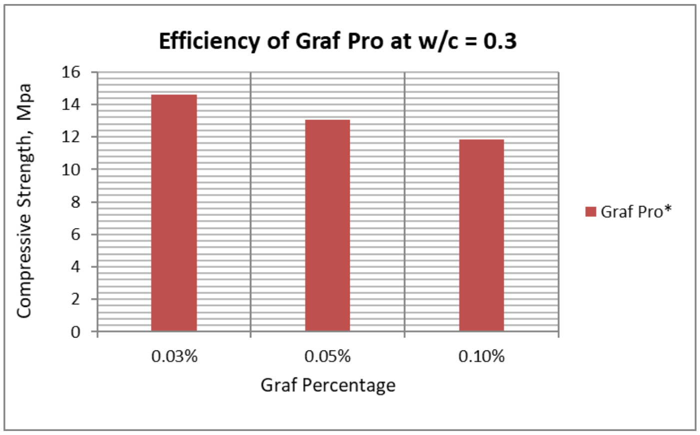


Figure 6: Effect of increasing Graf Pro Ratio on Compressive Strength

As it is clear, the higher the percentage of graphene, the lower the resistance, due to agglomeration. The large proportions of the nano agglomerate, giving the same effect as the lower ratios.
The lower the ratio, the easier the spread of nano graphene particles, but when the ratio is increased, it gives the same effect as the lower ratios.

As shown in Figure 7, By adding Graf Plus with ratios equal to 0.25%, 0.5%, and 1%, the compressive strength of mortar was equal to 12.42MPa, 12.32MPa, and 17.32MPa respectively.

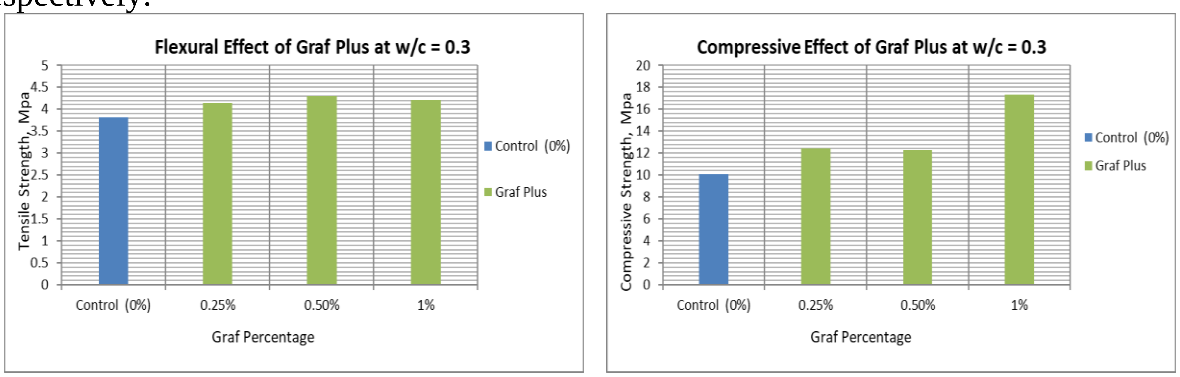
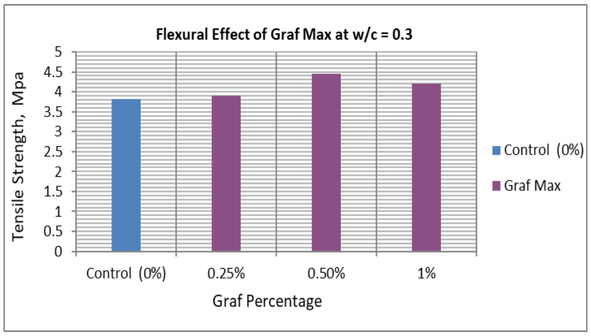


Figure 7: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Plus at w/c=0.3

It was found that adding Nano-particles enhanced the density of cement paste by increasing the ratios of Nano-particles regardless the type of Nano- particles. The addition of nano-Graf Plus particles increased the compressive strength of cement mortar specimens over the case where no such materials were used.
Finally, As shown in Figure 8, by adding Graf Max with ratios equal to 0.25%, 0.5%, and 1%, the compressive strength was equal to 10.91MPa, 10.73MPa, and 11.27MPa respectively. From the results shown in Table 4 and figure 5, it was found that adding Nano-particles enhanced the density of cement paste by increasing the ratios of Nano-particles regardless the type of Nano- particles. The addition of nano-particles increased

the compressive strength of cement mortar specimens over the case where no such materials were used. However, increasing the content over a certain threshold started to reduce the gain.



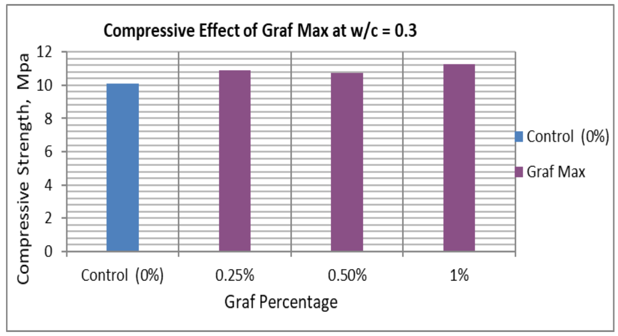
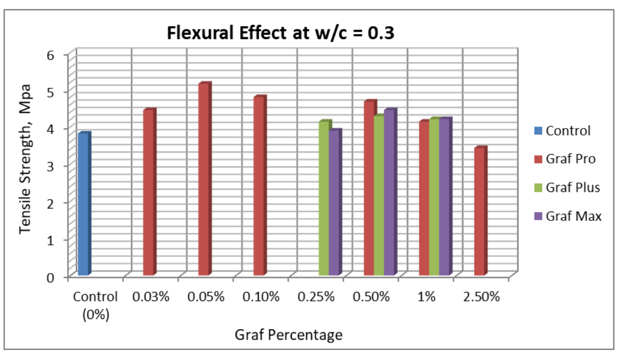


Figure 8: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Max at w/c=0.3

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 fig 9. As shown in figure 9, adding any of the three types of Nano graphene is more effective, the flexural strength increased. However, increasing the content of Graf Max reduce in compression than in tension, for the reason that the graphene ratio reduces the porosity of cement mortar and decreases the internal cracks.



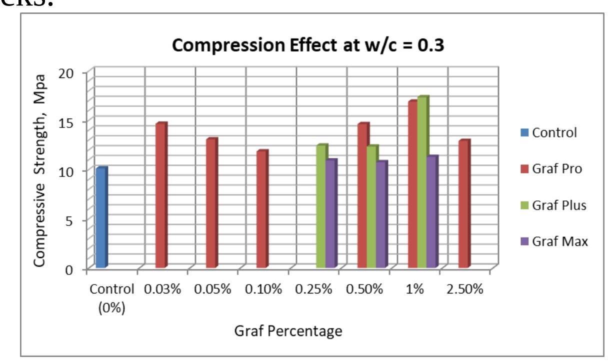


Figure 9: Flexural & Compressive Strength of Tested specimens at w/c=0.3

3.2. Effect of Graphene Nano-Particles on Compressive and Flexural Strength at W/C=0.4

As shown in Figure 10, The compressive strength of control concrete tested specimens at 56 days was equal to 22.97MPa. By adding Graf Pro with ratios equal to 0.5%, 1%, and 2.5%, the compressive strength of mortar was equal to 34.5MPa, 31.35MPa, and 31.01MPa respectively.

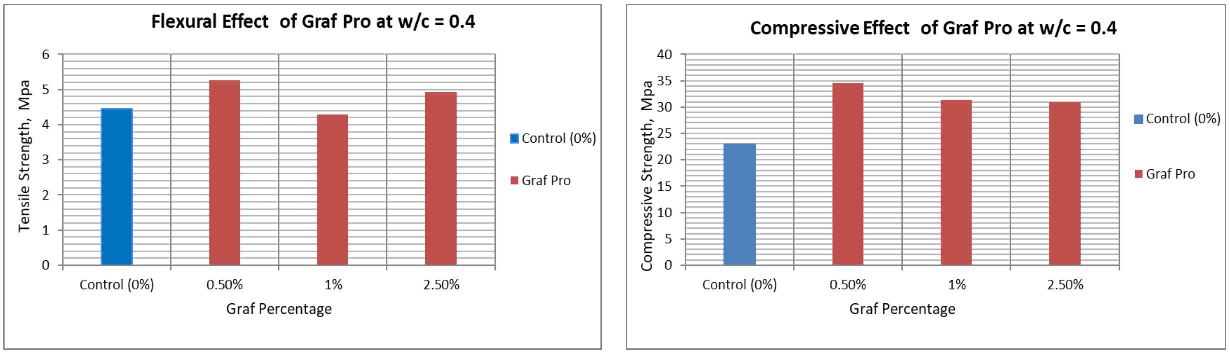


Figure 10: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Pro at w/c=0.4

By adding Graf Plus with ratios equal to 0.25%, 0.5%, and 1%, the compressive strength of concrete was equal to 27.37MPa, 26.12MPa, and 25.37MPa respectively as shown in figure11.

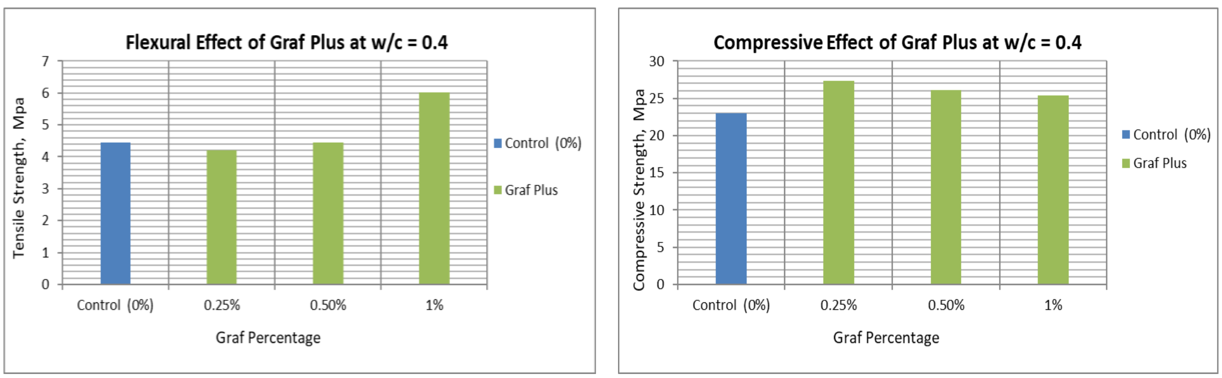


Figure 11: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Plus at w/c=0.4

Finally, as shown in figure12, by adding Graf Max with ratios equal to 0.25%, 0.5%, and 1%, the compressive strength was equal to 25.2MPa, 27.73MPa, and 31.42MPa respectively.

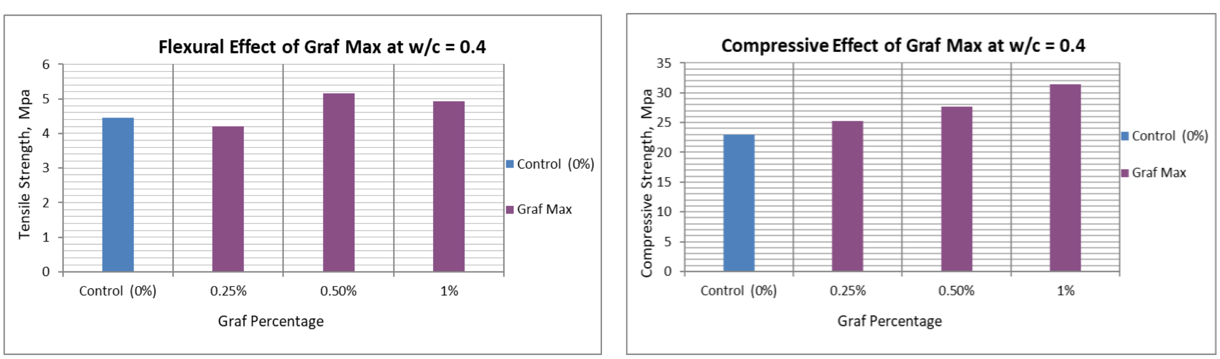


Figure 12: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Max at w/c=0.4

Figure13 presents the experimental flexural strength results of the tested specimens. Comparison between the flexural strength of the tested specimens without nano graphene (G1) and the flexural strength of tested specimens having Nano-particles was done.
From the results shown figure 13, the results indicated that by increasing w/c ratio from 0.3 to 0.4, the three types of Nano graphene were more efficient in increasing compressive strength.

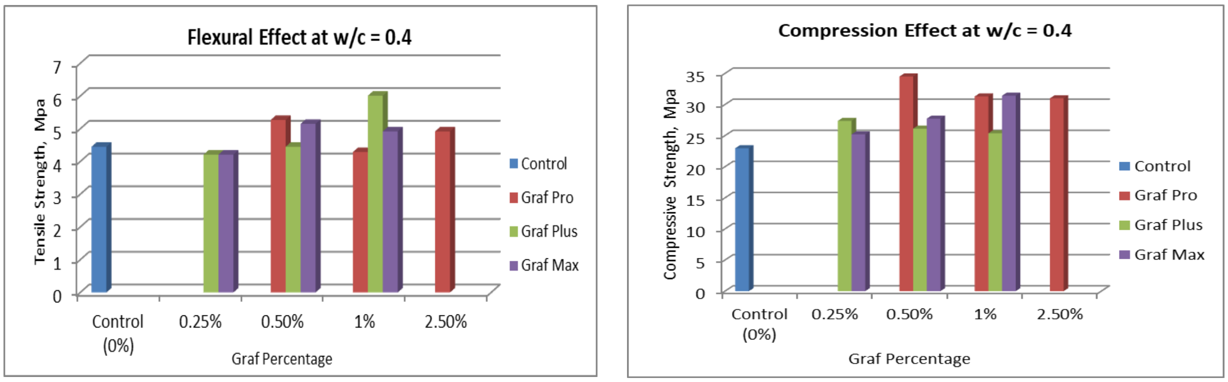


Figure 13: Flexural & Compressive Strength of Tested specimens at w/c=0.4

By comparing between the effect of Nano-particles on the compressive strength and flexural strength of concrete, it was found that the three types of graphene particles are more effective in compression than in flexure as Nano-particles enhanced the density of cement paste.
Also, the results indicated that by increasing w/c ratio from 0.3 to 0.4, the three types of Nano graphene were more efficient in increasing compressive strength.

3.3. Effect of Graphene Nano-Particles on Compressive and Flexural Strength at W/C=0.5

As shown in Figure 14, The compressive strength of control concrete tested specimens at 56 days was equal to 14.89MPa. By adding Graf Pro with ratios equal to 0.5%, 1%, and 2.5%, the compressive strength of mortar was equal to 26.72MPa, 22.47MPa, and 23.27MPa respectively.

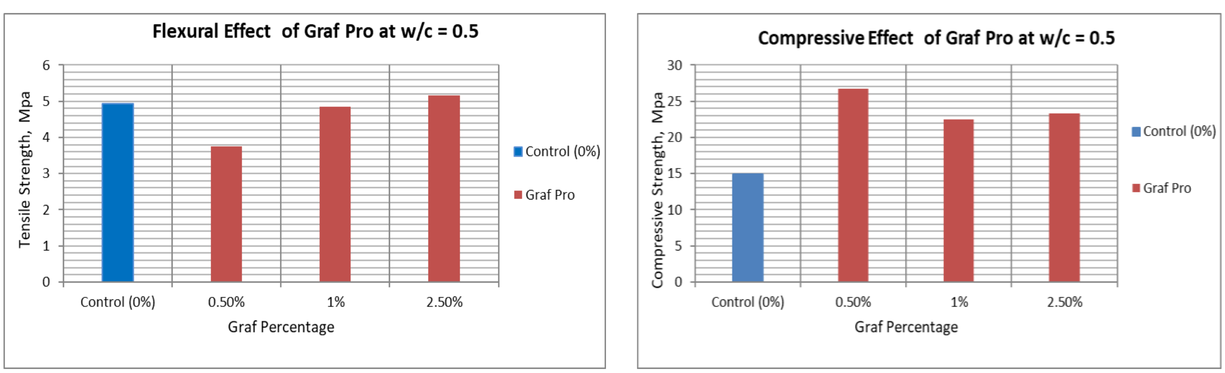


Figure 14: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Pro at w/c=0.5

As shown in Figure 15, By adding Graf Plus with ratios equal to 0.25%, 0.5%, and 1%, the compressive strength of mortar was equal to 20.12MPa, 22.55MPa, and 25.01MPa respectively.

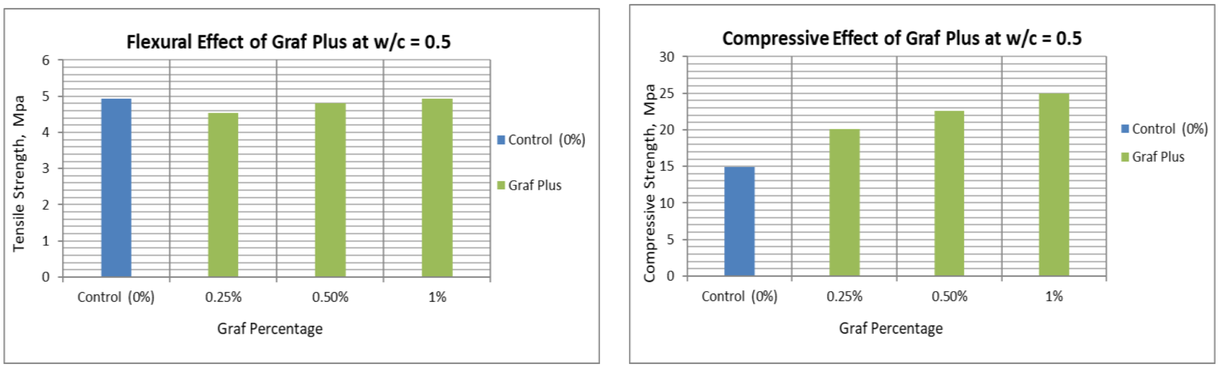


Figure 15: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Plus at w/c=0.5

Finally, As shown in Figure 16, by adding Graf Max with ratios equal to 0.25%, 0.5%, and 1%, the compressive strength was equal to 25.82MPa, 23.82MPa, and 22.88MPa respectively.

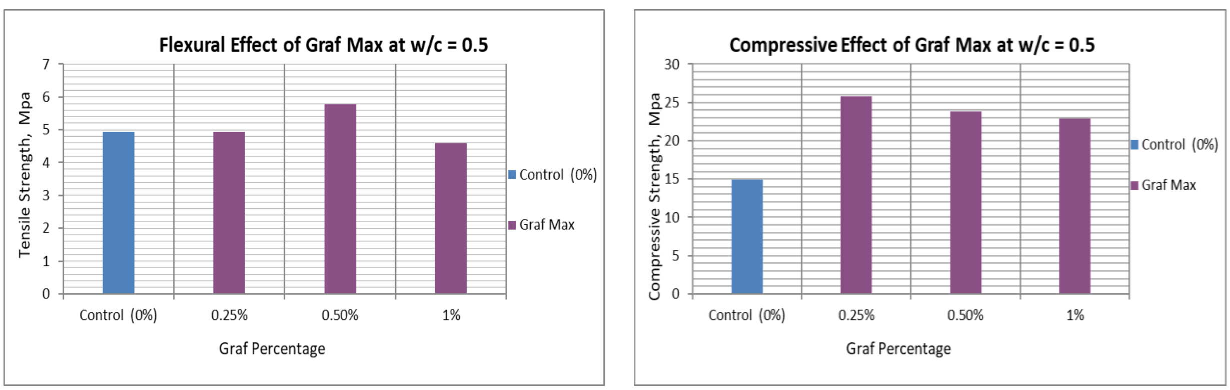


Figure 16: Flexural and Compressive Strength of Tested Specimens strengthened with Graf Max at w/c=0.4

Figure 17 presents the experimental flexural strength results of the tested specimens. Comparison between the flexural strength of the tested specimens without nano graphene (G1) and the flexural strength of tested specimens having Nano-particles was done.
From the results shown in figure 17, the results indicated that by increasing w/c ratio from 0.4 to 0.5, the three types of Nano graphene weren't such efficient in increasing flexural strength.

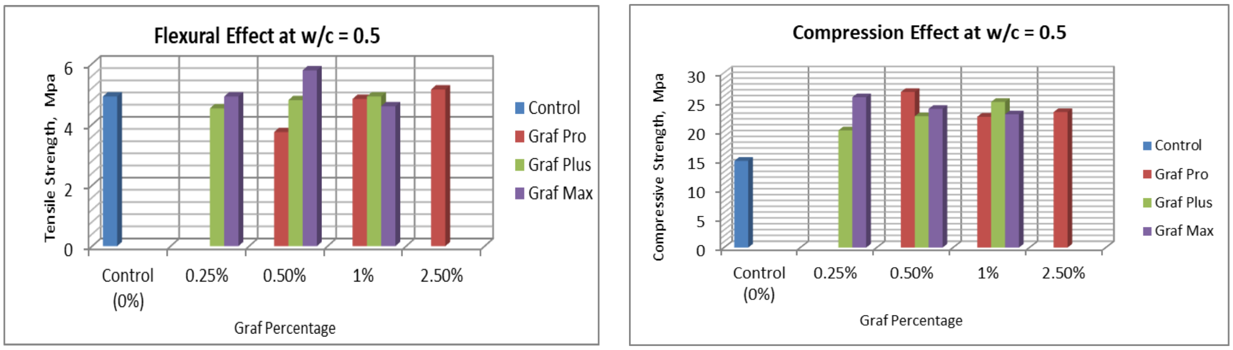
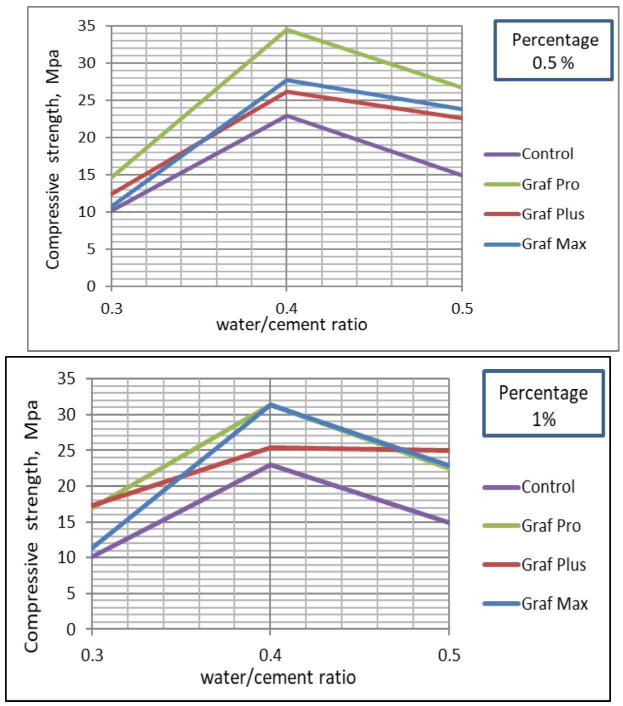


Figure 17: Flexural & Compressive Strength of Tested specimens at w/c=0.5



(a) (b)

Figure 18: Comparative Compressive Strength of Tested specimens at different w/c ratios at constant nano ratio (a) at 0.5%, (b) at 1%

Figure 18(a) presents the experimental compressive strength results of the tested specimens at (0.3, 0.4 and 0.5) w/c ratios at a ratio of 0.5% of the three different nano graphene particles while Figure 18(b) at a ratio of 1%. The results indicated that w/c ratio=0.5 is more efficient in cases of 0.5% of added particles followed by 0.4 then 0.3.

Also, the results indicated that w/c ratio=0.5 is more efficient in cases of 1% of added particles followed by 0.4 then 0.3 for Graf Pro& Graf Max while in case of Graf Plus, w/c=0.5 is more effective followed by 0.4 then0.4.

4. MICROSTRUCTURE INVESTIGATION

A number of Scanning Electron Microscope (SEM) micrographs illustrating various characteristics features of prepared samples.

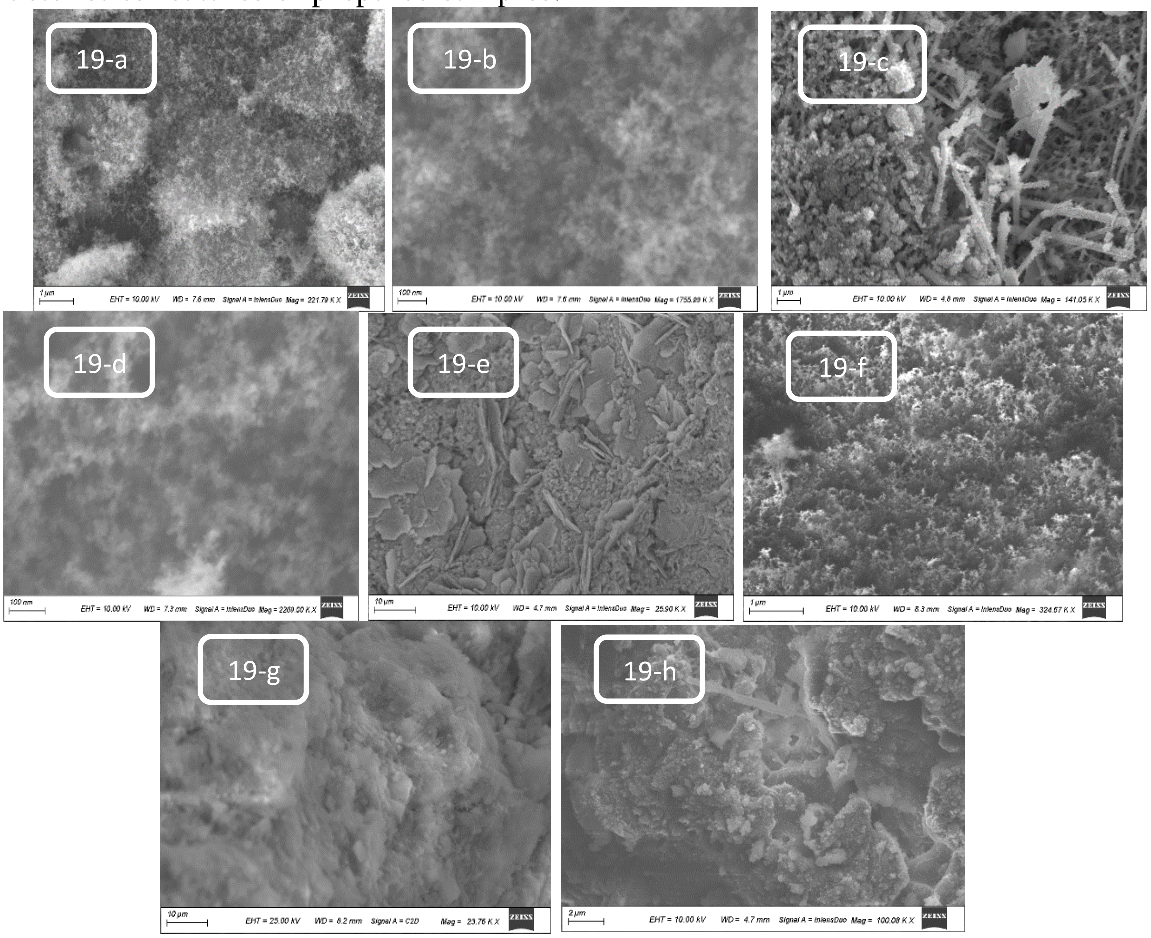


Figure 19: SEM for tested specimens, (a:c) group G2, (d:f) group G3 and (g,h) group G4

SEM investigations of hardened mortar specimens shown that nano graphene particles are dispersed homogeneously in the mortar matrix with some agglomeration especially in samples with high proportions of nano graphene particles added (figure19-c).

It is shown that the nano graphene particles are homogenously dispersed in the cement mortar matrix with little agglomeration. This is due to using super plasticizer for nano particles dispersing. which noticed from the SEM scanning (figure19-a) as some regions have no nano particles, while in other regions agglomerated nano particles could be seen.

It was noticed from the SEM scanning (figure 19-d) that uniformly dispersed nano graphene particles within the OPC paste can resulted in hydrated cement products with a dense and homogenous texture.

Generally, based on both mechanical tests and SEM investigation we can conclude that Nano Graphene particles stimulate the hydration reaction which ensures high bonding strength between mortar matrix and nano particles which appears in flexural and compressive strength values.

5. CONCLUSION

From experimental test results of mortar using the three types of Nano graphene-particles, the following was concluded.

1. Adding graphene nano-particles to cement mortar improved the flexural strength of tested specimens. It was found that the Graf Plus Nano-particles are more effective than Graf-max and Graf-pro for enhancement of the flexural strength.
2. Adding graphene nano-particles to cement mortar improved the compressive strength of tested specimens. It was found that the Graf-pro Nano-specimens are more effective for enhancement of the compressive strength.
3. Low percentages of nanographene with the use of additives at a higher percentage (3%) gave better results than high percentages of nanographene with fewer additives (1.5%).
4. Changing water-cement ratio showed that the optimum percentage was between 0.3 and 0.4 for each type of nano graphene individually.
5. The optimum percentage for replacement of cement with graphene nano-particles was 0.03% for Graf-Pro and 0.5% for Graf-Max and 0.25 % for Graf-Plus because, in this study, higher percentages had a negative effect on the compressive and flexure strength of cement mortar due to agglomeration and poor spread quality of Nano-particles.
6. Generally based on both mechanical tests and SEM investigation we can conclude that the graphene particles stimulate the hydration reaction, in addition to ensure high bonding strength between mortar matrix.

7. REFERENCES

[1]. Sudheer, Chandramouli and Kumar "Comparative Study on Performance of Concrete Enhanced with Graphene Compound" international journal of current engineering and scientific research (IJCESR), Volum-4, Issue-6, (2017).

[2]. M. Mallikarjuna and B. Sreenivas, " Strength Properties of Concrete when Mixed with Graphene Oxide" International Journal for Scientific Research & Development| Vol. 6, Issue 05, 2018 | ISSN (online).

[3]. Sudheer, Chandramouli and Kumar "Comparative study on performance of concrete enhanced with graphene compound" international journal of current engineering and scientific research (IJCESR), volum-4, issue-6, (2017).

[4]. M. Mallikarjuna and B. Sreenivas, " Strength Properties of Concrete when Mixed with Graphene Oxide" International Journal for Scientific Research & Development| Vol. 6, Issue 05, 2018 | ISSN (online).

[5]. Wang, Q., Wang, J., Lu, C., Liu, B., Zhang, K. and Li, C. (2015) ‘Influence of graphene oxide additions on the microstructure and mechanical strength of cement’, New Carbon Materials, 30(4), pp. 349–356.

[6]. Dimitar Dimov, Iddo Amit, Olivier Gorrie, Matthew D. Barnes, Nicola J. Townsend, Ana I. S. Neves, Freddie Withers, Saverio Russo, and Monica Felicia Craciun," Ultrahigh Performance Nanoengineered Graphene– Concrete Composites for Multifunctional Applications"http://www.afm-journal.de 14 June 2018.
[7]. ESS, Methods of testing cement, Determination of strength, 2421-2005.
[8]. the Egyptian Standard Specification No. 2421-7/2005, Iso 679/1989.
[9]. H.Elkady, Ata El kareim and M. Genidy " Behavior of Reinforced Concrete With Nano Fiber", Egypt,(2017).
[10]. V.K. Ganes, "Nanotechnology in Civil Engineering", European Scientific Journal, 8(27), (2009), 96-109.
[11]. S. Mann, "Nanotechnology and Construction", Nanoforum Report. www.nanoforum.org, May30, 2008.
[12]. Saurav, "Applications of Nanotechnology in Building Materials', International Journal of Engineering Research and Applications (IJERA), September- October (2012),2 (5), 1077-1082.
[13]. F. Sanchez, C. Ince, "Microstructure and Macroscopic Properties of Hybrid Carbon Nanofiber/Silica Fume Cement Composites", Composites Science and Technology 69 (2009) 1310-1318.
[14]. A.H. Shekari, M. S. Raazzaghi, "Influence of Nano Particles on Durability and Mechanical Properties of High-Performance Concrete", The twelfth East Asia-Pacific Conference on Structural Engineering and Construction,14, (2011), 3036-3041.
[15]. N. Farzadnia, A. Abdullah, A. Ali, R. Demirboga, M.P. Anwar, "Effect of Halloysite Nano clay on Mechanical Properties, Thermal Behavior and Microstructure of Cement Mortars", Cement and Concrete Research 48 (2013) 97-104.
[16]. M. S. Morsy, S. H. Alsayed and M. Aqel." Effect of Nano-clay on Mechanical Properties and Microstructure of Ordinary Portland Cement Mortar", International Journal of Civil & Environmental Engineering, 10 (1) (2012), 23-27.
[17]. Ata El-karim and Mostafa Osman" Effect of Nano Nano Fibers on The Behavior of Cement Morter and Concrete" International Journal of Civil, Environmental, Structure, Construction and Architectural Engineering Vol 9/No 1, 2015, page 64-69.
[18]. M. Auffan, J.Y. Bottero, G. V. Lowry, J. P. Jolivet and M. R. Wiesner, "Towards a Definition of Inorganic Nano Particles from an Environmental, Health and Safety Perspective", Nnano (2009), 242,1-8.
[19]. ARI News (2005)." Nanotechnology in Construction – One of the Top Ten Answers to Worlds Biggest Problems." www.aggregateresearch.com/article.asp?id=6279, June 1,2007.