ADDITIVE AND LIFE CYCLE ASSESMENT OF CONCRETE

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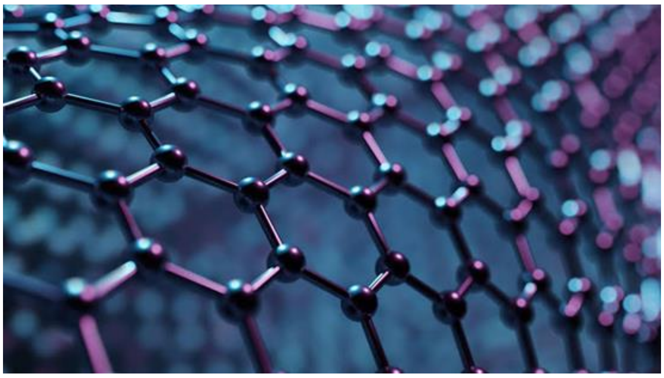
Abstract - *This project represents the result of an experimental investigation off graphene oxide on physical properties of concrete. Graphene is a simple substance with complex properties. At its most basic, it's just a single layer of carbon atoms arranged in a hexagonal matrixes, concrete lacks ductility resulting in low tensile strength and flexural strength and poor systems to crack formation studies has demonstrated that the edition of crap in oxide launch it can effectively enhance the complex you not flexural properties of ordinary Portland cement, Graphene oxide content were varied by 0.05%, 0.1%, 0.2% of cement content. All the specimens were cured for the period of 7, 14 & 28 days before crushing. Tests were performed at the age of 7, 14 & 28 days. Test results indicated that the inclusion of graphene oxide in concrete enhanced the compressive, split tensile and flexural strength. Concrete structures represent a huge investment in terms of materials and energy and they lead to significant environmental impacts. Thus, there is a need to choose the most sustainable and eco-friendly alternative. To fully assess and fairly compare the environmental burdens of those two structures, the life cycle assessment (LCA) has been chosen.*

Key Words: Graphene oxide, reduced graphene oxide, Synthesis, Properties of graphene and graphene oxide, life cycle assessment.

1. INTRODUCTION

Graphene is among the allotropes of carbon; its carbon atoms are arranged in a single layer. These carbon atoms are organized in a honeycomb lattice with a two-dimensional arrangement. The carbon–carbon bond distance in a single graphene sheet approximates 0.142 nm. It is the building-block of Graphite (which is used, among others things, in pencil tips), but graphene is a remarkable substance on its own - with a multitude of astonishing properties which repeatedly earn it the title "wonder material". Also incredibly strong - about 200 times stronger than steel. On top of that, graphene is an excellent conductor of heat and electricity and has interesting light absorption abilities. Graphene as construction material: The high traction and tearing resistance of graphene make of it the "ideal additive" for cement and concrete. Graphene has some brilliant properties that No other material has. Graphene has great efficiency against construction applications such as concrete. The most important applications are in pillars, pipes, roads, concrete screens and dams, elements that require greater durability over time, this additive reduces the use of cement that pollute severely, which is good for the environment and modifies the procedure of traditional construction of materials with concrete.

In order to know which course of actions might be the best in terms of sustainability, several assessment tools with different purposes are available: amongst others, Environmental Impact Assessment (EIA), Material Flow Analysis (MFA), or Strategic Environmental Assessment (SEA). Life Cycle Assessment (LCA) is also one such assessment tool. Even though it is more product-oriented, its development within the building sector is ongoing. It evaluates the potential environmental impacts of a structure throughout its life cycle, i.e. from cradle to grave.



One of the great advantages is that graphene, being composed of carbon, is an organic material which means that it is not only greener but also healthier.

Graphene oxide: - Concrete researchers have recently focused on using nanomaterials to develop superior coating materials. In particular, graphene oxide, produced by the chemical exfoliation of graphite, has emerged as a promising candidate. Due to the superior mechanical properties conveyed by its high surface area and strength, as well as its excellent dispensability in water, graphene oxide appears to be an excellent candidate for the surface protection of concrete. Recent years, the application of nanotechnology (1-100nm) has shown an impressive results in solving several engineering related problems in electronics and biomedicine. Through chemical and physical processes, nanomaterials improve material properties such as thermal, mechanical, electrical, lubricity and rheological. Comparing with the micro/macro sized particles, the surface area to volume ratio of the nanoparticle is higher **Amanullah et al, (2009) [1].**

Nanomaterials improve cement properties **(Ruhal et al, 2011 [2], Ershadi, et al (2011) [3], Li, et al 2003) [4], Rui et al. (2015) [5].** Among others, Graphene is known for its superb material properties

And has shown a great potential in other industries, such as electronics and polymer composites.

Graphene is about 200 times stronger than steel [6]. Graphene Oxide (GO) is a derived from graphene. **Wang et al 2015[7]** have reported the influence of GO impact of graphene oxide on the microstructure and mechanical strength of cement, which has potential of providing a Nano reinforcement. However, the research on GO is still at an early stage. This paper presents the effect of GO in the conventional cement mortar. The investigation is through various experimental studies.

1.1 OBJECTIVE

- To experimentally test conventional concrete with graphene concrete by compression, flexural tensile.
- To compare the strength properties of conventional concrete with graphene concrete.
- In order to know which course of actions might be the best in terms of sustainability
- To identify environmental hot spots in products and materials and establishes the benchmark against which improvements can be measured.

1.2 SCOPE

- To reduce the production of CO_2 and to produce an Eco-friendly concrete.
- To propose a solution for resource optimization.
- The best procedure in terms of sustainable development (LCA) to be aware of a wide range of environmental issues.

2. SYNTHESIS OF GRAPHENE OXIDE

Graphene oxide was synthesized by Hummers method through

Oxidation of graphite. The stepwise preparation is given as follows:

1. Graphite flakes (2 g) and $NaNO_3$ (2 g) were mixed in 50 mL of

H_2SO_4 (98%) in a 1000 mL volumetric flask kept under at ice bath (0-5°C) with continuous stirring.

2. The mixture was stirred for 2 hrs. at this temperature and potassium permanganate (6 g) was added to the suspension very slowly. The rate of addition was carefully controlled to keep the reaction temperature lower than 15°C.

3. The ice bath was then removed, and the mixture was stirred at 35°C until it became pasty brownish and kept under stirring for 2 days.

4. It is then diluted with slow addition of 100 ml water. The reaction temperature was rapidly increased to 98°C with effervescence, and the color changed to brown color.

5. Further this solution was diluted by adding additional 200 ml of water stirred continuously.

6. The solution is finally treated with 10 ml H_2O_2 to terminate the reaction by appearance of yellow color.

7. For purification, the mixture was washed by rinsing and centrifugation with 10% HCl and then deionized (DI) water several times.

8. After filtration and drying under vacuum at room temperature, the graphene oxide (GO) was obtained as a powder.

2.1 PROPERTIES Of GRAPHENE

1. Electronic Properties:-
Because graphene has a delocalized pi-electron system across the entirety of its surface, the movement of electrons is very fluid.
The graphene 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

cm2V-1s-1, with the potential of producing up to 200,000 cm2V-1s-1.

2. Thermal Properties:-
The repeating structure of graphene makes it an ideal material to conduct heat in plane. Interplant conductivity is problematic and typically other nanomaterials such as CNTs are added to boost interplant conductivity.
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.

3. Mechanical Strength:-
Graphene is one of the strongest materials ever discovered with a tensile strength of 1.3 x 1011 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.

2.2 APPLICATIONS OF GRAPHENE

There are many applications of graphene because it's a revolutionary material. It has many applications replacing conventional materials as well as the ability to support applications previously not possible before the advent of 2D materials. The applications of Graphene are truly endless and many are yet to be conceived of yet.

1. Precast Products
2. Marine Construction
3. Well Cementing
4. Sensors
5. Storage Cylinders

2.3. STRUCTURAL COMPOSITIES

Graphene is incorporated into various composites for applications where strength and weight are limiting factors, for example in the aerospace industry.
Graphene is being incorporated into many materials to make the existing material stronger and more lightweight. For the aviation industry, a composite material which is much lighter than steel but will still provide the necessary strength will save a lot of money on fuel consumption, which is why graphene has started to be incorporated into such materials.
Graphene-based structural composites have a huge potential to become a widely used alternative to many materials used today.

2.4 COMPONENTS OF LCA

Life cycle assessment (LCA) is the latest addition to the sustainability toolbox for buildings. LCA looks at the upstream and downstream burdens throughout the entire building life cycle, with a focus on embodied environmental impacts. Embodied impacts become more critical as operating consumption, such as energy and water, is reduced through optimization of design and building management. Key components of LCA are:

1. Goal and scope definition
2. Inventory analysis
3. Impact assessment
4. Interpretation

The goal & scope definition step ensures that your LCA is performed consistently. In the inventory analysis, you look at all the environmental inputs and outputs associated with a product or service. An example of an environmental input – something you take out of the environment to put into the product's life cycle – is the use of raw materials and energy. Environmental outputs – which your product's life cycle puts out into the environment – include the emission of pollutants and the waste streams. Together, this gives you the complete picture. In the life cycle impact assessment (LCIA), you draw the conclusions that allow you to make better business decisions. You classify the environmental impacts, evaluate them by what is most important to your company, and translate them into environmental themes such as global warming or human health. Finally, the interpretation phase will provide you the conclusions that you got throughout the process, which are entirely affected by scope, and goals that you defined in the first part of the process.

This study relies on various assumptions regarding designs, transportation distances, construction processes and on several omissions which narrow the scope of the analysis. This LCA study only takes into account the construction phase of the structure and the approach mainly relies on aggregated data (e.g. concrete production including manufacturing of cement). Additionally, it was shown that environmentally and structurally advantageous concrete mixtures could be made with high-volumes of fly ash and limestone. A wide range of early and long term strengths were attainable depending on the selected mixture proportion. GHG emissions and criteria air pollutants were also successfully reduced and were in all cases similar to or lower than for ordinary portland cement concrete.

3. MATERIAL PROPERTIES

1. Cement:-
Type of cement: PPC
Specific Gravity: 3.13
Consistency: 26.27%

2. Coarse Aggregate:-
Size of Aggregate: 10mm-20mm
Specific Gravity: 10mm-2.745
20mm-2.765
Water Absorption: 10mm-0.5%
20mm-0.35%
3. Manufactured Sand:-
Specific Gravity: 2.72
Water Absorption: 2.40%

Table -1:-

PHYSICAL PROPERTIES

SPECIFIC GRAVITY AND WATER ABSORPTION

	Samples	Cement	Fine aggregate	Coarse Aggregate	
				20 mm	10 mm
Specific Gravity	S1	3.2	2.5	2.78	2.78
	S2	2.94	2.36	2.5	2.58
	S3	3.20	3	2.7	2.78
	Average	3.15	2.62	2.7	2.72
Water absorption	Average	-	1.0%	0.5%	0.7%

Table -2:-

SIEVE ANALYSIS

IS sieve	Mass retained (g)	% retained (g)	Retained cumulative(%)	Cumulative finer passed (%)
4.75 mm	0	0	0	100
2 mm	12	12	13	88
1 mm	255	51	64	36
300 μ	110	22	86	14
150 μ	35	7	93	7
75 μ	20	4	97	3
Pan	15	3	100	0

3.1. Conventional Concrete

Conventional Concrete, also known as normal concrete or conventional vibrated concrete (CVC), is a dense aggregate mix that requires mechanical vibrations and/or poking to remove air pockets that become trapped during the pouring and mixing process. Although the popular Portland Concrete is an example of a commonly used variety of conventional concrete, there are many variations that use a variety of admixtures. Gravels are generally the coarse aggregate components of conventional concretes. Sands and crushed stone, usually crushed to approximately 3/8 inch, make up the fine aggregate portion of the mix. Together, Gravel and crushed stone/sand account for approximately 60-75 percent of a conventional concrete mixture. The remaining 25-30 percent is generally some combination of admixture materials including but not limited to iron, silicone, limestone, and clay. The larger size of aggregate particles in conventional concrete also contributes to its overall pump able yield stress. Conventional concrete usually has a yield stress of around 100 to 1000 Pa (Newton's per meter square). Meaning, conventional concrete will require greater energy expenditure to move through pipes from, for instance, a mixing truck to the worksite. This also means conventional cements will need more mechanical manipulation to flow into the obscure pockets of molds. Concrete flow is usually measured by a process called a slump-cone test. A cone vessel, shaped somewhat like a loud horn, is filled with a wet concrete mixture. When the cone is removed, the clump of remaining concrete flows outward. The width of the circular concrete pile is measured giving you slump flow value. Conventional concrete, without any admixtures, generally has a slump flow value of about four inches.

Table -3:-

MIX RATIO-MODEL I

The mix ratio is calculated for M30 grade of concrete.

(Conventional concrete)

Material	Cube	Prism	Cylinder
PPC	1.50 kg	2.225 kg	0.698 kg
20mm	2.09 kg	3.10 kg	0.974 kg
10mm	1.39 kg	2.068 kg	0.649 kg
M Sand	2.52 kg	3.744 kg	1.175 kg
Water	749 ml	1111 ml	348 ml

3.2. LCA OF CONCRETE: ANALYSIS

The Canadian concrete industry has been working with experts from MIT, the Athena Sustainable Materials Institute and the International Institute for Sustainable Development to identify and measure concrete's contribution to the sustainability performance of our buildings and infrastructure projects. MIT studies show that the passive energy efficiency of concrete's thermal mass — gains of 8% over other building materials — more than make up for the embodied impacts of the cement and concrete manufacturing process. Used strategically and integrated with smart design and technologies, concrete's thermal mass reduces the operational energy needs of large commercial buildings. Such an example is Manitoba Hydro Place (MHP), which has achieved a 70% energy efficiency improvement over the Model National Energy Code for Buildings.

The new peer-reviewed study Emission Omissions: Carbon accounting gaps in the built environment, conducted by the International Institute for Sustainable Development finds that up to 72% of a wood product's carbon emissions may currently be omitted from wood LCAs and that when these emissions are taken into account, concrete's embodied carbon footprint could be up to 6% less intensive than that of wood products. In addition, this research confirmed that the production of OPC (Ordinary Portland Concrete) in Campania, Italy is associated with high CO2 emissions; the use of recycled aggregates ensured the reduction of GW (Global Warming); the use of recycled aggregates can improve the environmental management problem. In conclusion, the results of the study indicated that the use of recycled aggregates is a potential field of research that could ensure tangible environmental benefits in the future in the context of the Campania Region and in a national context. In addition, the study points out some critical issues. In Buildings 2018, 8, 70 9 of 12 particular, the LCA analysis did not consider the technical and economic aspects. Thus, starting from the current scenario, three main issues will be investigated in future research. The first issue concerns the development of a life cycle costing analysis (LCC) to determine the most cost-effective option among the four alternatives. The second issue is concerned with the analysis of the environmental and economic implications as a function of different distances, which affect the impacts due to transport. Based on these sensitivity analyses, it will be possible to choose the available resources that generate the lowest environmental and adverse economic impacts. The third line of research will be concerned with the investigation of the use of innovative composite materials [64–67]. A last recommendation is for LCA analysts to perform a similar study. Since inventory analysis could vary from one area to another, it is desirable to improve the precision of the LCA data.

3.3. GRAPHENE BASED CONCRETE

Graphene oxide (GO) may have a huge impact in construction industry in near future. Because of the oxygenated functionalities attached on the aromatic structure, it has better dispersibility property than any other graphene-based derived. Many of the researchers have given their views on the influence of GO on the mechanical and durability properties in ceramic matrix. Three mixes were prepared with inclusion of GO (0%, 0.1%, 0.3% and 0.5% by weight of cement). Tests on mechanical and water permeation properties were conducted.

Table -4:- (0.1 % of Graphene oxide)

MIX RATIO-MODEL II

(0.1% of Graphene added)

Material	Cube	Prism	Cylinder
Graphene oxide (GO)	1.50 g	2.225 g	0.698 g
PPC	1.348 kg	1.998 kg	0.627 kg
20mm	2.17 kg	3.215 kg	1.009 kg
10mm	1.44 kg	2.145 kg	0.673 kg
M Sand	2.62 kg	3.888 kg	1.210 kg
Water	750 ml	1115 ml	350 ml

Table -5:- (0.3 % of Graphene oxide)

MIX RATIO -MODEL III

(0.3% of Graphene oxide added)

Material	Cube	Prism	Cylinder
Graphene oxide (GO)	4.50 g	6.70 g	2.10 g
PPC	1.345 kg	1.993 kg	0.625 kg
20mm	2.17 kg	3.215 kg	1.009 kg
10mm	1.44 kg	2.145 kg	0.673 kg
M Sand	2.62 kg	3.888 kg	1.210 kg
Water	750 ml	1115 ml	350 ml

Table -6:- (0.5 % of Graphene oxide)

MIX RATIO -MODEL IV

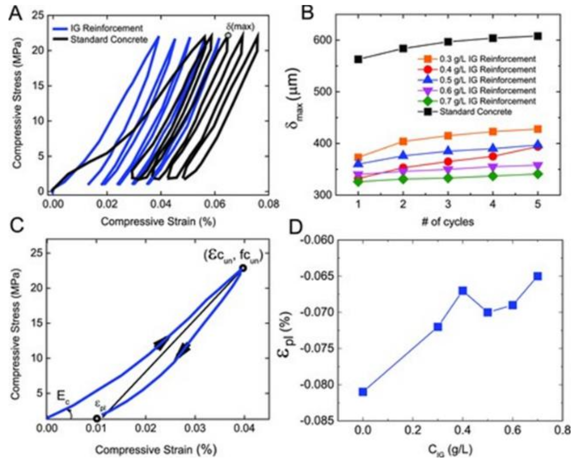
(0.5% of Graphene added)

Material	Cube	Prism	Cylinder
Graphene oxide (GO)	7.50 g	11.12 g	3.49 g
PPC	1.342 kg	1.989 kg	0.624 kg
20mm	2.17 kg	3.215 kg	1.009 kg
10mm	1.44 kg	2.145 kg	0.673 kg
M Sand	2.62 kg	3.888 kg	1.210 kg
Water	750 ml	1115 ml	350 ml

3.4. CONCRETE TESTING

Testing on concrete specimens has been conducted by using following tests:

Compressive Strength: Concrete compressive strength requirements can vary from 2500 psi (17 MPa) for residential concrete to 4000 psi (28 MPa) and higher in commercial structures.



Tensile Strength: The tensile strength of concrete is generally in the range of 10 % to 12% of its compressive strength.

Flexural Strength: Flexural strength is one measure of the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending.

4. RESULTS

The compression test results shows that 8.97 % of strength is increased of 0.1%, 5.12 of strength is increased of 0.3%, 3.7% of strength is increased of 0.5% replacement of cement at 28 days.

The flexural test results shows that, 13.14% of strength is increased of 0.1%, 8.57% of strength is increased of 0.3%, 3.23 of strength is increased of 0.5% replacement of cement at 28 days.

The split tensile test results shows that, 20.98% of strength is increased of 0.1%, 19.13% of strength 0.3%, 6.17% of strength is increased pf 0.5% replacement of cement at 28 days.

Table -7:-

FLEXURAL STRENGTH

MODELS	7 DAYS (MPa)	28 DAYS (MPa)
M1 CONVENTIONAL CONCRETE	2.90	4.375
M2 0.1% OF GRAPHENE OXIDE CONCRETE	3.5	4.95
M3 0.3% OF GRAPHENE OXIDE CONCRETE	3.75	4.75
M4 0.5% OF GRAPHENE OXIDE CONCRETE	3.3	4.4

Table -8:-

TEST RESULTS

COMPRESSIVE STRENGTH

MODELS	7 DAYS (N/mm²)	28 DAYS (N/mm²)
M1 CONVENTIONAL CONCRETE	16.9 N/mm²	30.46 N/mm²
M2 0.1% OF GRAPHENE OXIDE CONCRETE	19.4 N/mm²	33.11 N/mm²
M3 0.3% OF GRAPHENE OXIDE CONCRETE	19.89 N/mm²	32.02 N/mm²
M4 0.5% OF GRAPHENE OXIDE CONCRETE	21.31 N/mm²	31.59 N/mm²

4. CONCLUSIONS

The casting and testing of specimens were done according to the IS codes.

Addition of 0.1% of G.O itself gives the satisfying results when compared to 0.3%, 0.5%.

Increase in compression, flexural and split tensile strength was found when compared to conventional concrete.

REFERENCES

1. Ingrao, C.; Scrucca, F.; Tricase, C.; Asdrubali, F. A comparative Life Cycle Assessment of external wallcompositions for cleaner construction solutions in buildings. J. Clean. Prod. 2016, 124, 283–298
2. Vandenbroucke, M.; Galle, W.; De Temmerman, N.; Debacker, W.; Paduart, A. Using Life Cycle Assessment to Inform Decision-Making for

Sustainable Buildings. Buildings 2015, 5, 536–559.
3. Surahman, U.; Kubota, T.; Higashi, O. Life Cycle Assessment of Energy and CO2 Emissions for Residential Buildings in Jakarta and Bandung, Indonesia. Buildings 2015, 5, 1131–1155.
4. Curran, M.A. Life Cycle Assessment; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2008.
5. Xiao, D.; Wang, H.; Zhu, J.; Peng, S. Sequent and accumulative life cycle assessment of materials and products. Mater. Des. 2001, 22, 147–149.
6. Jincheng, X.; Weichang, H.; Xinli, K.; Tianmin, W. Research and development of the object-oriented life cycle assessment database. Mater. Des. 2001, 22, 101–105.
7. Finkbeiner, M.; Inaba, A.; Tan, R.; Christiansen, K.; Klüppel, H.J. The new international standards for lifecycle assessment: ISO 14040 and ISO 14044. Int. J. Life Cycle Assess. 2006, 11, 80–85.
8. Finnveden, G.; Hauschild, M.Z.; Ekvall, T.; Guinée, J.; Heijungs, R.; Hellweg, S.; Suh, S. Recentdevelopments in life cycle assessment. J. Environ. Manag. 2009, 91, 1–21.
9. De Souza, D.M.; Lafontaine, M.; Charron-Doucet, F.; Chappert, B.; Kicak, K.; Duarte; F.; Lima, L.Comparative life cycle assessment of ceramic brick, concrete brick and cast-in-place reinforced concrete exterior walls. J. Clean. Prod. 2016, 137, 70–82.
10. Graphene definition, meaning – what is graphene in the British English Dictionary & Thesaurus – Cambridge Dictionaries Online". Cambrid
11. Geim, A. K.; Novoselov, K. S. (26 February 2007). "The rise of graphene". Nature Materials. 6 (3): 183–191. arXiv:cond-mat/0702595. Bibcode:2007NatMa...6..183G. doi:10.1038/nmat1849. PMID 17330084. S2CID 14647602.
12. Peres, N. M. R.; Ribeiro, R. M. (2009). "Focus on Graphene". New Journal of Physics. 11 (9): 095002. Bibcode:2009NJPh...11i5002P. doi:10.1088/1367-2630/11/9/095002.
13. Boehm, H. P.; Clauss, A.; Fischer, G. O.; Hofmann, U. (1 July 1962). "Das Adsorptionsverhalten sehr dünner Kohlenstoff-Folien". Zeitschrift für Anorganische und Allgemeine Chemie. 316 (3–4): 119–127

WEBSITES

https://www.sciencedirect.com/science/article/pii/B9780857094247500037

https://www.researchgate.net/publication/307476448_LIFE_CYCLE_ASSESSMENT_OF_CONCRETE_STRUCTURES

https://www.tandfonline.com/doi/abs/10.1080/14786451.2015.1100197?journalCode=gsol20

https://digitalassets.lib.berkeley.edu/etd/ucb/text/Gursel_berkeley_0028E_14522.pdf

1https://www.dezeen.com/2018/05/03/graphene-reinforced-concrete-stronger-university-of-exeter-scientists/

https://www.graphenano.com/en/el-grafeno-llega-a-la-construccion-para-aumentar-la-resistencia-del-hormigon/

https://fieldlens.com/blog/building-better/graphene-new-steel/#:~:text=Steel%20may%20not%20have%20the,applications%20could%20overcome%20its%20limitation

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6498302/

https://www.richardvanhooijdonk.com/blog/en/revolutionary-graphene-concrete-could-be-an-absolute-game-changer-for-construction-and-the-planet/

https://www.azobuild.com/article.aspx?ArticleID=8257

https://nanographene.net/