ISSN 1533-9211

DOI 10.17605/OSF.IO/CTFA6

PERFORMANCE EVALUATION OF NANO GRAPHENE IN CEMENT MORTAR

RAJE GOWDA[1]* and R MOUROUGANE[2]

[1, 2] Department of Civil Engineering, Ramaiah Institute of Technology, Bangalore, India.

Abstract

This paper aims to analyse the beneficial use of graphene in cement mortar by comparative study of the mechanical properties of normal strength mortar over the mortar reinforced with graphene. Also the use of construction and demolition waste in different proportions namely 25% and 50% as partial replacement for fine aggregate was made. 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 at 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 increase in the proportion of graphene upto 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: Graphene, Cement Mortar, C&D Waste.

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 affect 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 [1]. 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}[2].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.

ISSN 1533-9211
DOI 10.17605/OSF.IO/CTFA6

Due to exceptional mechanical properties and signs to revolutionize the construction industry, the interest to study the Nano materials for the construction field is increasing among the researchers. One of the Nano materials 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 [3]. Being lighter than plastic but having strength 200 times that of steel shows the potential of Graphene to completely change the construction industry on its head. 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 [4]. 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 economies the construction industry. 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, researches are going on to use these materials in collaboration so that we get a stable construction industry and a sustainable environment.

2. EXPERIMENTAL PROGRAMME

2.1 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 following tables show the physical properties of the materials used.

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

ISSN 1533-9211
DOI 10.17605/OSF.IO/CTFA6

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 grapheme

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 m^2/gm

2.2 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.

Table 4: Varieties of mortar mixes

S.No.	Mix type	Cement (kg)	Sand (kg)	CDW (kg)	Graphene (gm)	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

ISSN 1533-9211
DOI 10.17605/OSF.IO/CTFA6

2.3.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: Mould with prism compartments

2.4. 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.

2.5.Test Methodology

2.5.1 Flexural Strength Test

The cured specimen was taken out from water and allowed to lose its dampness. After that 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:

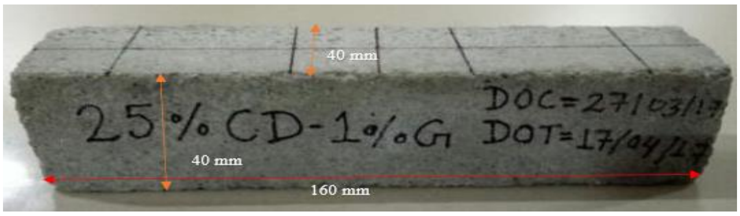


Fig 2: Flexural strength test specimen

ISSN 1533-9211
DOI 10.17605/OSF.IO/CTFA6

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 below:

$$\sigma_f = Pl/bd^2$$

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.

Fig 3: Flexural strength test set up

Fig 4: Flexural strength test specimen at failure

2.5.2 Compressive Strength Test

One halve 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

ISSN 1533-9211
DOI 10.17605/OSF.IO/CTFA6

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:

$$\sigma_c = P/A$$

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

Fig 5: Compressive strength test specimen in zig and test setup

2.5.3Split 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 following formulae:

$$\sigma_t = 2P/\pi bd$$

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

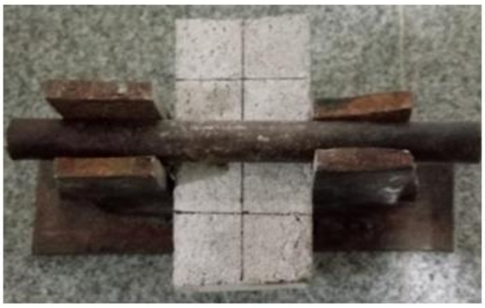


Fig 6: Tensile strength test set up

ISSN 1533-9211

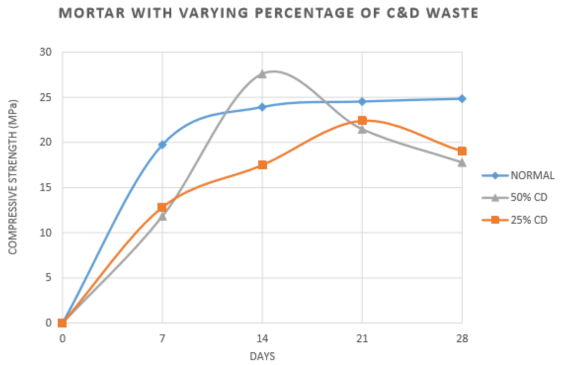
DOI 10.17605/OSF.IO/CTFA6

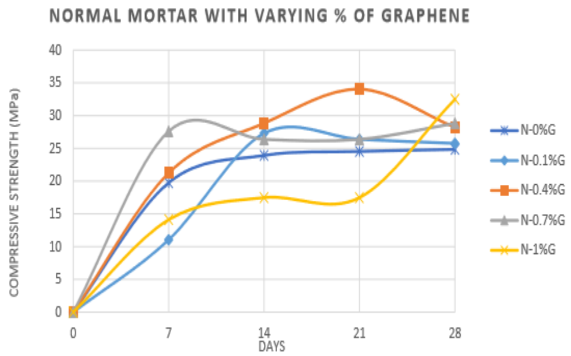
3. RESULTS AND DISCUSSIONS

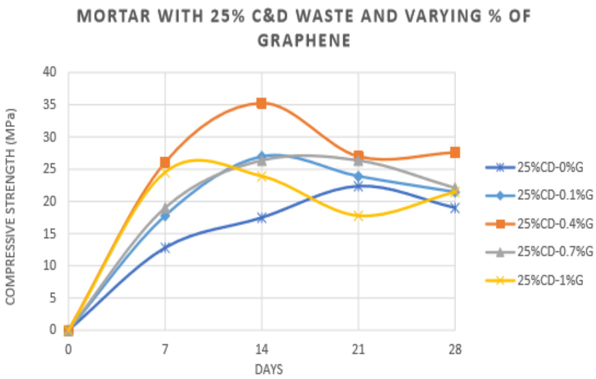
The tables below indicate the 28day compressive strength, flexural strength and split tensile strength for various tested samples.

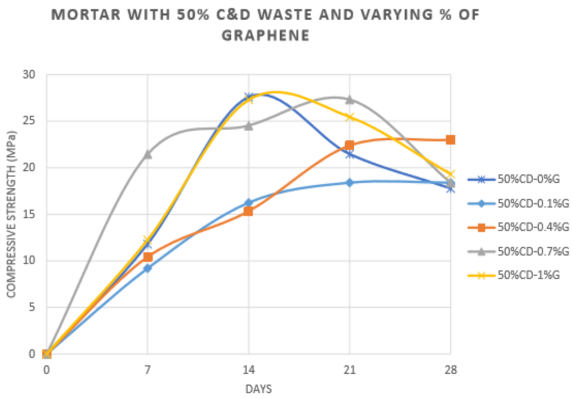
3.1 Compressive Strength

The results of compressive strength values for cement mortar with varying percentage of construction and demolition waste and varying percentage of graphene are discussed below:









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.

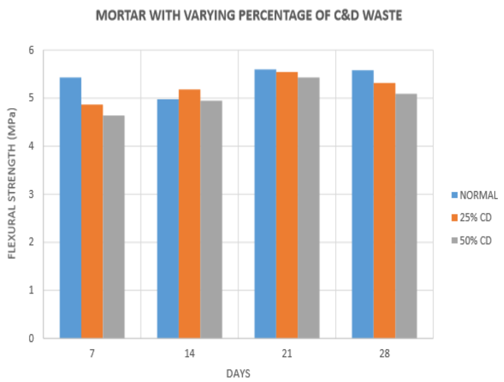
Also, there is increase in compressive strength of mortar with the incorporation of graphene in different proportions. This is because graphene is a nanoparticle which fills the nano voids decreasing the porosity thus reducing the transition zone in mortar leading to the increase in compressive strength.

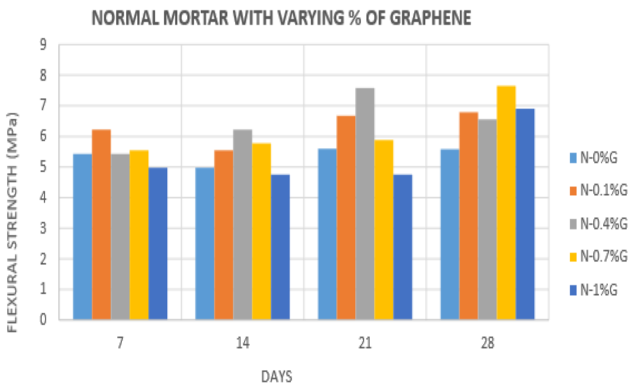
It is seen that the incorporation of graphene in varying percentage in mortar with 25% C&D waste has led to increase in the compressive strength where in addition of 0.4% graphene by weight of cement has shown the optimum result. This is because with the increase in % of

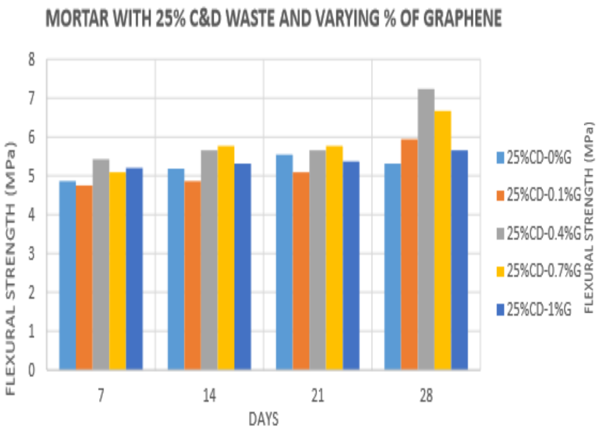
ISSN 1533-9211
DOI 10.17605/OSF.IO/CTFA6

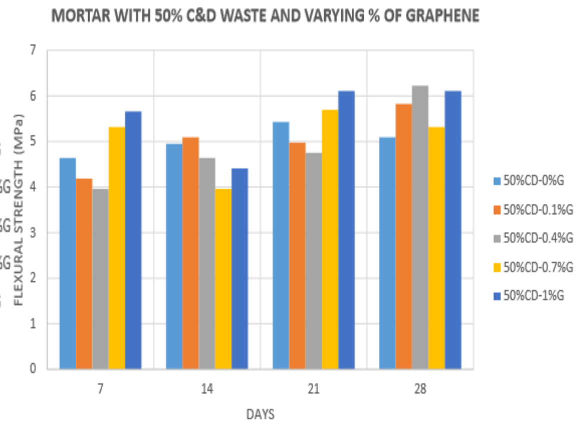
graphene, the graphene molecules tend to come close to each other leading to their re-agglomeration thus resulting in poor distribution of graphene molecules in the mortar. It is seen that the incorporation of graphene in varying percentage in mortar with 50% C&D waste has led to increase in the compressive 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.

3.2 Flexural Strength







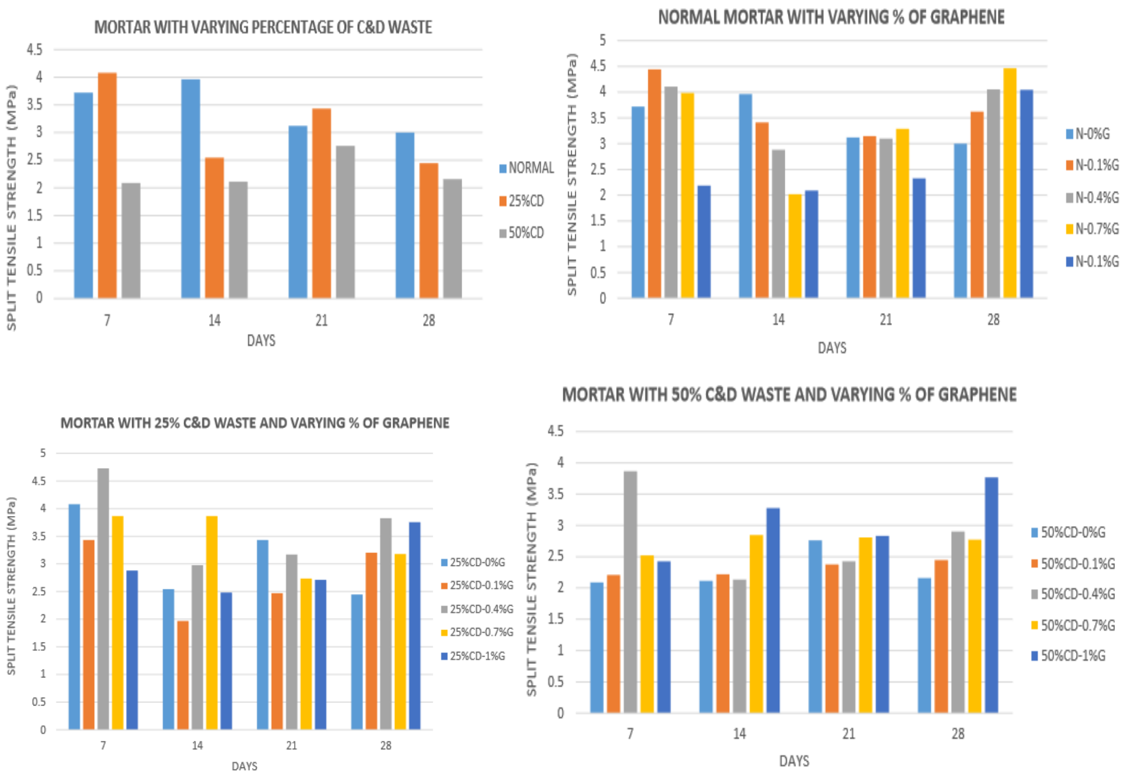


It is seen that there is decrease in flexural strength of mortar incorporated with 25% and 50% construction and demolition waste compared to the normal cement mortar. This is due to the formation of transition zone between C&D waste and sand particles and also due to the increase in porosity of mortar. 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.

3.3 Split Tensile Strength



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.

4. CONCLUSIONS

- 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.
- The flexural, compressive and split tensile strength decreases with the use of C&D waste.

ISSN 1533-9211

DOI 10.17605/OSF.IO/CTFA6

- The optimum results in case of flexural and compressive strength tests were in case of .4% replace however, there was significant increase in the strength with addition of .4% and 1% graphene by weight of cement.
- To sum up, with the addition of graphene, there was positive compensation of loss only for the 25% replacement of sand by construction and demolition waste. This trend was not continuous for 50% replacement of sand.
- Thus, it can be concluded that 25% replacement of sand with 0.4% Graphene is the optimum value as per the results obtained.

References

1. G. Quercia, P. Spiesz, And H.J.H. Brouwers "Effects of Nano-silica (NS) Additions on Durability of SCC Mixtures" -Durability of Reinforced Concrete from Composition to Protection – 2014
2. https://en.wikipedia.org/wiki/Nanomaterials
3. J. Makar, J. Margeson, And J. Luh, "Carbon nanotube/cement composites-early results and potential application," in Proceedings of the 3rd International Conference on Construction Materials: Performance, Innovations and Structural Implications, pp.110, Vancouver, Canada, August2005.
4. S Sanju, S Sharadha And J Revathy, "Performance on the Study of Nano Materials for the Development of Sustainable Concrete", International Journal of Earth Sciences and Engineering
5. Meyer, Christian. "Concrete." AccessScience, McGraw-Hill Education, 2016.
6. R.S.Ahalya, N.Sakthieswaran , G.Shiny Brintha & O.Ganesh Babu(2016), "Microstructure Analysis Of Cement Mortar On Partial Replacement Of Fine Aggregates By Industrial Wastes", ISSN: 2321-9653
7. CPHEEO Manual on "Solid waste Management" published by Jain Book Agency, C-10, Connaught place, New Delhi, 2008, pp. 57-63
8. Saini, Rajiv; Saini, Santosh; Sharma, Sugandha (2010),"Nanotechnology: The Future Medicine". Journal of Cutaneous and Aesthetic Surgery. 3 (1): 32–33. doi:10.4103/09742077.63301. PMC 2890134 . PMID 20606992
9. T Pardeep,Nano:the essentials, mcgraw-hill education
10. Kralj, Slavko; Makovec, Darko ,"Magnetic Assembly of Superparamagnetic Iron Oxide Nanoparticle Clusters into Nanochains and Nanobundles" ACS Nano, 27 October 2015
11. Rodgers, P,"Nanoelectronics: Single file". Nature Nanotechnology. doi:10.1038/nnano.2006.5
12. Buzea, C.; Pacheco, I. I.; Robbie, K. (2007),"Nanomaterials and nanoparticles: Sources and toxicity". Biointerphases. 2 (4): MR17–MR71. doi:10.1116/1.2815690. PMID 20419892
13. Buzea, Cristina; Pacheco, Ivan; Robbie, Kevin (2007). "Nanomaterials and Nanoparticles: Sources and Toxicity". Biointerphases. 2 (4):MR17 MR71. doi:10.1116/1.2815690. PMID 20419892
14. Cooper, Daniel R.; D'anjou, Benjamin; Ghattamaneni, Nageswara; Harack, Benjamin; Hilke, Michael; Horth, Alexandre; Majlis, Norberto; Massicotte, Mathieu; Vandsburger, Leron; Whiteway, Eric; Yu, Victor, " Experimental Review of Graphene", 3 November 2011.
15. Graphene" (PDF). ISRN Condensed Matter Physics. International Scholarly Research Network. 2012: 1–56. doi:10.5402/2012/501686. Retrieved 30 August 2016

The Seybold Report
ISSN 1533-9211
DOI 10.17605/OSF.IO/CTFA6

16. Faugeras, Clement; Faugeras, Blaise; Orlita, Milan; Potemski, M.; Nair, Rahul R.; Geim, A. K. (2010). "Thermal Conductivity of Graphene in Corbino Membrane Geometry". ACS Nano. 4 (4): 1889–1892.

17. Von Ardenne M., "Improvements in electron microscopes". GB 511204, convention date (Germany) 18 February 1937

18. Everhart, T. E.; Thornley, R. F. M. (1960). "Wide-band detector for micro-microampere lowenergy electron currents". Journal of Scientific Instruments. 37 (7): 246– 248. Bibcode:1960JScI...37..246E. doi:10.1088/0950-7671/37/7/307

19. Mohd Monish, Vikas Srivastava1, V. C. Agarwal And Rakesh Kumar "Utilization of demolished waste as fine aggregate in Concrete" J. Acad. Indus. Res. Vol. 1(7) December 2012 398

20. J. Vengadesh Marshall Raman And M. Sriram" Study on Replacement Level of Concrete Waste as Fine Aggregate in Concrete" International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 5 Issue II, February 2017.

21. Tang Luping, Johan Liu and Nan Wang "Pre-Study of Graphene-Enhanced Cementitious Materials"