Effect of Sonicated Graphene on Compressive Strength of Cement Graphene Composites

Shreelakshmi Janardhanan[1], Dr.G.Arunkumar[2], S.Kalaiselvi[3]
[1]Dept of Civil Engineering
[2]Associate Professor, Dept of Civil Engineering
[3]Assistant Professor, Dept of Civil Engineering
[1, 2] Government College of Engineering, Salem, Tamilnadu, India
[3]Sona College of Technology, Salem, Tamilnadu, India.

Abstract- *Cement composites play a key role in improvement of concrete by imparting purpose specific characters to it. Graphene, as a material with high traction and tearing resistance has a number of advantages like greater strength, crack resistance, water tightness, improved durability etc. This makes it a promising material to be used as an additive with cement. The tedency of Agglomeration and non-uniform dispersion of graphene particles has been the greatest challenge in making use of it on a large scale. This paper mainly intents to find the effect of sonicated proportions of graphene on the strength of graphene-based cement composites. Compressive strength results for 15 minutes of sonication with graphene percentage of 0.02,0.03,0.04,0.05,0.06 in cement are found. It tells us about the optimum percentage of graphene to be added for maximum strength of this novel cement compsite.*

Keywords- Agglomeration, Cement composites, graphene, sonication, sustainable, water tightness.

I. INTRODUCTION

Graphene having high traction and tearing resistance makes it an ideal additive for cement reducing its use up to 30%. Graphene concrete improves all the durability features by virtue of its higher resistance to carbonation, chlorides and sulphates. It virtually gets invulnerable against external aggression. This feature can be directly taken as the optimization of natural resources and a decrease in carbon di oxide emissions which is potential threat to mankind resulting in catastrophic events if not paid attention to.

In most favorable conditions, this composite material is more than twice as strong and four times more water resistance than existing concrete. It increases the flexibility of concrete as graphene becomes a support element reducing cracks and clefts improving the performance of structures from even a seismic point of view. It is especially useful for sea constructions where concrete is constantly suffering sulphate and chloride attacks and graphene acts like a water proofing layer.To achieve the optimum results from graphene concrete it is vital to have proper exfoliation and dispersion of graphene. This can be best done using sonication process, for which the key is apt sonication energy and time. This unprecedented range of functionalities is an important step in encouraging a more sustainable construction industry worldwide.

Made up of carbon atoms arranged in a honeycomb lattice pattern, graphene forms a nearly transparent sheet about one atom thick and is two hundred times stronger than steel yet six times lighter. Almost 2D, graphene interacts with light and other materials in unique way. It absorbs about 2% of light and is impermeable even to lighter gases like Hydrogen & Helium. It's also a highly efficient conductor of both heat & electricity.

Graphene is a unique nanocarbon having hexagonal layered structure. Each carbon connected to three neighboring carbon atoms by σ bonds with sp2 hybridized orbitals. It is the building unit of graphene and other nanocarbon structures. The modulus of graphene has been found as 1TPa while the strength is about 130 Gpa. Attempts in nanotechnology have focused on modifying the existing components of cement but here we allow a layer of graphene to be suspended in water. It produces a high yield of concrete without defects which can be used in conjuction with modern manufacturing techniques. There are many types of graphene. True Graphene is only one atomic layer thick (often called a monolayer) and it typically exists as a film but it can be floated off the substrate and can be redeposited onto another substrate or used in its isolated form. There are 3 main ways to synthesize graphene, they are Chemical Vapor Deposition, Chemical or Plasma Exfoliation from natural Graphite, Mechanical cleavage from natural Graphite. Graphene can also be fully synthetic but those methods haven't proven to be commercially viable.

Graphene oxide (GO) is most commonly produced by the oxidation of graphite oxide. The oxidation process is beneficial, as it functionalizes the surface of the graphene layers with multiple species of oxygenated functional groups.

The multiple functional groups provide an enhanced layer separation and improved hydrophilicity. The hydrophilicity allows the graphene oxide to undergo ultrasonic irradiation, which produces a single/a few graphene layers that are highly stable when dispersed in DI Water and other solvents.GO has many desirable properties. It disperses very easily in various mediums including aqueous solvents, organic solvents and various matrices.The presence of both electron rich oxygen species and an electron rich graphene backbone allow for further surface functionalization, which gives rise to an adaptable material for multiple applications.

Graphene oxide does however suffer from a low electrical conductivity and is an electrical insulator. Graphene oxide is also soluble in many solvents, both aqueous and organic.To gain the benefits of graphene oxide, it is typically dispersed, added into a formulation, made into a film or other Nano-enabled product and then reduced to restore the graphene structure.Because graphene has a delocalized pi-electron system across the entirety of its surface, the movement of electrons is very fluid.Thegraphene system also exhibits no band gap, due to overlapped pi-electrons, allowing for an easy movement of electrons without the need to input energy into the system.

The electronic mobility of graphene is very high and the electrons act like photons, with respect to their movement capabilities.The electrons are also able to move sub-micrometer distances without scattering. From tests done to date the electron mobility has found to be in excess of 15,000 $cm^2V^{-1}s^{-1}$, with the potential of producing up to 200,000 $cm^2V^{-1}s^{-1}$.The repeating structure of graphene makes it an ideal material to conduct heat in plane. Interplane conductivity is problematic and typically other nanomaterials such as CNTs are added to boost interplaneconductivity.The regular structure allows the movement of phonons through the material without impediment at any point along the surface. Graphene can exhibit two types of thermal conductivity- in-plane and inter-plane.The in-plane conductivity of a single-layered sheet is 3000-5000 W m^{-1} K^{-1}, but the cross-plane conductivity can be as low as 6 W m^{-1} K^{-1}, due to the weak inter-plane van der Waals forces.

The specific heat capacity for graphene has never been directly measured, but the specific heat of the electronic gas in graphene has been estimated to be around 2.6 µ J g^{-1} K^{-1} at 5 K. Graphene is one of the strongest materials ever discovered with a tensile strength of 1.3 x 10^{11} Pa. In addition to having an unrivaled strength, it is also very lightweight (0.77 mgm^{-2}). The mechanical strength of graphene is unmatched and as such can significantly enhance strength in many composite materials.

GiO (graphene oxide) undergoes sonication in preparing GO(graphene oxide) solution later into final product GOFs(graphene oxide flims) which is used in many structural applications. Without sonication GiO solution has large elongation but very low fracture strength and toughness, mainly due to inhomogeneous structures formed with the incompletely exfoliated Gio flakes. Even with a mild two minutes sonication, full exfoliation maintaining large amount of large size GO sheets is possible. Resulting GOF have good balance of both high strength & large elongation exhibiting superior toughness (1.09 +- 0.14 MJm^-3). Increase in time to 10, 30 or 60 min leads to deterioration of mechanical properties due to reduced GO sizes. Relation between sonication time of GiO and mechanical properties of GOF needs to be found for high performance GOFs. Recently it was pointed out that the sonication treatment for GO preparation lacks a systematic experimental control methodology. Hence in the present work we intend to explore the relationship between total sonication energy and average flake size of GO dispersion along with the optimum sonication time in order to reach the maximum strength and benefits of graphene concrete composites.

The ultrasound treatment removes oxygen functional groups from GO with a concomitant decrease in GO adsorption capacity when dispersing or exfoliating GO. The loss of oxygen functional bond increases disorder and defects on GO sheets, along with weakening pi-pi interaction. The pathways of GO’s structural and functional groups changed by ultrasound are based on generation of OH radicals from ultrasonic cavitation. These radicals can react with facile oxygenated groups such as epoxide, carbonyl, hydroxyl etc leading to partial removal of these groups and thus the breakage of GO sheets. The effects are readily observed even in mild sonication such as ultrasonic bath, signifying their importance in many applications employing ultrasonication to disperse GO.

Graphene oxide is water soluble, amphiphile nontoxic, bio degradable and can be easily dispersed into stable colloids. Ultrasonic exfoliation and dispersion is an efficient rapid and cost effective method to synthesize disperse and functionable graphene oxide on an industrial case in downstream processing ultrasonic dispersers produce high performance graphene oxide.

To incorporate graphene into composites, graphene must be dispersed or exfoliated as single nano-sheets uniformly into the formulation. The higher the grade of deagglomeration, the better the extraordinary material properties are exploited. Ultrasonic dispersion enables for a superior particle distribution and dispersion stability- even when formulating at high concentrations and viscosities. Ultrasonic processing of graphene gives outstanding dispersion qualities and excels conventional mixing methods so far.

In order to lend this characteristic of graphene, it must be dispersed into matrix or applied as a thin film coating onto a substrate Agglomeration, sedimentation and dispersion into a matrix are the factors resulting in material properties. Due to its hydrophobic nature, the preparation of a stable and highly concentrated graphene dispersion without surfactants is a challenging task. To overcome the vanderwall forces, strong shear forces generated by ultrasonic cavitation is most sophisticated method. Sonication allows to prepare a stable graphene dispersion at low process temperature of about 65°C. Since the process parameters of sonication can be precisely controlled, ultrasonic dispersion technology avoids damages of the chemical and crystal structures of graphene, resulting in pristine, defect free graphene flakes. Ultrasonically exfoliated few layers graphene with approximately 3-4 layers of size 1micrometer can be redispersed at concentrations of atleast 63mg/Ml

Advantages are-

1. High quality graphene.2. High yield3. Uniform dispersion4. High concentration 5. High viscosities
6. Rapid process 7. Low cost 8. Highly efficient and environment- friendly.

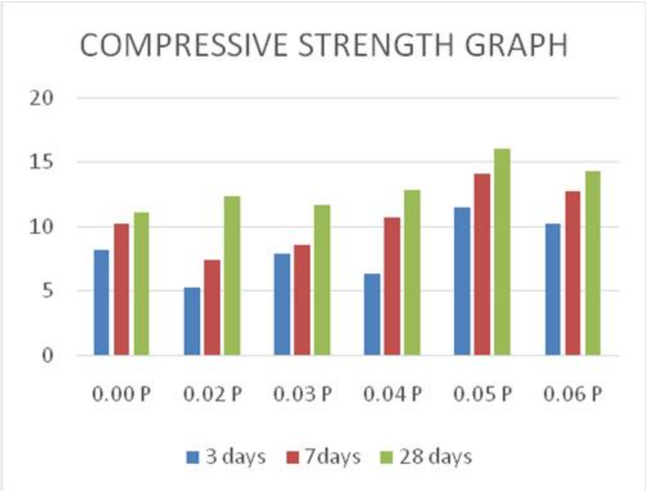
Ultasonication is a reliable method to produce graphene layers (mono, bi and few layer graphene) from graphite flakes or particles. While the other common exfoliation techniques such as ball and roll mills or high - shear mixers are linked to low quality and the use of aggresive reagents and solvents, the ultasonic exfoliation method convinces it's high quality output, high process capacity and mild processing conditions. Ultasonic cavitation creates intense shear forces, which separate the stacked graphite layers into mono, bi, and few layers of defect- free graphene.

II. MATERIAL USED

Ordinary Portland cement of 53 grade with a specific gravity of 3.15, manufactured sand with a specific gravity of 2.70 and water was used for this investigation to prepare cement mortar specimens. Graphene oxide powder was used in solution form after sonication. Cement mortar specimens of size 70.6 mm x 70.6 mm x 70.6 mm with 1:3 cement to fine aggregate ratio were prepared. Graphene Oxide is reinforced with cement at dosages 0.02%, 0.03%, 0.04%, 0.05%, 0.06% by weight. W/C ratio of 0.50 has been taken for all the mix specifications for sufficient workability.

III. RESULT DISCUSSION

COMPRESSION TEST



GRAPH SHOWING THE DIFFERENCE IN COMPRESSIVE STRENGTH BETWEEN CONVENTIONAL AND GRAPHENE CEMENT COMPOSITE

IV. CONCLUSION

The optimum percentage of graphene to be added to give the maximum strength in graphene cement composite cubes is found to be 0.05%. Further studies are required to know why the results are irregular with ups and downs with respect to increasing proportion of graphene which may primarily be the effect of reagglomeration of GO particles and its complex hydration properties

REFERENCES

[1] X. Liu et al., "Effects of graphene oxide on microstructure and mechanical properties of graphene oxide-geopolymer composites," Constr. Build. Mater., vol. 247, p. 118544, 2020, DOI: 10.1016/j.conbuildmat.2020.118544.

[2] . Lu, D. Hou, L.S. Meng, G.X. Sun, C. Lu, Z.J. Li, Mechanism of cement paste reinforced by graphene oxide/carbon nanotubes composites with enhanced mechanical properties, RSC Adv. 5 (2015) 100598–100605.

[3] P.S. Avanish, M. Monika, C. Amita, S.K. Dhawan, Graphene oxide/ ferrofluid/cement composites for electromagnetic interference shielding application, Nanotechnology 22 (46) (2011) 465701.

[4] M. Hu et al., "Effect of characteristics of chemical combined of graphene oxide-nanosilicananocomposite fillers on properties of cement-based materials," Constr. Build. Mater., vol. 225, pp. 745–753, 2019, DOI: 10.1016/j.conbuildmat.2019.07.079.

[5] Dikin DA, Stankovich S, Zimney EJ, Piner RD, Dommett GH, Evmenenko G, et al. Preparation and characterization of graphene oxide paper. Nature 2007;448 (7152):457–60.

[6] Suk JW, Piner RD, An J, Ruoff RS. Mechanical properties of monolayer graphene Oxide. ACS Nano 2010;4(11):6557–64.

[7] Mohammed A, Sanjayan J, Duan W, Nazari A. Incorporating graphene oxide in Cement composites: a study of transport properties. Constr Build Mater 2015;84:341–7.

[8] J. I. Paredes, A. Martı, and J. M. D. Tasco, "Graphene Oxide Dispersions in Organic Solvents," no. 18, pp. 10560–10564, 2008.

[9] S. J. Lee, S. H. Jeong, D. U. Kim, and J. P. Won, "Effects of graphene oxide on pore structure and mechanical properties of cementitious composites," Compos. Struct., vol. 234, no. September 2019, p. 111709, 2020, DOI: 10.1016/j.compstruct.2019.111709.

[10] C. Zhou, F. Li, J. Hu, M. Ren, J. Wei, and Q. Yu, "Enhanced mechanical properties of cement paste by hybrid graphene oxide/carbon nanotubes," Constr. Build. Mater., vol. 134, pp. 336–345, 2017, DOI: 10.1016/j.conbuildmat.2016.12.147.

[11] R. Roy, A. Mitra, A. T. Ganesh, and V. Sairam, "Effect of Graphene Oxide Nanosheets dispersion in cement mortar composites incorporating Metakaolin and Silica Fume," Constr. Build. Mater., vol. 186, pp. 514–524, 2018, DOI: 10.1016/j.conbuildmat.2018.07.135.

[12] ZeyuLua, Songhai Houb, AsadHanifc, WenbinHaod, ZongjinLia, Gaoxiong Sun, Comparative evaluation on the dispersion and stability of graphene oxide in Water and cement pore solution by incorporating silica fume, Cement and Concrete Composites 94 (2018) 33–42

[13] S. Stankovich et al., Graphene-based composite materials, Nature 442 (7100)(2006) 282–286.

[14] S. Lv, Y. Ma, C. Qiu, T. Sun, J. Liu, and Q. Zhou, "Effect of graphene oxide nanosheets of microstructure and mechanical properties of cement composites," Constr. Build. Mater., vol. 49, pp. 121–127, 2013, DOI: 10.1016/j.conbuildmat.2013.08.022.

[15] B. Han, L. Zhang, S. Zeng, S. Dong, X. Yu, R. Yang, J. Ou, Nano-core Effect in Nanoengineered Cementitious Composites, Composites Part A: Applied Science and Manufacturing, (2017).

[16] S. Lv, J. Liu, T. Sun, et al., Effect of GO nanosheets on shapes of cement hydration crystals and their formation process, Constr. Build. Mater. 64 (2014) 231–239.

[17] H. Du, H.J. Gao, S. Dai Pang, Improvement in concrete resistance against water and Chloride ingress by adding graphenenanoplatelet, Cement Concr. Res. 83 (2016)114–123.

[18] Y. Cao, J. Zhang, J. Feng, P. Wu, Compatibilization of immiscible polymer blends using graphene oxide sheets, ACS Nano 5 (7) (2011) 5920–5927.

[19] W.G. Li, Z. Luo, C. Long, C. Wu, W.H. Duan, S.P. Shah, Effects of nanoparticle on the dynamic behaviors of recycled aggregate concrete under impact loading, Mater. Des. 112 (2016) 58–66

[20] Z. Xu, C. Gao, Aqueous liquid crystals of graphene oxide, ACS Nano 5 (4) (2011) 2908–2915.

[21] S. Chuah, W. Li, S.J. Chen, J.G. Sanjayan, W.H. Duan, Investigation on dispersion of graphene oxide in cement composite using different surfactant treatments, Construct. Build. Mater. 161 (2018) 519–527.

[22] D. Hou, T. Yang, J. Tang, S. Li, Reactive force field Molecular dynamics study on graphene oxide reinforced cement composite: functional groups de-protonation, interfacial bonding and strengthening mechanism, Phys. Chem. Chem. Phys. 20 (13) (2018) 8773–8789.

[23] H. Du, S.D. Pang, Dispersion and stability of graphene nanoplatelet in water and its influence on cement composites, Constr. Build. Mater. 167 (2018) 403–413.

[24] S. Bai, L. Jiang, N. Xu, M. Jin, S. Jiang, Enhancement of mechanical and electrical properties of graphene/cement composite due to improved dispersion of graphene by addition of silica fume, Constr. Build. Mater. 164 (2018) 433–441.

[25] S. Parveen, S. Rana, R. Fangueiro, M.C. Paiva, Microstructure and mechanical Properties of carbon nanotube reinforced cementitious composites developed Using a novel dispersion technique, Cem. Concr. Res. 73 (2015) 215–227.

[26] D.G. Papageorgiou, I.A. Kinloch, R.J. Young, Graphene/elastomer Nanocomposites, Carbon 95 (2015) 460–484.

[27] Pan Z, He L, Qiu L, Korayem AH, Li G, Zhu JW, et al. Mechanical properties and microstructure of a graphene oxide-cement composite. Cement Concr Compos Compo 2015;58:140–7.

[28] Y. Shang et al., Effect of graphene oxide on the rheological properties of cement pastes, Constr. Build. Mater. 96 (2015) 20–28.

[29] R. A. e Silva, P. de Castro Guetti, M. S. da Luz, F. Rouxinol, and R. V. Gelamo, "Enhanced properties of cement mortars with multilayer graphene nanoparticles," Constr. Build. Mater., vol. 149, pp. 378–385, 2017, DOI: 10.1016/j.conbuildmat.2017.05.146.

[30] Y. Gao, H. Wen, S. Jian, M. Rui, and W. Qiang, "Influence of ultrasonication on the dispersion and enhancing effect of graphene oxide – carbon nanotube hybrid nanoreinforcement in cementitious composite," Compos. Part B, vol. 164, no. November 2018, pp. 45–53, 2019, DOI: 10.1016/j.compositesb.2018.11.066.

[31] V. D. Ho et al., "Influence of pristine graphene particle sizes on] S. Chuah, Z. Pan, J. G. Sanjayan, C. M. Wang, and W. H. Duan, "Nano reinforced cement and concrete composites and new perspective from graphene oxide," Constr. Build. Mater., vol. 73, pp. 113–124, 2014, DOI: 10.1016/j.conbuildmat.2014.09.040.

[32] Gong K et al. Reinforcing effects of graphene oxide on portland cement paste. J Mater Civil Eng 2014. A4014010.

[33] Pan Z, et al., Graphene oxide reinforced cement and concrete. 2012, WO Patent App. PCT/AU2012/001,582.

[34] W.G. Li, Z. Huang, F.L. Cao, Z.H. Sun, S.P. Shah, Effects of nano-silica and nano-limestone on flowability and mechanical properties of ultra-high-performance concrete matrix, Constr. Build. Mater. 95 (1) (2015) 366–374.

[35] Strano MS et al. The role of surfactant adsorption during ultrasonication in the dispersion of single-walled carbon nanotubes. J NanosciNanotechnol 2003;3(1–2):81–6

[36] Li GY, Wang PM, Zhao X. Mechanical behavior and microstructure of cement composites incorporating surface-treated multi-walled carbon nanotubes. Carbon 2005;43(6):1239–45.

[37] Z. Lu, D. Hou, A. Hanif, W. Hao, G. Sun, and Z. Li, "Comparative evaluation on the dispersion and stability of graphene oxide in water and cement pore solution by incorporating silica fume," Cem. Concr. Compos., vol. 94, no. July, pp. 33–42, 2018, DOI: 10.1016/j.cemconcomp.2018.08.011.