UNIVERSITY OF SOUTHERN QUEENSLAND

FACULTY OF HEALTH, ENGINEERING AND SCIENCES

Flexural behaviour of

Graphene-reinforced concrete beams

A Progress Report submitted by

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Abstract

Concrete is the most used material in the construction industry. The bonding agent for concrete is cement which is responsible for about 8% of the world's carbon emissions. The industry together education institutions have been working to reduce the amount of concrete that the industry uses. One way to reduce the use of concrete is to manipulate the mechanical properties of concrete by adding different materials to increase strength and durability. This paper utilises graphene as a material added to concrete to determine whether graphene has any effect on the slump, modulus of elasticity, flexural, compressive and tensile strength of concrete.

Graphene quantities used in this project are 0.03%, 0.05% and 0.1% by weight of cement. This project has demonstrated that the addition of graphene in concrete reduces the fluidity of fresh concrete. Graphene quantities of 0.03%, 0.05% and 0.1% by weight of cement showed a reduction in slump of 11.7%, 33.3% and 29.2% respectively when compared to the control sample. For flexural strength beams with 40mm x 150mm x 500mm layer of graphene concrete mix at the bottom of a layer of normal concrete of 110mm x 150 x 500mm to make up a beam of 150mm x 150mm x 500mm, as well as beams with full graphene concrete mix were tested and the results showed that addition of graphene also improved flexural strength, with 0.03%, 0.05% and 0.1% by weight of cement showing a 29.8%, 44.7% and 44% respectively for the 40mm beams and 0.03%, 0.05% and 0.1% by weight of cement showing a 12.3%, 7.1% and 4.7% respectively for the full graphene beams, which was a surprising result as we expected the full graphene beams to show better improvement when compared with the beams with only 40mm layer of graphene concrete mix. While compressive strength results show some improvement with some mixed results as 0.03%, 0.05% and 0.1% by weight of cement showing a 31.8%, 1% and 3.5% respectively, the results for 0.05% and 0.1% were lower than expected.

Modulus of elasticity showed a with the graphene quantities of 0.03%, 0.05% and 0.1% by weight of cement showed a reduction of 6%, 11.7% and 15.2% respectively, which means the concrete is more ductile and able to deflect more before failure. While the results for the indirect tensile tests were inconclusive as they showed a reduction in the tensile strength as graphene is added to concrete except for 0.03% of graphene samples. The results showed that graphene quantities of 0.03%, 0.05% and 0.1% by weight of cement showed a 6%, -16.9% and -4.1% respectively, this test will need to be investigated more with more samples per percentage.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111 & ENG4112 Research Project

Limitations of Use

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and the conclusions set out in the dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature:

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Chapter 1

1 Introduction

Concrete is a widely used source of construction material, and in recent years, researchers have been looking into various ways of making concrete stronger and more durable to reduce the amount of concrete needed. While fibre reinforced polymers and other materials have been widely researched, minimal research has been conducted on graphene reinforced concrete.

In this research, we intend to evaluate the effectiveness of graphene as an additive that increases the strength and durability of concrete. Graphene is an atom level material that was discovered in 2004 by two professors and researchers at The University of Manchester, Professor Andre Geim and Professor Kostya Novoselov. The University of Manchester professors won the Nobel Prize in Physics for their pioneering work. On one Friday, the two scientists were conducting some experiments and removed some flakes from a piece of bulk graphite with some sticky tape. They noticed some flakes were a lot thinner than others. By separating the graphite fragments repeatedly, they managed to create flakes that were just one atom thick, namely graphene. This experiment work by the two researchers led to graphene being isolated for the very first time and spawned a new area of research and development. (Manchester)

In this research, we intend to evaluate the effectiveness of graphene as an additive that increases the strength and durability of concrete. Experiments will be conducted as per Australian standards:

- slump test, :AS 1012.3.1:2014
- Flexural test :AS 1012.8.2:2014
- compressive strength, :AS 1012.8.1:2014
- tensile strength, :AS 1012.10:2000
- modulus of elasticity :AS 1012.11:2000

1.1 Project Aim and Objectives

1.1.1 Project Aim

(1) This project aims to investigate the flexural behaviour of graphene-reinforced concrete beams

1.1.2 Project Objectives

The objectives of this project were to:

(1) To analyse evidence-based research on graphene, industrial use of graphene and concrete graphene mix design.
(2) Design and plan testing the graphene reinforced concrete. Test variables include:
   - For beams tests, we will have a full graphene/concrete mix beams, and beams with 40mm (40x150x500mm) graphene reinforced concrete layer at the bottom of a normal concrete (110x150x500mm) beam for flexural tests.
   - For cylinders, we will have a 100mmD x 200mmH graphene reinforced specimens for compressive, indirect tensile tests and modulus of elasticity tests.
   - Graphene content of the samples will be 0.03%, 0.05% and 0.1%
(3) Design/implement laboratory experiments utilising the Australian standards.
(4) Analysis and evaluation of test data will be conducted.
(5) Analyse the results and the effects of graphene on concrete properties

If time and resources permit:

(6) Evaluate the practicality and cost-effectiveness of using graphene reinforced concrete beams on large scale projects.

1.2 Graphene background

Graphene has incredible mechanical properties as compared to other material. The strength of its 0.142 Nm-long carbon bonds, is the strongest material ever discovered, with an ultimate tensile strength of 130 GPa, compared to 0.4GPa for r A36 structural steel, or 0.375 GPa for Aramid (Kevlar). Graphene contains elastic properties that enable it to retain its original size after strain. It is these fantastic properties that we hope to harness and improve the properties of concrete in this research.

Table 1.1: Graphene properties compared with steel (Shamsaei et al. 2018)

Mechanical Properties		Graphene	Carbon Steel
	Modulus of elasticity (GPa)	1000	200
	Tensile strength (GPa)	130	0.2-1.5
	Elongation at break	20%	20
Physical Properties		Graphene	Carbon Nanotubes
	Aspect ratio	6000-600000	1000-10000
	Specific surface area (m^2/g)	2360	9000-1000
	density (kg/m^3)	2200	1330

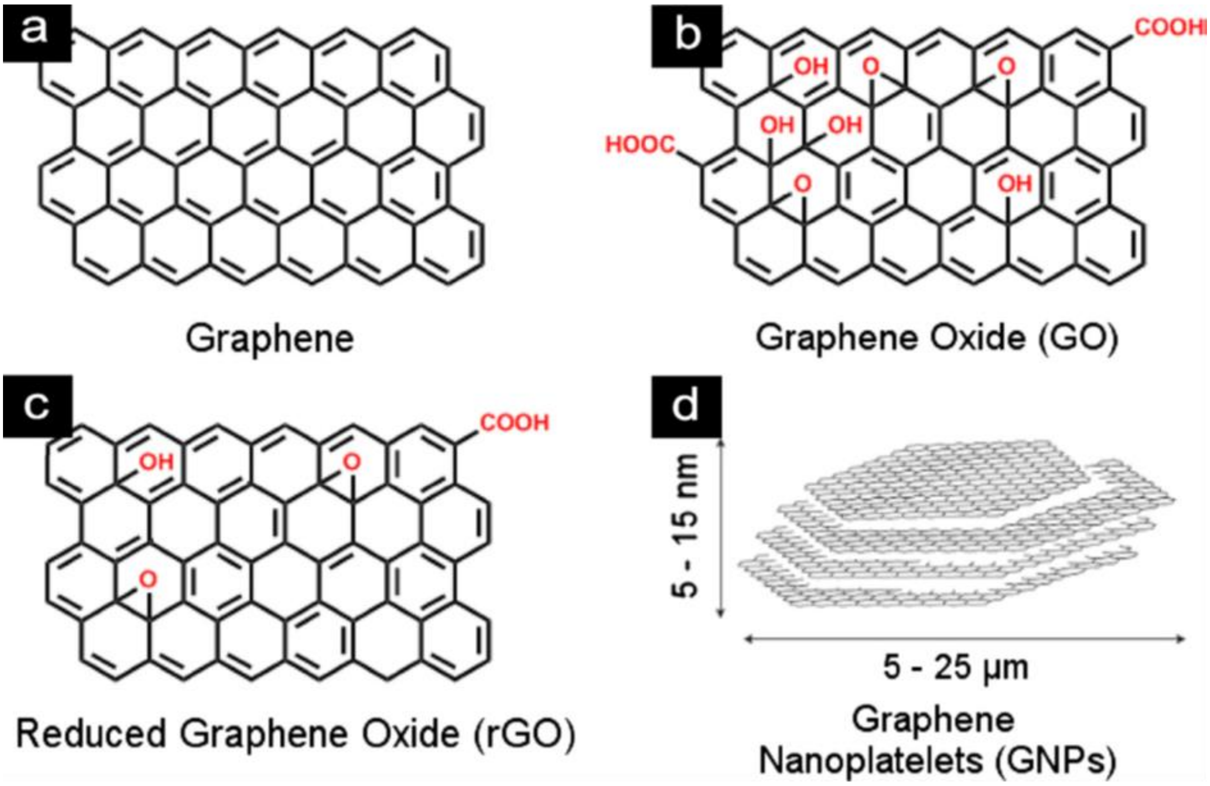


Figure 1.1: Graphene structure. (Shamsaei et al. 2018)

Graphene currently has many applications, but there are researches into the uses of graphene in broader fields, some of these applications are:

1.2.1 Optical electronics

Graphene is already in use in optical electronic, the property that makes it suitable for this application is the ability to transmit more than 90% of light, it can be used in LCD, touch screens. Graphene also has a high conductivity, which means less resistance, thus saving energy needed. Graphene is still underdeveloped in this field, and yet it can already match the properties of indium tin oxide, which is currently widely used in the touch screen manufacturing. There are a few other properties that will enable graphene to perform better than indium tin oxide in the future. It is suggested that optical absorption of graphene can be changed by adjusting Fermi levels, and high-quality graphene has high tensile strength while it is flexible. These properties will enable graphene to be used in foldable products like tablets or e-paper. (Marko Spasenovic 2015)

1.2.2 Composite material

Carbon fibre currently being used in the auto racing cars and aerospace aircraft development to reduce the weight and increase strength, some of the graphene properties surpass that of the carbon fibres which suggests that this will be an area that graphene will also thrive and produce even better products. Graphene can be dissolved in water and other liquids which means it can be incorporated into other materials such as plastics/polymers, this can enable parts to be made that exhibit higher strength and durability which can replace traditionally made metal alloy parts.

1.2.3 Energy storage

As we know, much of the broader debate of renewable energy is that the current technology in storage is not advanced enough yet. The problem with energy storage at the moment is that while batteries can hold large amounts of energy, they take a long time to charge while capacitors can charge relatively quick, they are not able to hold large amounts of energy. (Zhang et al. 2018). Current researches are looking at ways to enhance the abilities of lithium-ion batteries by adding graphene as an anode, to increase the storage capacity and reduce the charging time. The increased charging time is the most desired property for batteries. Graphene is also said to have the ability to be used in superconductors manufacturing and increasing their capacity to store more energy (Marko Spasenovic 2018)

1.2.4 Lubrication

Graphene has various application in the automotive industry, it can be added to current lubricants to enhance properties such as friction reduction, increase cooling effects of the parts in friction and provide better resistance. Graphene may be used in the development of unbreakable anti-fog windows. Graphene may be used in the development of more durable interiors which will be more resistant to UVA rays it can also be used as an anticorrosion/anti-scratch coat. Graphene will be used in the development of lighter, stronger and more durable chassis, and other car body parts that are venerable to wear and tear, like tires.

1.2.5 Ultrafiltration

Graphene can let water molecules pass through it, while it is impervious to other liquids and most gasses. This property makes graphene very valuable in the ultrafiltration sector, it can be used as a filtration medium and can also act as a barrier between two substances. Other electronic properties of graphene enhance its importance as a medium as it can have multiple uses as a filtration medium, it can also be used to detect any strain and pressure changes.

1.2.6 Medical and Medicine

Graphene has a large surface area, high electrical conductivity, high strength and it is also thin, which make it quite uniquely suited for biomedical and bioengineering. Graphene may be used in the development of efficient bioelectric sensor devices, with the ability to monitor and detect, cholesterol, haemoglobin level, glucose levels etc.

Chapter 2

2 Literature Review

2.1 Background

The amount of cement produced in the world in 2017 exceeded 4 billion tonnes. Cement production is a source of about 8% of the world's carbon emissions. Preston and Lehne (2018). To reduce the production of cement/concrete, we need to find ways that we can make concrete stronger and more durable. With graphene being the strongest material on earth, its only fair that some research is conducted to understand whether concrete mixed with graphene will be stronger than normal concrete. Once the concrete has been strengthened, the amount of concrete/cement needed for a project can be reduced, without compromising the integrity of the strength of the structure. In this research, we have analysed the impact of graphene on the mechanical properties of concrete. By analysing existing researches, where graphene is added to cement and to concrete, we have devised methodology and experimental design. (Preston & Lehne 2018)

2.2 Graphene added to cement

Zhu Pan et al. (2015) reported that the introduction of graphene oxide of 0.05 weight percentage of cement increased the compressive and flexural strength of cement graphene oxide mix by 15-35% and 41-58% respectively as shown on the graph in figure 2.1. These increases in mechanical properties are due to the remarkable properties of graphene oxide sheets (which have wrinkled morphology) which help improve the mechanical interlocking of the cement particles, creating a stronger cement paste. The particles of graphene oxide cement were review under the scanning electron microscope that showed that the graphene oxide sheets were acting as barriers for the propagating microcrack and delaying the crack propagation as compared with control samples which showed the cracks developing until the sample failed. It was also discussed that graphene oxide's high aspect ratio promoted the hydration process and the formation of strong interfacial forces.

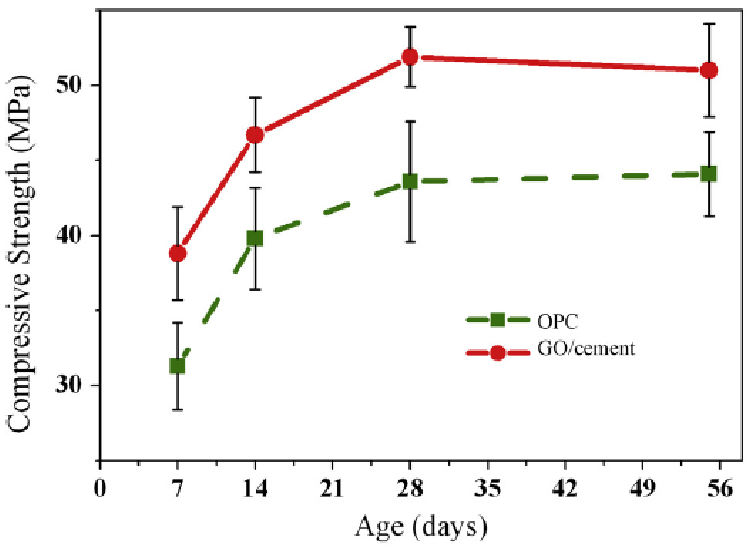


Figure 2.1: Compressive strength of Graphene Oxide cement compare to Ordinary Portland Cement.(Pan et al. 2015)

Zhu Pan et al. (2015) indicated that very low-level graphene oxide does improve the properties of cement significantly, this indicated the need to research the properties of graphene with construction materials further, in this research we will be looking at the properties of graphene-reinforced concrete and determine whether the mechanical property improvements seen in (Zhu Pan et al. (2015)) can be translated to concrete.

Shenghua Lv et al. (2013) specifies the use of low weight percentage to cement improved the tensile, flexural and compressive strength. The weight percentages used in this paper are 0.01, 0.02, 0.03, 0.04 and 0.05%. The cement-graphene composite was prepared by solid dosage of graphene into cement mix which consisted of cement, sand, polycarboxylate superplasticiser and water. It was noted that the wt% of 0.03% showed significant improvement in tensile and flexural strength properties of 60.7% and 78.6% after 28 days of curing while wt% of 0.04 and 0.05% showed less improvement with 0.05% showing tensile and flexural strength of 35.8% and 30.8% after 28 days. However, the compressive strength showed signs of continual improvement with the increased weight percentage, even though there is a significant improvement between 0.01% and 0.03% while there is a modest increment between 0.03% and 0.05%. (Lv et al. 2013)

In this paper it shows that there are optimum level of graphene added to cement mix that improves mechanical properties, I will be keeping a close eye on the properties of the concrete mixture in this research and see if they exhibit similar patterns, although there are differences between this research and Shenghua Lv et al. (2013) as they only tested for compressive and tensile strength. The other difference is that in this research, we will be using liquid-based graphene dissolved in water and then added to the concrete mixture and investigating weight percentages of 0.03, 0.05 and 0.1%. With these weight percentages, we can investigate the notion by Shenghua Lv et al. (2013) that after 0.03%, the increased advantages of graphene are reduced.(Lv et al. 2013)

Liulei and Dong (2017) investigated the effects of graphene nanosheets as an additive to cement mortar and ultra-high-strength concrete. The graphene percentages by weight of cement used for the cement mortar are 0.01% (MGO01), 0.03% (MGO03), 0.05% (MGO05), 0.08% (MGO08), and 0.1% (MGO10). Figure 2.2 shows an increase in strength from the control sample until MGO05 is reached on which the strength of the mortar then reduces. At MGO05, the flexural strength increased by 12.6% while at MGO10, the flexural strength increased by only 3.16% shown in figure 2.2.

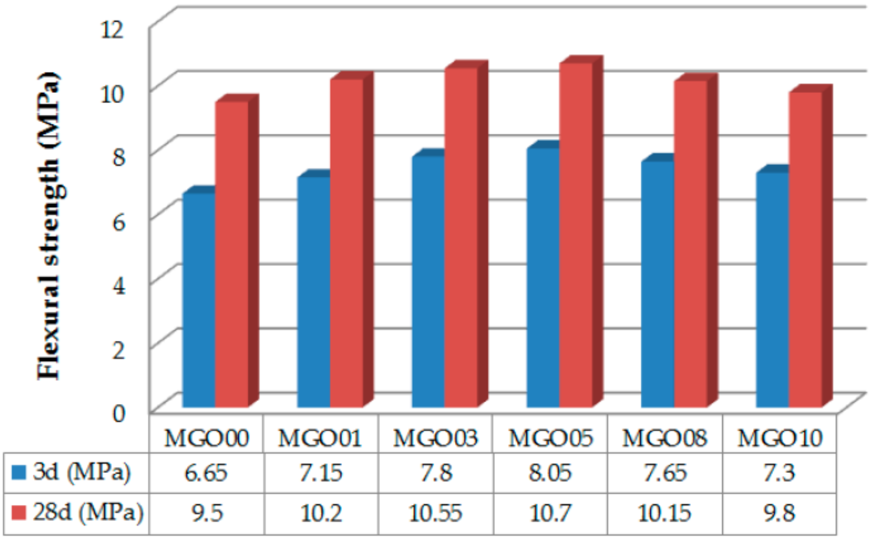
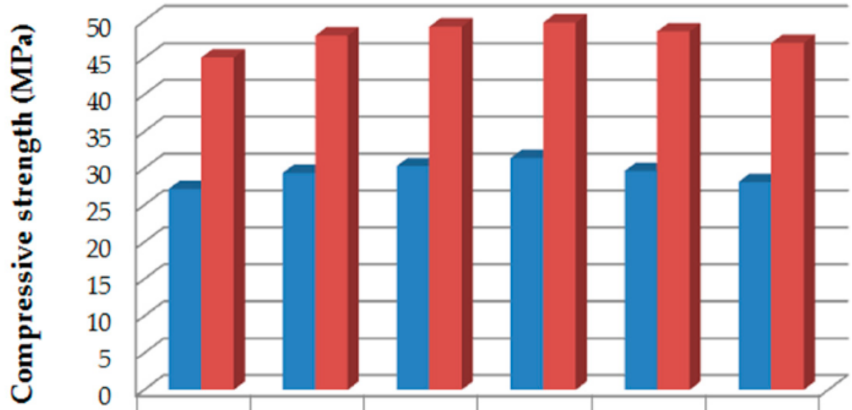


Figure 2.2: Flexural strength for 3 and 28 days (Liulei & Dong 2017)

The compressive test results show a similar trend to the flexural results with the increase in strength peaking ta MGO05 then reducing in MGO08 and MGO10. Figure 2.3 shows that MGO05 the compressive strength increased by 10.4% while at MGO10, the flexural strength increased by only 4.33%. A similar trend was observed with the results from this research with the compressive strength peaking at 0.03% and having 0.05% and 0.1% showing less compressive strength.



	MGO00	MGO01	MGO03	MGO05	MGO08	MGO10
3d (MPa)	27.19	29.38	30.31	31.41	29.63	28.16
28d (MPa)	45.08	48.02	49.23	49.77	48.59	47.03

Figure 2.3: Compressive strength for 3 and 28 (Liulei & Dong 2017)

2.3 Graphene added to concrete

Dimatar Dimov et al. (2018) acknowledges that recent researches are focused on the properties of graphene mixed with cement, which they show that the cement mix presented remarkable improvement in the tensile, flexural and compressive strength as well as other properties like durability and permeability. At this stage, more research is still needed in finding out whether these remarkable improvements in properties will translate to concrete mixtures, little is known on how graphene will behave with the addition of large aggregates. Dimatar Dimov et al. (2018) investigated the incorporation of two types of graphene, surfactant functionalised graphene and graphene nanoplatelets of industrial grade, as well as evaluating ultra-thin graphite to compare the results. Dimatar Dimov et al. (2018) incorporated graphene dissolved in water into the concrete mixture at a few different concentrations between 0.01g/l and 1g/l, as shown in figure 2.4. It was concluded that graphene concrete had improvements in compressive and tensile strength. (Dimov et al. 2018)

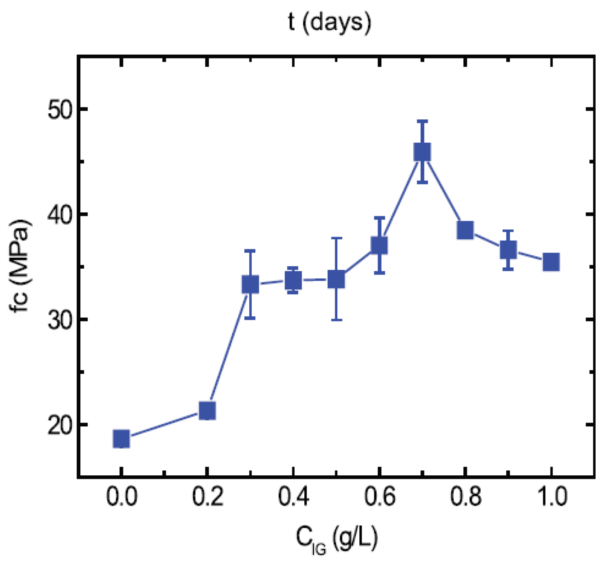


Figure 2.4: Compressive strength of Graphene reinforced concrete. (Dimov et al. 2018)

It's been shown that aqueously dissolved graphene used in concrete exhibit similar improvements in the compressive strength and yield strength while Dimatar Dimov et al. (2018) did not analyse the flexural and tensile strength of concrete/graphene mixture, this research will investigate the flexural, tensile, compressive strength and hopefully yield similar results. They are challenges to the approach and methodology employed in this research, as we will be only applying graphene to the bottom part of the beams which is usually the part that is tension and thus is the part of concrete that typically will fail first with crack stating at the bottom and propagating upwards. This research aims to reduce these cracks and thus increase the capacity of the beam. (Dimov et al. 2018)

Yu-You Wu et al. (2019) acknowledges concrete's lack of ductility, which results in low tensile and flexural strength, with recent researches showing improved properties of cement when graphene oxide nanosheets are added to cement. Yu-You Wu et al. (2019) investigates the slump and physical property of concrete with an addition of nano graphene sheets at 0.00 to 0.08% weight of cement concentrations of graphene nano sheets. It's been reported that cement production has exceeded 3600 million tonnes per year. Andrew (2018). Therefore, there is a need for engineers and researchers to find ways to reduce the amount of cement and concrete that we use, Yu-You Wu et al (2019) used concrete cubes of 100 mm x 100 mm x 100 mm for compressive strength test and split tensile strength test and 100 mm x 100 mm x 400 mm beam for flexural strength test. With results from the compressive strength test showing that the test samples with graphene nanosheets of 0.02% to 0.08% had an improvement in the strength of 12.84% to 34.04% when compared to control samples as shown in figure 2.5. Yu-You Wu et al. (2019) believes that the increased strength properties are due to the promotion of the hydration process or carboxylic groups and hydration products mixing and forming a powerful interfacial force between them. Graphene has a large surface area which makes it quite suited to form these interfacial forces, which results in reducing the propagation of microcracks. Yu-You Wu et al. (2019) where utilising concrete squares as their test samples as per the Chinese standard, whereas we are utilising cylinder as per Australian standards. (Yu-You et al. 2019)

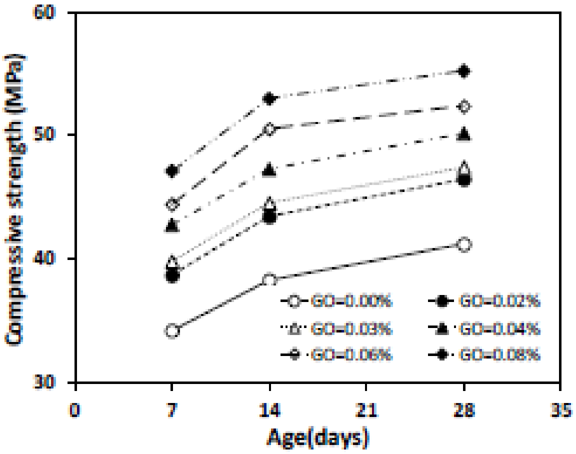


Figure 2.5: Compressive strength of concrete at different ages. Yu-You et al. (2019)

According to Yu-You Wu et al. (2019), the addition of nanosheets of graphene of 0.02% to 0.08% improves the flexural strength of concrete by 2.77% to 15.6% after 28 days of quiring as shown in figure 2.6. These results are showing a reduced increment in strength as compared to the compressive strength, which is expected as concrete has a low flexural strength as compared to the compressive strength. In this research we aim to achieve similar results, with the methodology differing slightly from Yu-You Wu et al. (2019), as we have one of the beams with a layer of 110 mm x 150 mm x 500 mm of normal concrete and a layer at the bottom of the sample of 40 mm x 150 mm x 500 mm mixed with graphene. In this project, we are utilising Australian standards for sizes of samples and the method of casting as well as testing, whereas, Yu-You Wu et al. (2019) are utilising Chinese standards. (Yu-You et al. 2019)

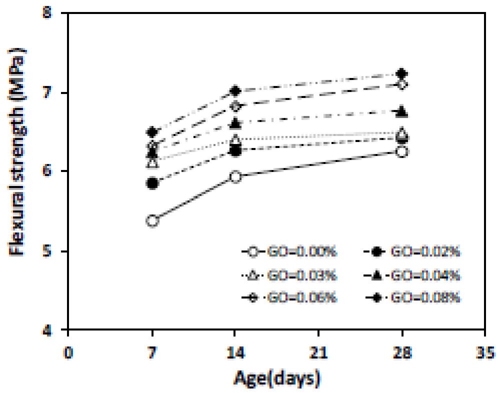


Figure 2.6: Flexural strength of concrete at different ages. (Yu-You et al. 2019)

Liulei and Dong (2017) investigated the effects of graphene nanosheets as an additive to cement mortar and ultra-high-strength concrete. 0.00%,0.01% and 0.03% by weight of cement graphene were used for the ultra-high-strength concrete samples, the samples had dimensions of 100 mm x 100 mm x 300 mm. After 7 days of curing the samples were tested for compressive and flexural strength with the compressive strength results showing an increase in strength of 3.66% and 4.55% for 0.01% and 0.03% respectively, while the flexural strength showed an increase in strength of 11.88% and 6.96% for 0.01% and 0.03% respectively. After curing the samples for 28 days compressive tests were completed, and it was found that 0.01% sample compressive strength increase by 7.82% when compared with the control sample and 0.03% sample compressive strength increased by 4.59%. It appears that 0.01% by weight of cement is optimum. Figure 2.7 shows that ductility increases with the increment in the percentage of graphene, with the samples having 0.03% of graphene deflecting more before rapturing. (Liulei & Dong 2017)

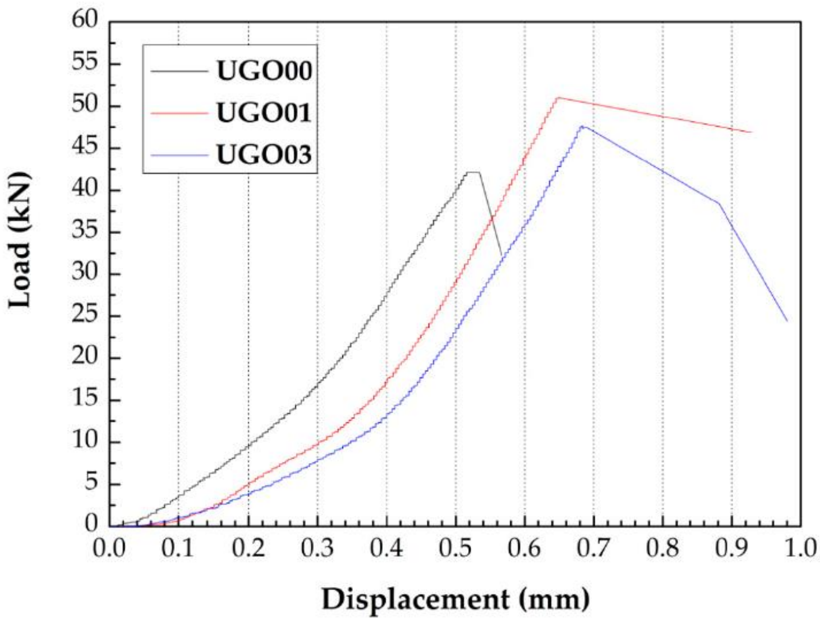


Figure 2.7: Graphene concrete deflection graph. (Liulei & Dong 2017)

2.4 Challenges of using graphene in cement/concrete

Ezzatollah Shamsaei et al. (2018) investigates the significant challenges in the dispersion of graphene into cement and concrete mixtures. It is shown that graphene nanosheets (GNS) are quite difficult to dispense as a solid into dry cement which will then be used to create concrete, it was acknowledged that the graphene nanosheets tend to form into clusters which sometimes can even combine and form graphite, which has less desirable properties. Ezzatollah Shamsaei et al. (2018) also investigated other forms of graphene dry mixing involving chemical dispersion, which some researchers have successfully dispensed graphene nanosheets by steric separations, which is a technique that separates compounds only based on size. For the results of steric exclusion separations to be successful, there should be no directed forces between the compounds being separated and the surface of the particles used as the stationary phase, as an example silica fume has been used in the dispersion of graphene nanotubes (GNT). Other techniques used is to dissolve graphene into a liquid and then add to the concrete mixture, this is the technique that this research will employ as the university does not have the specialised equipment like an ultra-sonification machine or high shear mixer to carry out the dispersion. GMG will be providing the aqueous graphene, and at the right concentrations it will be added to the water, then the mixture of cement and aggregate. (Shamsaei et al. 2018)

Chapter 3

3 Methodology

3.1 Background

This chapter describes the methodology and laboratory equipment used for the experimental work carried out for this research report. The apparatus, trials and testing program that will be undertaken are discussed in the following sections. The experiments and tests were done according to Australian standards. The beams for flexural strength will be 150mmW x 150mmH x 500mmL beams with one set of beams having full graphene concrete mix and one set of the beams having the 40mm bottom layer of the beam with graphene concrete mix. The top layer of 110mm x 150mm x 500mm will be poured first into the mould, the 40mm x 150mm x 500mm layer of graphene concrete layer will be added to complete the sample. The control samples will be cast in the same manner to ensure that results can be compared. Compressive strength, indirect tensile strength and modulus of elasticity were conducted on 200mmH 100mmD concrete cylinders with full graphene concrete mixture. Summarised descriptions and procedures for each test are listed below. The slow steps taken to produce quality concrete specimen are as per figure 3.1.

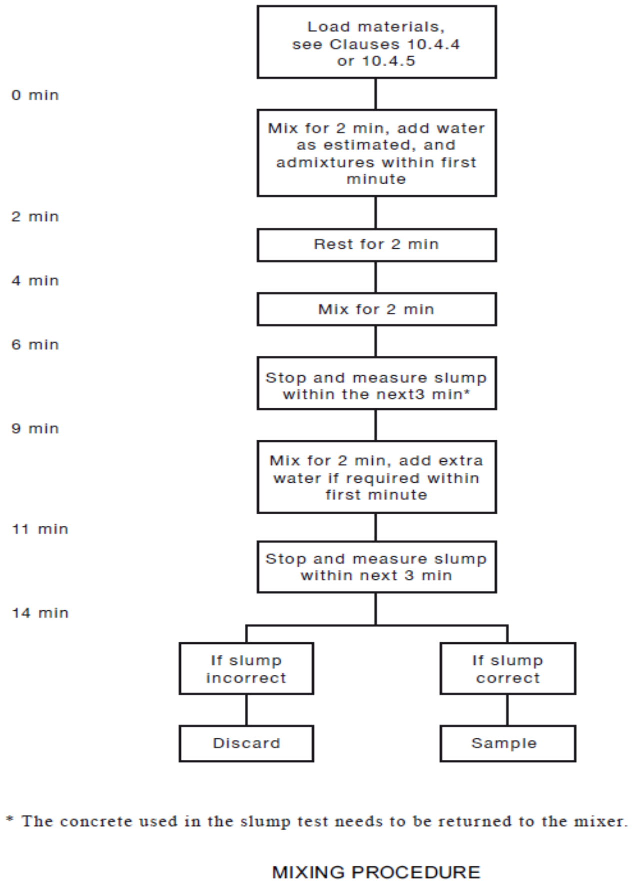


Figure 3.1:Mixing procedure. (AS 1012.2:2014)

3.2 Slump test

Slump test is a measure of the consistency, workability, and to ensure the uniformity of fresh concrete. This test was carried out as soon as the concrete mixing is complete. The equipment used in the experiments are:

- slump cone
- steel tamping rod
- rule
- scoop

3.2.1 Procedure for preparing samples and testing. (AS 1012.3.1:2014)

a) Ensure the cone is clean and moist the inside of the cone uniformly with a damp cloth just before the test.
b) The slump cone will be placed with the large side down, on a flat steel plate, then the cone will be held in place by placing both feet on each footrest, ensuring that the cone remains in place during rodding of concrete.
c) The cone filling should be completed within 3min.
d) The cone will be filled in three layers of about a third of the height of the cone, ensuring that the last layer is above the cone height, so that when performing the 25 strokes for the top layer, we still have the concrete left at the top of the cone, which we then level with the scoop and ensuring that we have a flat finish surface that is level with the top of the cone.
e) After each layer is filled into the cone, we will then use the rod to compact the concrete with 25 strokes. While applying the strokes, the rod should be as vertical as possible, distributing the stocks as uniformly as possible to ensure consistency. For the bottom layer, we might have to tilt the rod slightly to ensure we can compact the side, but for the next two layers, we keep the rod vertical and ensure we only penetrate to the layer we are compacting.
f) Then we maintain a firm downward pressure, remove the feet from the footrest the we lift the cone vertical upwards the reveal the test sample, if the sample collapses laterally or shears the test will need to be completed again with another sample taken with a bucket, with another failure showing that the concrete consistency is not proper. Therefore, we mix the concrete or analyse the calculations and ensure we added the right amount of water.
g) The results of a successful test will be recorded and for a slump of less than 100mm the measurements will be recorded to the nearest 5mm

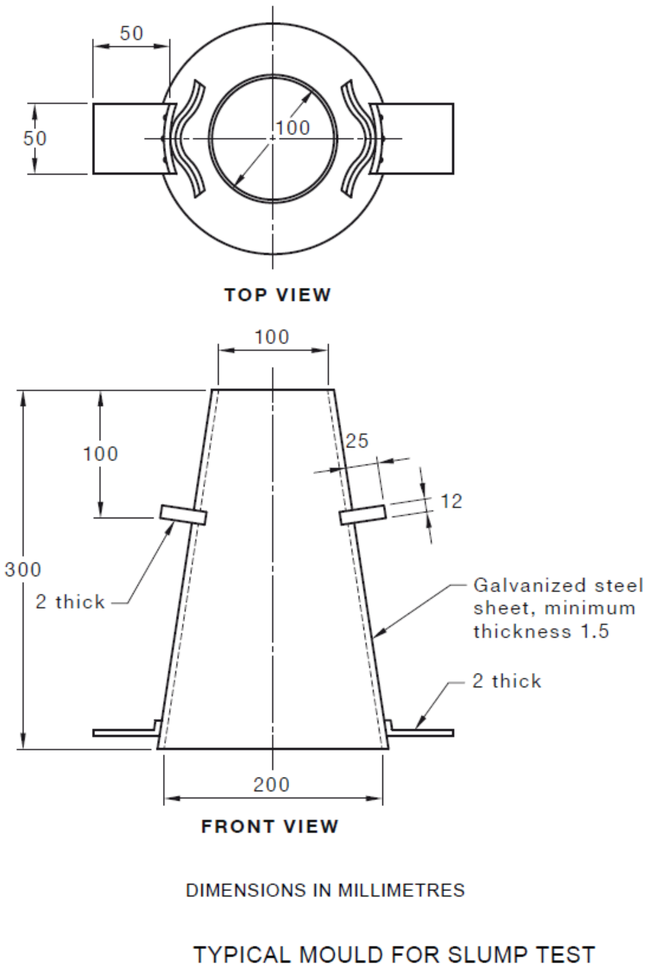


Figure 3.2: Typical mould for slump test. (AS 1012.3.1:2014)

3.3 Flexural test

This test aims to tests the flexural capacity of the concrete as well as modular of elasticity. A 150mmW x 150mmH x 500mm mould will be used as per AS 1012.8.2:2014 clause 7.3.

3.3.1 Procedure for preparing samples and testing. (AS 1012.8.2:2014)

a) A concrete release agent will be applied to inside surfaces of the mould to ensure the concrete does not stick to the mould.
b) The sample will be taken as soon as the concrete mix is done and placed in the mould.

c) A consistency test will be performed, in accordance with AS 1012.3.1, AS 1012.3.2, AS 1012.3.3, AS 1012.3.4 and AS 1012.3.5.
d) Casting will then commence without any delay, ensuring that there was not segregation while transporting the sample to the mould, we will be trying to minimise the distance travelled between the mixing station and the moulding area, of course taking in account safety as well. A scoop will be used to place the concrete in the mould, placing the concrete symmetrically, take care to avoid segregation.
e) The concrete will then be compacted without causing segregation or excessive laitance.
f) Moulding should be completed within 20min, after completion of concrete mixing.
g) 48 hours after moulding the specimen should be removed from the standard moist-curing and demoulded, then returned to the moist curing condition within 3 hours of demoulding. The specimen needs to have a smooth finish, and within acceptable tolerances as per AS1012.8.2:2014 clause 6.1.1.
h) After 28 days of curing, the test sample will be ready for testing. We ensure the surface of the specimen is free of grit.
i) The specimen is placed on its side to the position that it was moulded, then centred on the supporting rollers.
j) The load rollers are placed in position, to be in contact with the top of the specimen. A seating load of less than 100N is applied, the rollers are then checked to ensure the specimen is settled in position.
k) The loading proceeds with incremental loads applied. The applied force will be gradual and continuous at a rate of 1MPa per minute until the specimen can’t sustain the applied force and fails the maximum force will then be recorded. The type of failure and appearance of the specimen will also be recorded.

3.4 Compressive strength

In this test, we aim to determine the compressive strength of concrete samples, a 100mm diameter and 200mm height cylinders moulds are used in this test as per AS 1012.8.1:2014 clause 5.

3.4.1 Procedure for preparing samples and testing. (AS 1012.8.1:2014)

a) A concrete release agent will be applied to inside surfaces of the mould to ensure the concrete does not stick to the mould.

b) The sample will be taken as soon as the concrete mix is completed, then we trowel sample until it looks uniform and place in the mould.

c) A consistency test will be performed, in accordance with AS 1012.3.1, AS 1012.3.2, AS 1012.3.3, AS 1012.3.4 and AS 1012.3.5.

d) With a scoop, we fill the mould to about 100mm deep, and then we proceed to apply 25 compactions stocks using a rod.

e) Then the next layer is scooped in to be above the top of the mould, ensuring that after compaction, the concrete sample will be at the top level of the mould.

f) The compactions are done with the rod held as vertically as possible and ensuring uniform compaction throughout the mould for consistency. The rod should not strike the bottom plate of the mould, and for the top layer, the rod must not penetrate to the bottom layer. We also need to ensure that there is no segregation or excessive laitance.

g) We then tap the side of the mould with a mullet to remove any air pockets.

h) The top of the sample is kept smooth by striking top it with the scoop while ensuring the sample is at the same height as the mould.

i) The specimens will be kept in their moulds between 18 and 36hours.

j) After the initial moist curing, the specimens will be demoulded, identified and stored under standard moist curing conditions until testing.

k) Measuring and testing will be conducted as quickly as possible after removing the test specimen from the curing environment.

l) The test samples and the machinery will be cleaned and ensure they are free of grit and any other particles.

m) The specimen is placed in the test machine, ensuring that the sample is at the centre of thrust, the rubber cap is the place on the test sample. We then ensure that the hydraulically activated platen is floating.

n) The top platen is then lowered to touch the capped specimen, a load is applied gradually and consistently at a rate of 20MPa per minute until the specimen cannot hold any more load and fails. The maximum load is then recorded.

3.5 Tensile strength

for indirect tensile test, the specimens are prepared with the same procedure as for compressive test, from steps a) to j), then we test the specimens differently as follows. (AS 1012.10:2000)

a) Measurements of the samples are taken to ensure they are within acceptable tolerances. The diameter of the cylinder is measured at three points, close to both ends and then the middle of the cylinder, then taking the average as the diameter of the sample. The length measurements are done along the line that will be in contact with the bearing strips.
b) We then align the hardboard bearing strips between the top and the bottom platens of the specimen and ensuring that the specimen is centred.
c) A small load is applied to remove any side constraints, then a load is applied gradually and consistently at a rate of 1.5MPa per minute indirect tensile stress until the specimen can sustain no increase in force. The maximum load is then recorded.

Chapter 4

4 Experimental Program

4.1 Recourses

4.1.1 Concrete Materials

Table 4.1:Total Concrete Materials Quantities Needed

	7mm Stone	10mm Stone	Sand	Cement
	20kg bags	**20kg bags**	**20kg bags**	**20kg bags**
Price per 20kg bag	5	5	5	6.6
Exact Number of bags	9.2	9.2	9.5	7.9
Final Number of bags	10	10	10	8
Price total	$ 50.00	$ 50.00	$ 50.00	$ 52.80

4.1.2 Graphene Quantities

Table 4.2: Total Graphene Quantities Needed

Graphene	Water	Cement	Total Concrete Weight	Graphene	Graphene
%	L	kg	kg	Total kg	Total g
0.03	15.81	34.54	172.66	0.01036	10.36
0.05	15.81	34.54	172.66	0.01727	17.27
0.1	15.81	34.54	172.66	0.03454	34.54

For 0.03% (by weight of cement)

We needed 10.36g of graphene in 15.81 L of water and GMG provided 10.36g in 13 L then we added to 2.81 L of water to form 15.81L of graphene/water mixture

For 0.05% (by weight of cement)

We needed 17.27g of graphene in 15.81 L of water and GMG provided 17.27g in 13 L then we added to 2.81 L of water to form 15.81L of graphene/water mixture

For 0.1% (by weight of cement)

We needed 34.54g of graphene in 15.81 L of water and GMG provided 34.54g in 13 L then we added to 2.81 L of water to form 15.81L of graphene/water mixture

4.2 Risk Assessment

4.2.1 Introduction

A series of lab experiments were conducted for this research. With all the moulding and tests completed at University of Southern Queensland Toowoomba campus, P3 and P11 laboratories. A detailed risk assessment has been conducted in conjunction with my supervisors and the laboratory stuff, this risk assessment is to ensure that the experimental work carried out was performed as safely as possible. The assessment also identifies hazards associated with the work to be carried out.

The steps taken on the risk assessment are linked to the steps in the scientific method in figure 4.1, these steps include defining the scope of the project, identifying the hazards, evaluating the hazards and establishing the control measures, performing the work and what lessons and conclusions can be drawn.

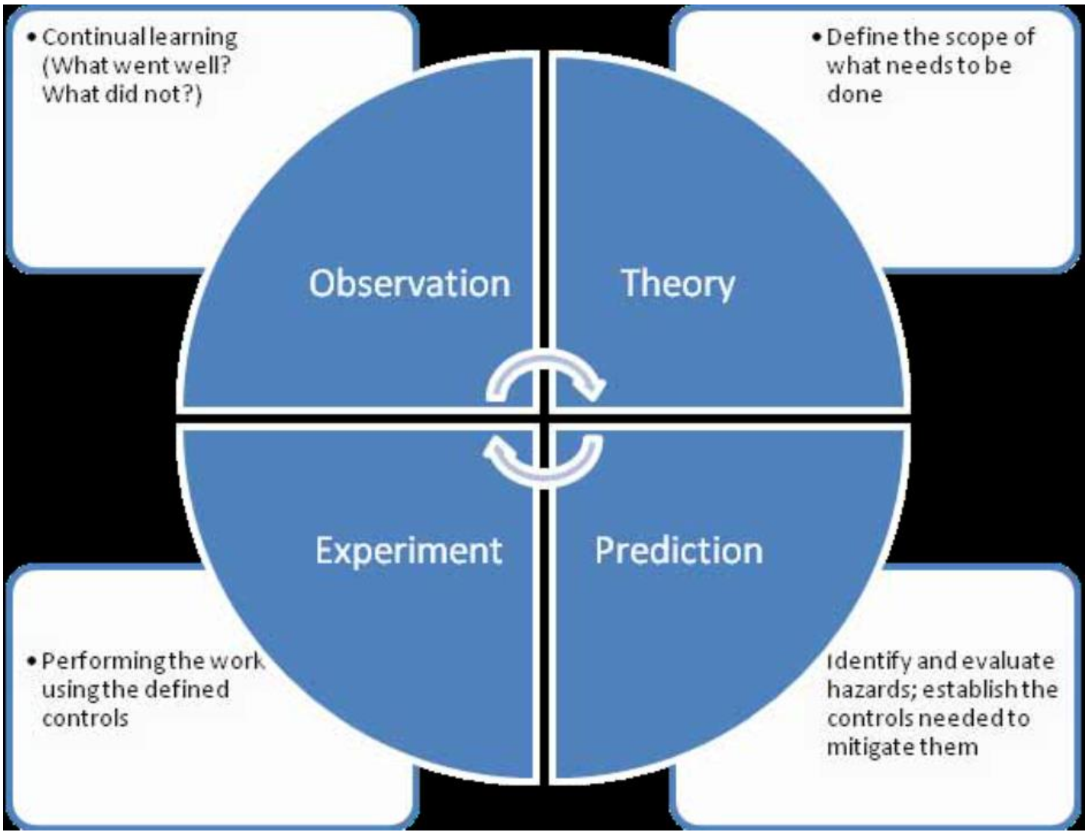


Figure 4.1: Integration of Hazard Identification, Evaluation, and Control with Scientific Method

4.2.2 Defining the scope

The scope of the project is a crucial initial step to risk assessment and evaluation. We need to understand the tasks and processes that are planned for the project to complete a risk assessment and come up with a risk management plan. In chapter 1, the project aims, and objectives are outlined, and in chapter 3, the steps taken to create moulds for testing are also outlined.

4.2.3 Hazard identification

The University of Southern Queensland already has procedures in place to minimise or eliminate hazards, the purpose of defining the scope and using that scope in risk assessment is to ensure that none of the tasks or processes lie outside the procedures outlined. However, a specific risk assessment still must be carried out for this project to ensure all hazards are identified and controlled.

Concrete moulding and sample preparation were carried out at laboratory P3. Hazards were identified that are associated with the tasks to be undertaken at the laboratory P3. An example of these hazards that are associated with concrete moulding are below:

- Manual lifting and shifting cement bags and aggregates
- Exposure to cement/concrete dust
- Rotating machine parts, concrete mixing bowl
- Spillage of water when adding to concrete mixtures, causing a slippery surface
- Switching on and switching off the machine

Sample testing was carried out at laboratory P11, Hazards were identified that are associated with the tasks to be undertaken at the laboratory P11. An example of these hazards that are associated with testing are below:

- Handling, shifting (cylinders and beams)
- Setting up of fixture and machine
- Fixing jaws of the sans machine
- Projectile fragment failed samples
- Testing of material
- Switching on and switching off the machine

4.2.4 Hazard evaluation

Hazard evaluation is the process of taking the qualitative hazards data identified and turning it into quantitative data. The risk matrix is the tool used to assess the severity of the hazards, by assigning a probability and the consequence to the hazards we can identify the level of the hazard from low to extreme. All the hazards and all the consequences were that identified were unlikely to happen with insignificant and/or minor injuries due to the existing University safety policies.

Risk Matrix

Probability	Consequence: Insignificant No Injury 0-$5K	Minor First Aid $5K-$50K	Moderate Med Treatment $50K-$100K	Major Serious Injury $100K-$250K	Catastrophic Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1,000	L	M	H	H	H
Unlikely 1 in 10,000	L	L	M	M	M
Rare 1 in 1,000,000	L	L	L	L	L

Recommended Action Guide	
Extreme:	E = Extreme Risk – Task ***MUST NOT*** proceed
High:	H = High Risk – Special Procedures Required (Contact USQSafe) Approval by VC only
Medium:	M = Medium Risk - A Risk Management Plan/Safe Work Method Statement is required
Low:	L = Low Risk - Manage by routine procedures.

Figure 4.2: Risk matrix

4.2.5 Selection of hazard controls

The hazard controls selected are already in line with the existing university safety policies. Examples of these controls are shown in the table below, please find the complete risk management plan in appendix C.

Table 4.1: Risk Assessment

Hazard	The risk	Consequence	Controls	Probability	Risk level
Manual lifting and shifting cement bags and aggregates	Back or spinal injury	Minor	Lab safety induction provided, Wear personal protective equipment (steel cap safety shoes, heavy-duty gloves). And using proper manual handling procedure according to USQ safety manual. The action is taking place under the supervision of technical staff.	Unlikely	Low
Exposure to cement/concrete dust	Skin irritation and breathing problems	Minor	Wear personal protective equipment (Safety steel cap shoes, dust masks, safety goggles and safety gloves)	Unlikely	Low
Rotating machine parts, concrete mixing bowl	The material can fly from the mixer causing body injuries	Minor	Lab safety induction given, wear appropriate PPEs [steel cap safety shoes, eye protection safety goggles and heavy-duty gloves], the activity is happening under supervision, Refer to SOP for the emergency stops attached to the mixer.	Unlikely	Low
Cleaning and washing the equipment	Trip Hazzard	Minor	Wear PPE, including safety boots.	Unlikely	Low
Spillage of water when adding to concrete mixtures, causing a slippery surface	Slipping causing injury	Minor	Ensure use proper water pressure, Clean up spillage, Wear PPE	Unlikely	Low
Switching on and switching off the machine		Minor	Lab safety induction given, wear appropriate PPEs [steel cap safety shoes, eye protection safety goggles and heavy-duty gloves], the activity is happening under supervision, Refer to SOP for the emergency stops attached to the mixer.	Unlikely	Low
Handling, shifting (cylinders and beams)	The specimen can fall on the feet	Minor	Wear personal protective equipment (steel cap safety boots) follow proper techniques in USQ safety manual. The action is taking place under supervision.	Unlikely	Low

Setting up of fixture and machine	Crushing of fingers, physical injury due to falling parts	Minor	Lab safety induction provided, wear personal protective equipment, the action is taking place under the supervision of trained personnel, make sure fixtures are undamaged, Seek second person help for heavy items	Unlikely	Low
Fixing jaws of the sans machine	Hand and head injuries	Minor	Wear personal protective equipment (Safety helmet, Steel caps safety shoes, Safety gloves, safety goggles) Lab safety induction provided, the action is taking place under the supervision of a well-trained person.	Unlikely	Low
Projectile fragment failed samples	The material can fly from Sans machine causing Body injuries	Minor	Lab safety induction provided, Wear personal protective equipment (steel cap safety shoes, heavy-duty gloves, safety goggles and safety helmet). The action is taking place under supervision. Maintain clear distance while the machine is running. Refer to SOP for the emergency stops attached to the sans machine.	Unlikely	Low
Testing of material	Physical injury from flying broken specimen, crushing fingers from moving parts	Minor	Lab safety induction provided, Wear personal protective equipment. Use safety screen and eye protection, keep clear during testing from moving parts, The action takes place, under-trained person. Use gloves when handling broken specimen, adopt to safety work procedure attached to the machine.	Unlikely	Low
Switching on and switching off the machine	Electrical shock	Minor	Lab safety induction provided. Wear PPE. Use of leather gloves, Trained personnel to operate machines, emergency procedures are in place.	Unlikely	Low

4.2.6 Performing the experimental work within controls and continual learning

The experiment went well as planned, and all the control measure were adopted and utilised, particularly during the compressive strength test as some of the test samples with more graphene failed with an explosion which the machine guards in place prevented the flying debris reaching us.

4.3 Graphene Concrete Mix Design

4.3.1 Target strength

$$T = C + 1.65S$$

T = target strength

C = characteristic strength

S = The standard deviation (a measure of quality control) of a large number of test results.

Grade designation	Characteristic strength MPa	Assumed standard deviation MPa
Standard grades		
25	25	4.8
32	32	5.34
40	40	5.9
50	50	6.2
Flexural grades		
F2.5	2.5	0.5
F3.5	3.5	0.6
		0.5
Indirect-tensile grades		
IT2.0	2.0	
IT2.5	2.5	0.5

Figure 4.3: Assumed standard deviation (University of Southern Queensland, Study Material, 2014)

The characteristic strength that we are aiming for is 32MPa, therefore:

$$T = 32 + 1.65 \times 5.34$$

$$T = 40.8\ MPa$$

$$T \approx 40\ MPa$$

4.3.2 Mix Design

Target strength of the mix is 40MPa

Expected mixing ratios to get the target strength are:

Table 4.2: Mix Design Ratios (University of Southern Queensland, Study Material, 2014)

Water/cement ratio (0.3 to 0.5 is recommended for 40MPa)	0.5
Aggregate/cement ratio (about 3.5 is recommended for 40MPa)	3.5
Fine aggregate/cement ratio (about 0.5 is recommended for 40MPa)	0.5

Table 4.3: Mix designs proportions for one cubic metre

MIX DESIGN PROPORTIONS (2400kg per m3		
7mm Stone	**560**	kg
10mm Stone	**560**	kg
Sand	**560**	kg
Cement	**480**	kg
Water	**240**	L

$Assumed\ concrete\ density = 2400kg/m^3$

Five materials will be combined to form the concrete mix design. We can use the ratios to get the exact weights of each material in 1m³ of concrete.

$$mix\ design\ propotions = \frac{2400}{5} = 480kg$$

The proportion for cement is 1 therefore

$$Cement = 480kg$$

Water/cement ratio is 0.5 accordingly:

$$Water = 0.5 \times 480kg = 240kg$$

The aggregate/cement ratio is 3.5 therefore

$$aggregate = 480 \times 3.5 = 1680kg$$

Then we have equal proportions of all three aggregates:

$$10\ mm\ aggregate = \frac{1680kg}{3} = 560kg$$

$$7\ mm\ aggregate = \frac{1680kg}{3} = 560kg$$

The ratio of fine aggregate/coarse aggregate is 0.5 is also achieved.

$$Sand = \frac{1680kg}{3} = 560kg$$

Calculations for quantities for 1 beam ($0.15mH \times 0.15mW \times 0.5mL$)

$$Volume\ of\ the\ beams = 0.15mH \times 0.15mW \times 0.5mL = 0.01125m^3$$

$$Cement\ weight\ in\ 1\ beam = beam\ volume \times cement\ weight\ in\ 1m^3$$

$$Cement = 0.01125 \times 480 = 5.4\ kg$$

$$10\ mm\ aggregate\ weight\ in\ 1\ beam = beam\ volume \times 10\ mm\ aggregate\ weight\ in\ 1m^3$$

$$10\ mm\ aggregate = 0.01125 \times 560 = 6.3\ kg$$

$$7\ mm\ aggregate\ weight\ in\ 1\ beam = beam\ volume \times 7mm\ aggregate\ weight\ in\ 1m^3$$

$$7\ mm\ aggregate = 0.01125 \times 560 = 6.3\ kg$$

Sand moisture content (MC) average is about 6%, but with the moulding taking place in the dry months of the year and assumption for the moisture content was taken as 3.5%. So, we need to account for the moisture in the soil when calculating the quantities for the sand and water. Therefore MF (moisture factor) is calculated below.

$$\text{MF} = 1 + \frac{3.5}{100} = 1.035$$

By using the moisture factor we ensure that we add the correct weight of sand including the weight of the water trapped inside and around the sand particles, we then have to make an allowance when we add the weight of water to ensure we subtract the moisture weight already combined with the sand.

$$Sand\ weight\ in\ 1\ beam = beam\ volume \times sand\ weight\ in\ 1m^3 \times MF$$

$$Sand\ weight = 0.01125 \times 560 \times 1.035 = 6.5\ kg$$

$$Water\ weight\ in\ 1\ beam = \ beam\ volume\ \times water\ weight\ in\ 1m^3 - sand\ weight \times MC$$

$$Water = (0.01125\ \times 240) - \left(6.5 \times \frac{3.5}{100}\right) = \ 2.47\ kg$$

The quantities are calculated the same way for the cylinders.

Calculations for quantities for 1 cylinder ($0.1mD\ \times 0.2mH$)

$$Volume\ of\ cylinder = \frac{\pi \times D^2}{4} \times H$$

$$Volume\ of\ cylinder = \frac{\pi \times 0.1^2}{4} \times 0.2mH = 0.001571m^3$$

$$Cement\ weight\ in\ 1\ \text{cylinder} = \ \text{cylinder}\ volume\ \times cement\ weight\ in\ 1m^3$$

$$Cement = \ 0.001571\ \times 480\ \ = \ 0.75\ kg$$

$$10\ mm\ aggregate\ weight\ in\ 1\ \text{cylinder} = \ \text{cylinder}\ volume \times 10\ mm\ aggregate\ weight\ in\ 1m^3$$

$$10\ mm\ aggregate = \ 0.001571\ \times 560\ \ = \ 0.88\ kg$$

$$7\ mm\ aggregate\ Weight\ in\ 1\ \text{cylinder} = \text{cylinder}\ Volume\ \times 7mm\ aggregate\ weight\ in\ 1m^3$$

$$7\ mm\ aggregate = \ 0.001571 \times 560\ \ = \ 0.88\ kg$$

$$Sand\ weight\ in\ 1\ cylinder = \ \text{cylinder}\ volume\ \times sand\ weight\ in\ 1m^3 \times MF$$

$$Sand\ weight = \ 0.001571\ \times 560 \times 1.035 = \ 0.91\ kg$$

$$Water\ weight\ in\ 1\ \text{cylinder} = \text{cylinder}\ volume\ \times water\ weight\ in\ 1m^3 - sand\ weight \times MC$$

$$Water = (0.001571\ \times 240) - \left(0.91 \times \frac{3.5}{100}\right) = \ 0.345\ kg$$

Table 4.4: Mix design spreadsheet

Sample Number	Tests and Test Size	Concrete/Graphene Thickness	Graphene Percentage	Concrete/Graphene Sample Size	Final Concrete Sample Size	7mm Stone	10mm Stone	Sand	Total Aggregate Weight	Water	Cement	Total Concrete Weight
	m	m	%	m3	m3	kg	kg	kg	kg	L	kg	kg
	Beams (0.15 x 0.15 x 0.5)											
1	Flexural tests	0.15	0.03	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923
2		0.15	0.05	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923
3		0.15	0.1	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923
4		0.04	0.03	0.003000	0.011250	1.6800	1.6800	1.7388	5.0988	0.6591	1.4400	7.1979
		0.11	0	0.008250	0.011250	4.6200	4.6200	4.7817	14.0217	1.8126	3.9600	19.7943
5		0.04	0.05	0.003000	0.011250	1.6800	1.6800	1.7388	5.0988	0.6591	1.4400	7.1979
		0.11	0	0.008250	0.011250	4.6200	4.6200	4.7817	14.0217	1.8126	3.9600	19.7943
6		0.04	0.1	0.003000	0.011250	1.6800	1.6800	1.7388	5.0988	0.6591	1.4400	7.1979
		0.11	0	0.008250	0.011250	4.6200	4.6200	4.7817	14.0217	1.8126	3.9600	19.7943
	Cylinders (0.1D x 0.2H)	Volume m3										
1	Compressive test	0.001570796	0.03	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
2		0.001570796	0.05	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
3		0.001570796	0.1	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
4	MOE	0.001570796	0.03	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
5		0.001570796	0.05	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
6		0.001570796	0.1	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
7	Split Tensile Test	0.001570796	0.03	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
8		0.001570796	0.05	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
9		0.001570796	0.1	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
	Control	Volume m3										
7	Control Sample	0.15	0	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923
8	Control Sample 40mm	0.15	0	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923
10	cylinder control	0.001570796	0	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
11	cylinder control	0.001570796	0	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688
12	cylinder control	0.001570796	0	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688

4.4 Sample Preparation

4.4.1 Moulding Plan

P3 lab had 3 of 150mm x 150mm x 500 beams moulds and 6 of 100mmD x 200mmH. With only three moulds for the beams available, a plan was devised to complete moulding, within a week. The plan was to complete moulding three beams and at least 4 cylinders per day and de-mould in the morning before starting the next batch. The plan was as follows:

Monday 26/08/19

1 0.03% 40mm graphene beam
2 0.03% full graphene beam
3 0.03% full graphene beam
4 Four cylinders of full graphene and one control

Tuesday 27/08/19

1 0.05% 40mm graphene beam
2 0.05% full graphene beam
3 40mm Control beam

4 Six cylinders of full graphene

Wednesday 28/08/19

1 0.1% 40mm graphene beam
2 0.1% full graphene beam
3 Full Control beam
4 Four cylinders of full graphene and one control

Thursday 29/08/19

1 0.03% 40mm graphene beam
2 0.03% full graphene beam
3 0.05% 40mm graphene beam
4 Two controls cylinders

Friday 30/08/19

1 0.1% 40mm graphene beam
2 0.1% full graphene beam
3 0.05% full graphene beam

Originally 15mm and 10mm aggregates were going to be used. Unfortunately, the available material was 20mm, 10mm and 7mm aggregate. 10mm and 7mm aggregate was selected for concrete mix, by selecting two different aggregate sizes we hoped to get better compaction when moulding.

4.4.2 Steps in sample preparations.

1. The moulds were first cleaned, ensuring that the mould is clear of residual concrete.
2. Taking measurements of the mould to ensure that the mould dimensions are as per Australian standards, as shown in figure 6.3. Adjustments would then be made if necessary.

Figure 4.4: Mould measuring pictures

3. The moulds will then be oiled, to make it easy to demould and ensure that the concrete does not stick to the sides of the mould and thus distorting the shape of the sample.
4. 10mm aggregate is measured and added to the mixing wheelbarrow.
5. 7mm aggregate is measured and added to the mixing wheelbarrow, then 10mm and 7mm aggregates are mixed.
6. Sand is measured and added to the mixing wheelbarrow, the mixture is then mixed to ensure uniform distribution.
7. Cement is measured and added to the mixing wheelbarrow, the mixture is then mixed to ensure uniform distribution before we add water.
8. Water/graphene water is measured then only half is added to the mixture, then thorough mixing is performed, then the rest of the water/graphene water is added, and the mixing is completed.
9. Slump test is performed to check consistency and workability, as shown in figure 6.4.

Figure 4.5: Slump test picture

10. For 40mm graphene beams, normal concrete is filled at two levels and using the vibrator for just a second at three deferent areas, the two ends and in the middle to create compaction but ensuring that there is no separation. After the first level has been poured, the concrete is at 110mm of the mould, then measurements are taken in four different places to ensure the measurements are consistent, this measuring is shown in figure 4.6.

Figure 4.6: 40mm graphene/concrete moulding pictures

11. The sample is then left to set as mixing for the graphene/concrete is completed. The reminder 40mm is filled with graphene/concrete. Compaction on the 40mm layer is done using the compaction rod, only penetrating about 30mm so that the graphene/concrete does not mix with the normal concrete at the bottom.
12. The cylinder moulds were prepared, as explained in chapter 3, clause 3.3 and shown in figure 6.6.

Figure 4.7: Cylinder moulding picture

4.5 Testing

4.5.1 Flexural Testing

Flexural testing of concrete is to measure the tensile capacity and strength of the concrete. This test, as outlined in the Australian standards, is performed on an unreinforced concrete beam of dimensions 150mm in height by 150mm in width and 500mm in length. The SANS machine will be used for flexural testing. The SANS machine can apply an increasingly constant load until the specimen fails on which the break load will be recorded. Flexural testing measures the ability of the concrete beam to resist failure in bending while a constant load is applied. In this research, the aim is to test the flexural properties of concrete mixed with graphene against that of normal concrete and compare the results to ascertain whether graphene increases the tensile strength of unreinforced concrete.

4.5.1.1 Testing equipment

Specimen machine placement and testing will be conducted as per Australian standard AS 1012.11-2000, as shown in table 4.5 and figure 4.8.

Table 4.5: Centre to centre of the supporting and loading rollers. (AS 1012.11- 2000)

CENTRE-TO-CENTRE DISTANCES OF THE SUPPORTING AND LOADING ROLLERS

Nominal size of specimens mm	Centre-to-centre distance of rollers	
	Supporting rollers (L) mm	Loading rollers (l) mm
150 × 150	450 + 10, − 5	$\frac{L}{3} \pm 1$
100 × 100	300 + 8, − 3	

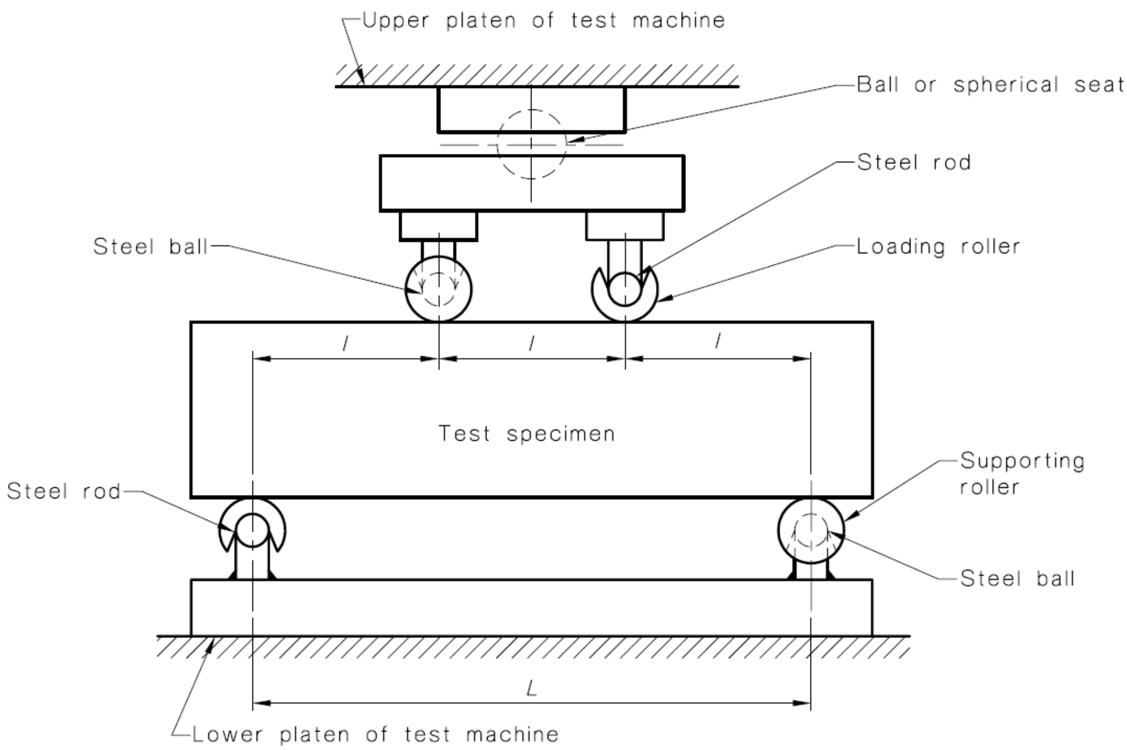


Figure 4.8: Diagrammatic view of a suitable flexure testing apparatus

4.5.1.2 Testing procedure

Testing procedure is detailed below.

1. Test specimen is cleaned to ensure grit and any excess water is removed.
2. The test specimen is turned upside down from the moulding position, this part of the procedure is a variation from the Australian standards, which specifies that the specimen is to be placed on its

side. Since the specimen has a layer of graphene added to the top of the mould be to ensure that this layer is at the bottom while testing, to check the effects of graphene on concrete.

3. The support rollers are placed at 25mm from the edge of the specimen of both ends and the length L on figure 7.1 is checked to ensure its 450mm. The loading rollers are then lowered at a distance 150mm from the support rollers and from each other to ensure that the distance between all rollers is 150mm. A setting load of 100N is applied as an initial load then all measurements are checked again and then marked to ensure the specimen is set correctly.
4. A gradual load of 1MPa/min is applied to the specimen until the specimen can't sustain any load. The load when the specimen breaks are then recorded as well as the mode of failure.
5. The width of the specimen at the breakpoint is measured and recorded.
6. The fracture needs to happen between the rollers, if this does not happen the modulus of rapture is not recorded, instead, a measurement from the failure point to the nearest support is recorded.

4.5.2 Modulus of Elasticity

4.5.2.1 Testing equipment

Modulus of elasticity measures the stiffness of the concrete. The Australian standard AS 1012.17-1997: *Methods of testing concrete - Determination of the static chord modulus of elasticity and Poisson's ratio of concrete specimens* is utilised in this test. A higher elastic modulus in concrete means that the sample can withstand higher stress, but in turn, the concrete becomes more brittle and more prone to sudden failure. A low elastic modulus indicates that concrete will bend and deform very easily as compared to concrete with a higher modulus of elasticity, with samples with more graphene displaying a lower modulus of elasticity, this shows that graphene increases the ductility of concrete. (Vasavan 2017)

Figure 4.9: Modulus of Elasticity sample

4.5.2.2 Testing procedure

Testing procedure is detailed below.

1. Before the test commences, the samples are checked for defects

    a. The sample is checked to ensure that there is no damage and that there is no aggregate protruding from the ends of the cylinder more than 5 mm.

    b. The sample is checked to ensure that the edges are not broken away such that the radial or vertical break is more than 10 mm from the edge line and the corresponding circumferential break exceeds 40 mm.

2. The height and diameter of the sample are measured to ensure the test is carried out on a sample within acceptable tolerances:
    a. The diameter at any cross-section should not be more than 2mm from the end diameter measurements. The cylinder of nominal height 200 mm and diameter 100 mm is used.

b. The height of the cylinder should be more than 1.95 times more than the diameter.

3. The sample's smooth end is placed at the bottom while the rough end is at the top, then the rubber cap is placed at the top of the test sample
4. The strain-measuring frame (Compressometre figure 4.10) is placed carefully at the centre of the test sample the and the frame pins that hold the frame in place are removed, then the test sample together with the strain-measuring frame is positioned in the test machine.

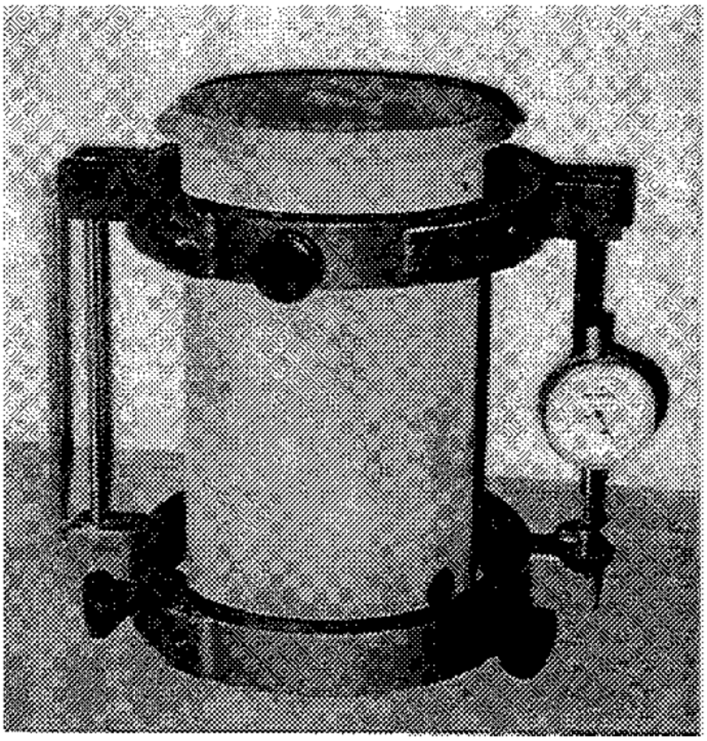


Figure 4.10: Compressometre

5. The machine is set to apply a steady load to the cylinder steadily up to a maximum load equal to 40% of the estimated compressive strength. The dial gauge reading is recorded at every 10 kN.
6. The stress and strain for each reading are calculated from the following data:
   a. Stress (MPa) = Load (kN) / (Cross-sectional area (m2) × 1000)
   b. Strain = Displacement (mm) / Length (mm)
7. The results are plotted on a stress/strain graph, as shown in figure xxx. The readings from the graph showing 33% of the compressive strength of the concrete are noted, and the calculation for modulus of elasticity is determined.

4.5.3 Compression Testing

Compressive strength is the most used property to determine the strength of concrete. Concrete is mainly used because of its compressive strength properties. In this research, we test whether graphene added to concrete will increase the compressive strength. The concrete design mix was calculated at 32MPa of characteristic compressive strength and target strength of 40MPa.

4.5.3.1 Test equipment

The SANS machine will be used for testing the cylindrical specimens for compressive strength. SANS machine complies with AS 2193 for the relevant range of compressive forces.

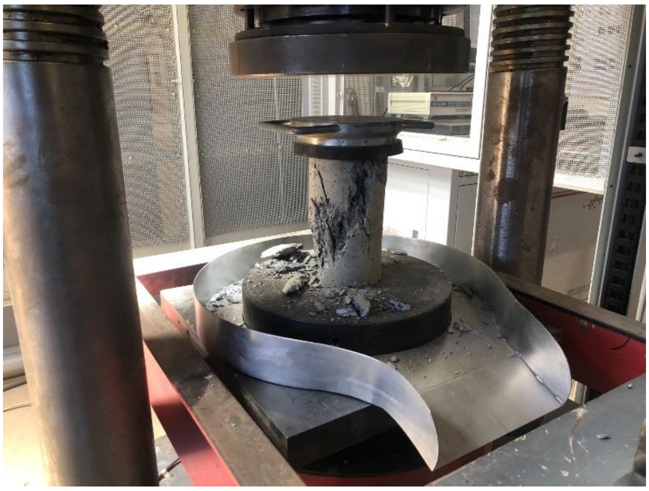


Figure 4.11: Compression test sample

4.5.3.2 Test procedure

Testing procedure is detailed below.

1. Test samples will be removed from the moist curing environment, and testing is to be completed as quickly as possible after removing the test samples from the curing area.
2. The samples are cleaned and wiped to ensure they are no grit. The test samples are then measured to ensure they are within the acceptable limits, the diameter should be within 0.2mm, the height of the samples is measured and reordered, then the height of the samples including the caps is measured and recorded to the nearest 1mm.

3. The platens of the testing machine are cleaned with a clean rag and a suitable/recommended solvent at the beginning of the testing, and whenever is deemed necessary to ensure they are clean and clear of grit and films of oil.
4. The uncapped bearing surfaces of the sample are brushed and cleaned to ensure they are free of grit.
5. The moulding lubricant is cleaned from the samples, particularly the area that is in contact with the platens.
6. The sample is then placed in the testing machine, ensuring that the axis of the sample is aligned with the centre of thrust and concentrically on the machine platen.
7. The hydraulically activated platen needs to be floating at this stage.
8. The capped sample and the upper platen will be brought together to ensure that uniform bearing is achieved.
9. Without applying any sudden or shock force, a force at a rate of 20 +/- 2 MPa is applied per minute continuously until the sample cannot sustain any increase in force. The maximum force is then recorded from the testing machine.
10. The type of failure is also recorded and at this stage, photos are also taken.
11. When the sample exhibits an abnormal failure, the force is applied to fully break the sample to facilitate further examination.

4.5.4 Indirect Tensile Testing

4.5.4.1 Test equipment

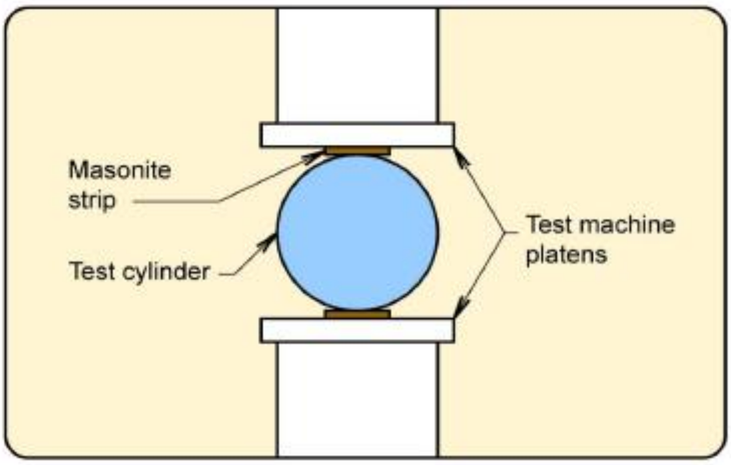


Figure 4.12: Indirect Tensile test

4.5.4.2 Test procedure

1. Before the test commences, the samples are checked for defects

    a. The sample is checked to ensure that there is no damage and that there is no aggregate protruding from the ends of the cylinder more than 5 mm.

    b. The sample is checked to ensure that the edges are not broken away such that the radial or vertical break is more than 10 mm from the edge line and the corresponding circumferential break exceeds 40 mm.

2. The height and diameter of the sample is measured to ensure the test is carried out on a sample within acceptable tolerances:
    a. The diameter at any cross section should not be more than 2mm from the end diameter measurements. The cylinder of nominal height 200 mm and diameter 100 mm is used.
    b. The height of the cylinder should be more than 1.95 time more than the diameter.
2. The hardboard bearings between the bottom and top platens are aligned.
3. The sample is placed at the centre of the machine.
4. A small initial force is applied, and the side restrains are removed.
5. Without shock a continuous force of 1.5 MPa /min is applied until no increase in force could be sustained. The maximum force is recorded.

4.1 Challenges in the experimental works.

The flexural and modulus of elasticity tests, will be conducted on beams which were moulded in layers. By pouring normal concrete allowing the concrete to set and then adding the 40mm of graphene concrete on top. Some weakness may arise between the layer and thus encourage premature failure, to try and avoid this the surface of the set concrete will be roughed up to encourage the bond between the layers. To also ensure that the results are meaningful the control samples will be moulded in the same way

Chapter 5

5 Results and Discussion

Graphene at three percentages namely 0.03%, 0.05% and 0.1% by weight of cement, were added to the concrete mix material, to test and understand if graphene will increase the mechanical properties of concrete. In this chapter, we will discuss the various test conducted and analyse the results.

5.1 Slump test results

Slump test was conducted on every batch of concrete and recorded in table 5.1. All concrete batched except batch 3 had a true or typical slump. The slump range for this project was selected at 120 to 40mm of slump with a target of 80mm +/- 40mm. This is quite a large range for slump, but we did not know how graphene will affect the concrete mix and therefore did not wish to affect other tests by having a narrow slump range. Batch 3 initially had only 30mm of slump which is outside the slump range by -50mm

Table 5.1: Slump test results

Batch Number	Initial Slump (mm)	Comments	Final Slump (mm)	Date of test	Type of concrete
1	95	Slump accepted	95	26/08/2019	0.03% graphene
2	105	Slump accepted	105	26/08/2019	Normal concrete
3	30	Slump rejected 0.1L of water added	110	27/08/2019	0.05% graphene
4	100	Slump accepted	100	27/08/2019	Normal concrete
5	85	Slump accepted	85	28/08/2019	0.1% graphene
6	105	Slump accepted	105	28/08/2019	Normal concrete
7	90	Slump accepted	90	29/08/2019	0.03% graphene
8	75	Slump accepted	75	29/08/2019	0.05% graphene
9	75	Slump accepted	75	30/08/2019	0.1% graphene
10	80	Slump accepted	80	30/08/2019	0.05% graphene
Average Slump (mm)			92		

Rejected batch 3 was taken out of the results, and remaining slump results were rearranged in order of:

1. 0% graphene (control)
2. 0.03% graphene by weight of cement
3. 0.05% graphene by weight of cement
4. 0.1% graphene by weight of cement

This rearrangement was to get a better understanding of whether graphene added to concrete affect the slump result, results are shown in Table 5.2

Table 5.2: Slump test results rearranged

Batch Number	Final Slump (mm)	Date of test	Type of concrete	Average Slump (mm)	Change %
2	105	26/08/19	Normal concrete		
6	105	28/08/19	Normal concrete		
4	100	27/08/19	Normal concrete	103.3	0
1	95	26/08/19	0.03% graphene		
7	90	29/08/19	0.03% graphene	92.5	11.7
10	80	30/08/19	0.05% graphene		
8	75	29/08/19	0.05% graphene	77.5	33.3
5	85	28/08/19	0.1% graphene		
9	75	30/08/19	0.1% graphene	80	29.2
Average Slump (mm)	81				

The slump results show that the amount of graphene added to the concrete mix affects the fluidity of the concrete mixture. The results are showing control samples at 105mm and 100mm slump while 0.03% showing a decrease in measure slump of 11.7%, and 0.05% and 0.1% showed a decrease in slump of 33.3% and 29.2 respectively as shown in table 5.2 and figure 5.1. These results show that the graphene in the concrete mix reduces the fluidity of the concrete mix. (Liulei & Dong 2017) found a similar trend with their research in the mortar mini-slump test results shown in figure 5.2

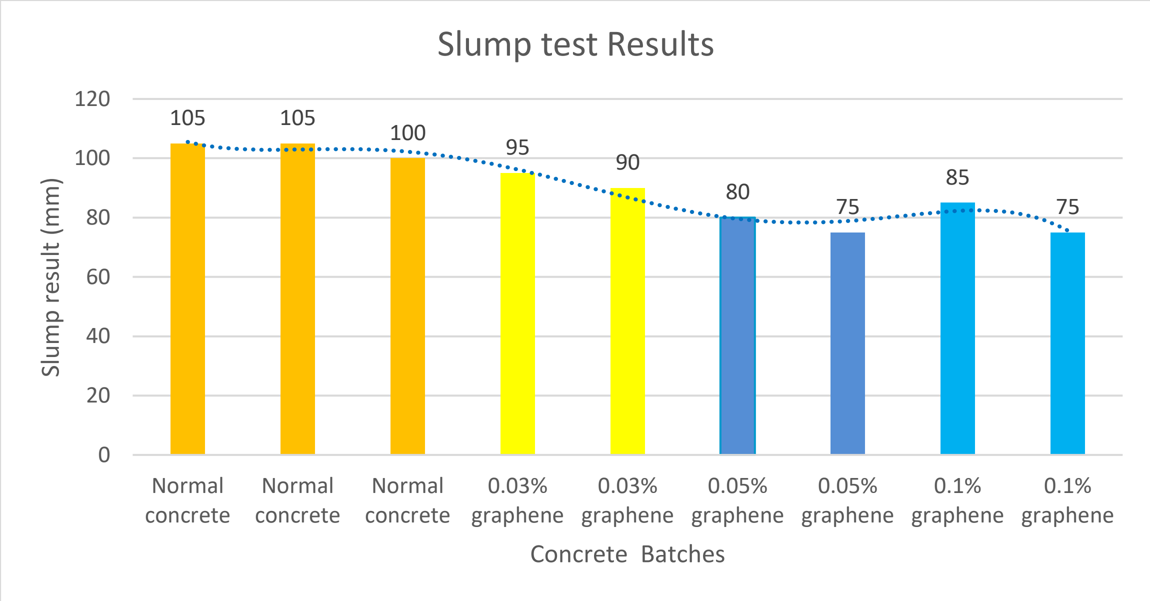


Figure 5.1: Slump test result graph

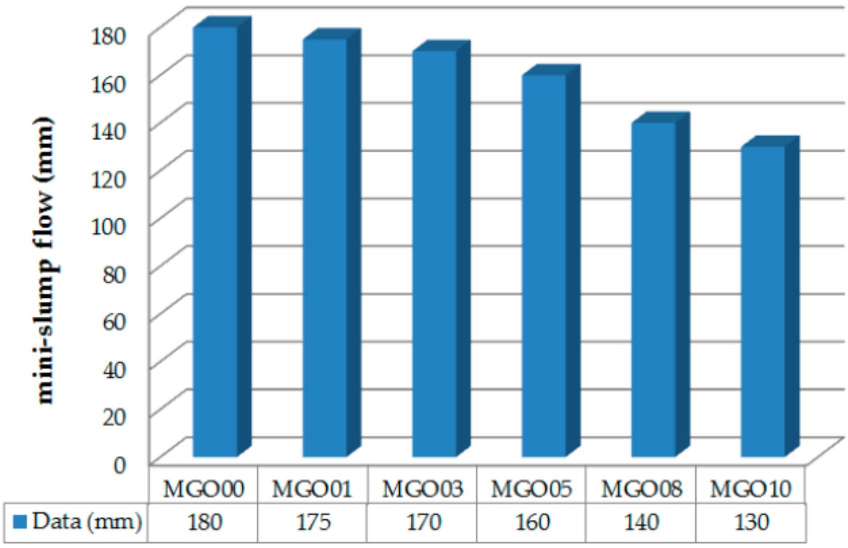


Figure 5.2: Mini slump test results (Liulei & Dong 2017)

5.2 Flexural test results

The flexural test was conducted on two different types of beams, one with a full graphene concrete mix and one with graphene concrete mix only on the bottom 40mm of the beam. The results from the flexural test with the graphene on a beam with 40mm of graphene concrete mix at the bottom of the test sample are shown in table 5.3

5.2.1 40mm Beam results

Table 5.3: Flexural results for 40mm Beam results

SAMPLE	Graphene %	Sample type	Rapture reading (P) kN	fcf (Mpa)	Average fcf (Mpa)	Change %
1	Control	40mm BEAM	19.380	2.584	2.58	0.0
3	0.03	40mm BEAM	26.680	3.557		
4		40mm BEAM	23.646	3.153	3.36	29.8
7	0.05	40mm BEAM	29.000	3.867		
8		40mm BEAM	27.073	3.610	3.74	44.7
11	0.1	40mm BEAM	25.206	3.361		
12		40mm BEAM	30.613	4.082	3.72	44.0

5.2.2 Calculations

Once the load is applied, and then a fracture occurs within the middle third of the specimen, the modulus of rupture was calculated as below:

$$f_{cf} = \frac{PL\,(1000)}{BD^2}$$

Where:

f_{cf} = modulus of rupture, in megapascals

P = maximum applied force indicated by the testing machine, in kilonewtons

L = 450mm = span length, in millimetres

B = 150mm = average width of the sample at the section of failure, in millimetres

D = 150mm = average depth of sample at the section of failure, in millimetres

Rapture reading for the control sample was 19.38 kN

$$f_{cf} = \frac{19.38\ \times 450\,(1000)}{150 \times 150^2}$$

$$f_{cf} = 2.58\,MPa$$

The same method was used to calculate the flexural strength of the sample containing 0.03%,0.05% and 0.1% of graphene by weight of cement. The results show that the samples with graphene had higher flexural strength than the control sample. With 0.03% showing a 29.8%, 0.05 showing a 44.7% and 0.1% showing a 44% improvement in the flexural strength as shown in table 5.3 and figure 5.3. With literature review, we expected the optimum graphene content at either 0.03% or 0.05%, and these results show that 0.05% was the optimum percentage content as it shows a decrease in the strength increment as we go to 0.1%.

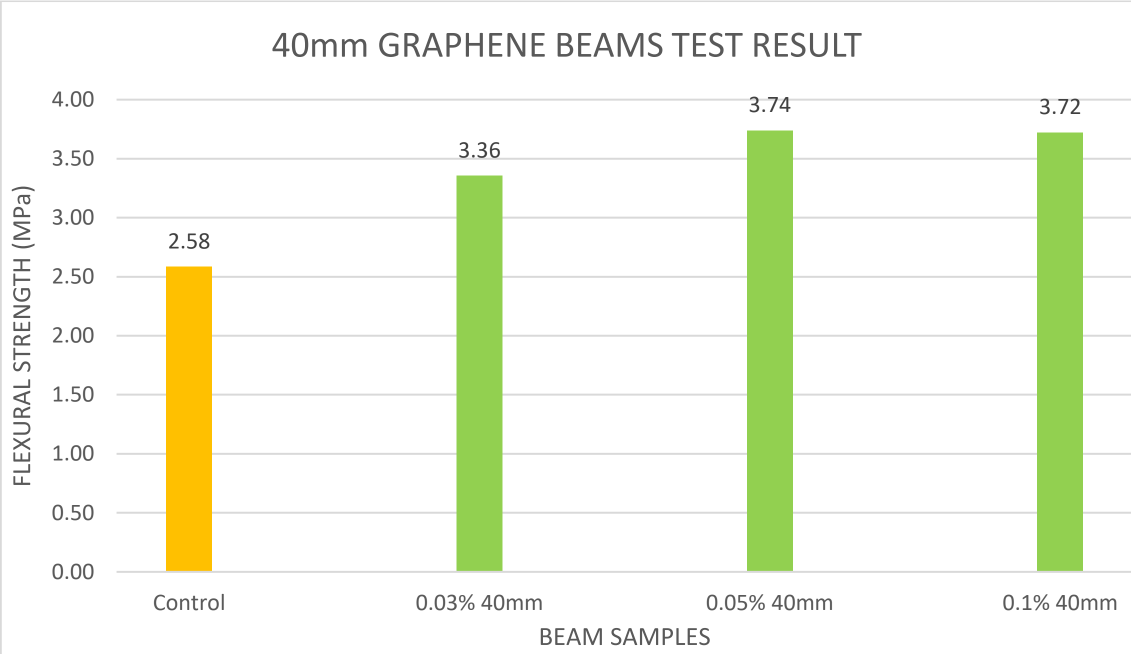


Figure 5.3: Flexural results for 40mm graphene beams

5.2.3 Full beam results

Table 5.4: Flexural results for full graphene Beams

SAMPLE	Graphene %	Sample type	Rapture reading (P) kN	fcf	Average fcf	Change %
2	Control	FULL BEAM	25.320	3.376	3.38	0.0
5	0.03	FULL BEAM	24.706	3.294		
6		FULL BEAM	32.166	4.289	3.79	12.3
9	0.05	FULL BEAM	23.446	3.126		
10		FULL BEAM	30.806	4.107	3.62	7.1
13	0.1	FULL BEAM	22.039	2.939		
14		FULL BEAM	30.992	4.132	3.54	4.7

Results for the full graphene beams were varied and unexpected. I believe that the control sample displayed a stronger than expected flexural strength which in turn resulted in the flexural strength improvements for the graphene samples being very small. As shown in table 5.4 the improvements in the flexural strength for 0.03%, 0.05% and 0.1% were 12%, 7% and 5% respectively. According to the results, the optimum percentage of graphene is 0.03%.

Due to the availability of the laboratory staff, I was not able to utilise the automated concrete mixer. Therefore, there were challenges with mixing the concrete manually, and the compaction of the 40mm graphene beams which had to be performed with the compaction rod instead of the vibrator. These challenges could have resulted in a mixed result we see. The full graphene beams were expected to be stronger as they have been cast as a single layer while the 40 mm beams were cast with two layers thus creating a weak plane between the layers as well as the fact that 73% (110mm x 150mm x 150mm) of the concrete on the 40mm graphene beams where normal concrete, however, the 40mm graphene beams show considerable improvements in the flexural strength as compared to the full graphene beams.

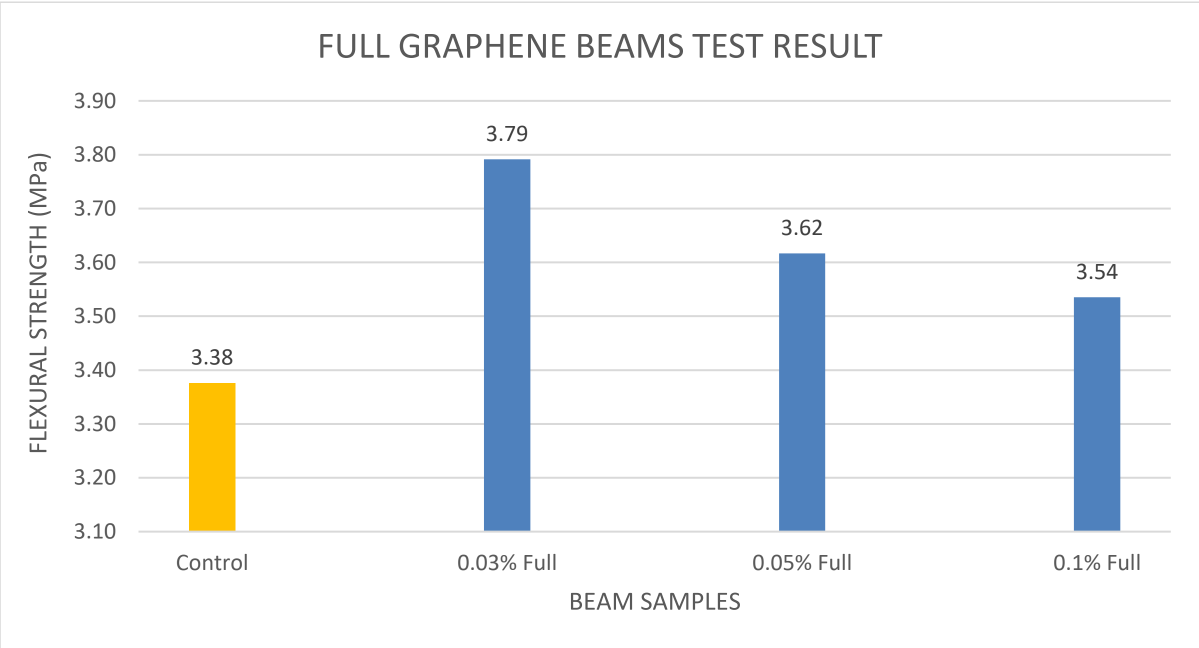


Figure 5.4: Flexural results for full graphene beams

5.2.4 Combined Flexural results

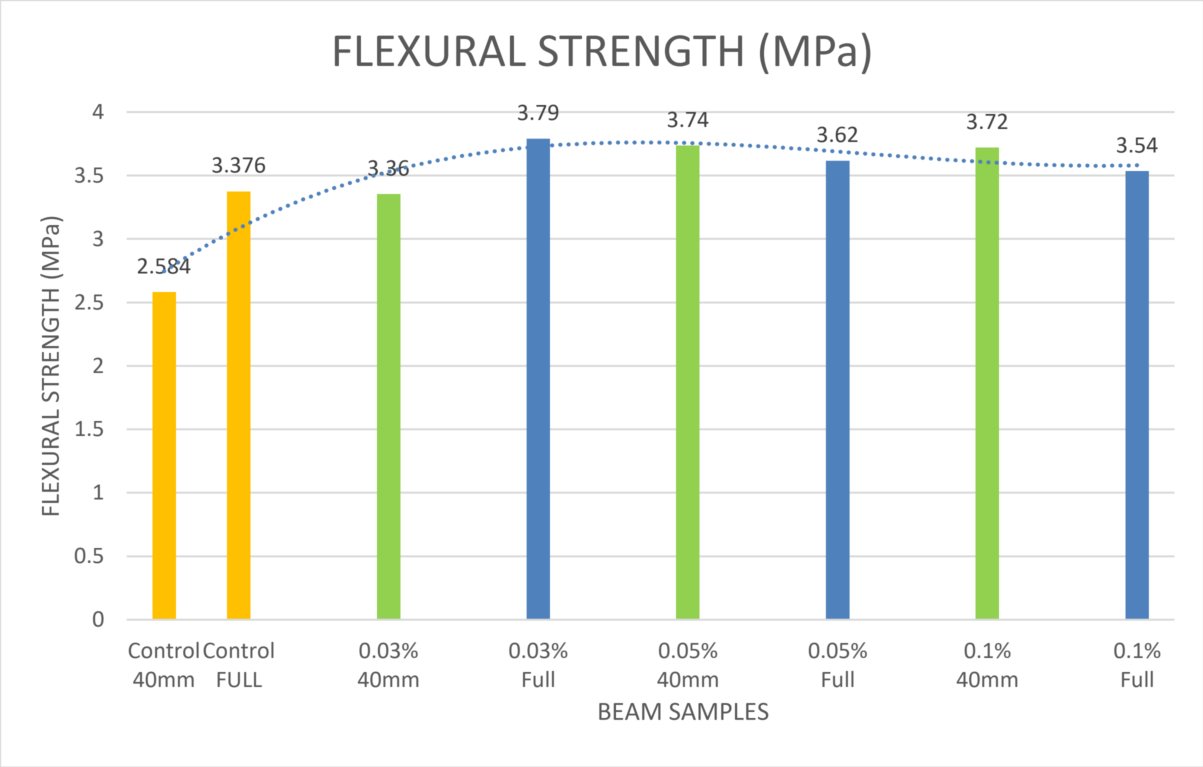


Figure 5.5: Flexural results for full and 40mm graphene beams

The full graphene results are inconsistent but the graph of the combined results on figure 5.5 shows a trend of the increment in flexural strength up to around 0.03% and 0.05% and then the decrease in the increment of flexural strength after 0.05%, which shows that there is an optimum amount of graphene that can be added to concrete to improve its properties. The control sample for the full graphene beams is quite high as compared to the 40mm graphene control beam, this value can also distort the results as it might not show much improvement in the flexural strength because the control sample failed at a higher reading. In the future, it would be more beneficial to have multiple control samples to get a consistent trend and reading.

5.2.5 Deflection

Deflection analysis was also conducted for the flexural beams with a graph of the results shown in figure 5.6. The results show with the exemption of 0.1% graphene by weight of cement samples that with an increase in graphene we get more deflection from the beam before its fails. The control sample failed after deflecting 2.35mm, while 0.03% graphene by weight of cement samples, 0.05% graphene by weight of cement samples and 0.1% graphene by weight of cement samples failed at 2.5mm,2.2mm and 1.15mm deflections respectfully. The deflection results suggest that the more graphene in the concrete sample, the more ductile the sample becomes. This analysis of harden concrete results in contrast with the result from fresh concrete test (slump test), which showed that with more graphene added to the concrete mix, the concrete becomes less fluid. As a liquid graphene could be acting to crystallise the cement particles in the fresh concrete mix thus making the concrete mix less fluid but with harden concrete the graphene nanosheets act as barriers and stop microcracks propagating more in the concrete during testing. Flexural test sample after rapture load is shown in figure 5.7, and more sample pictures can be found in Appendix D

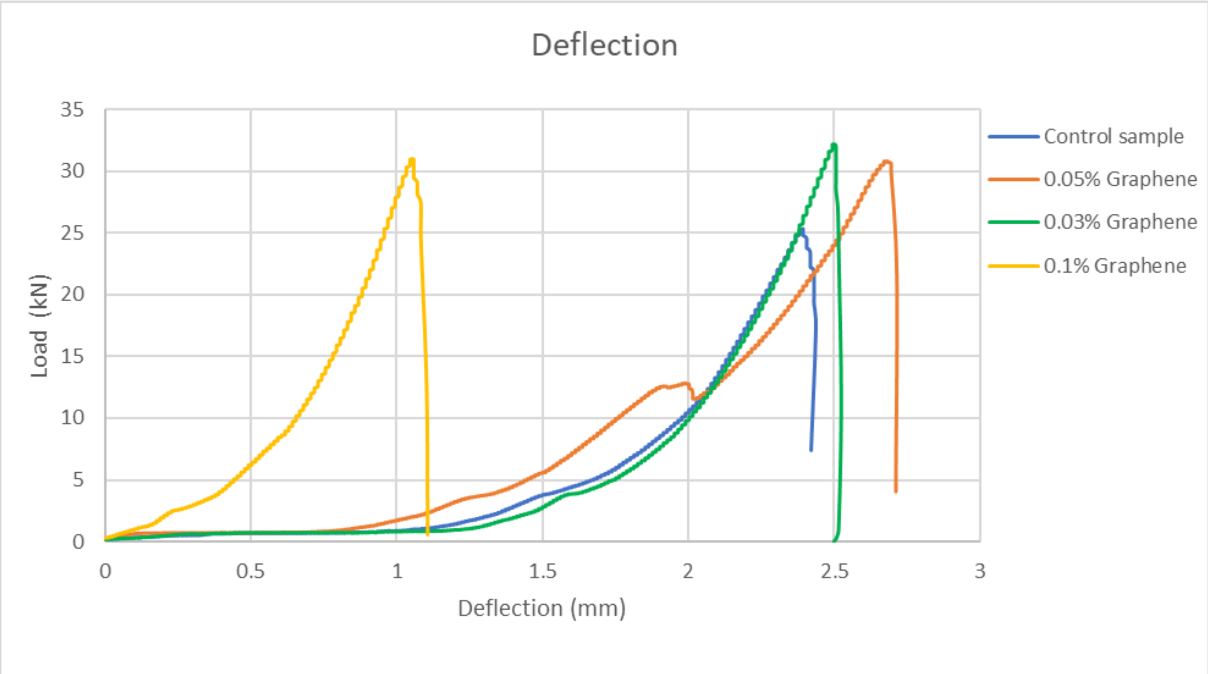


Figure 5.6: Deflections for flexural tests

Figure 5.7: Flexural test sample after rapture load

5.3 Compression test results

There were two samples per graphene percentage to test for compressive strength and one control sample to compare the results with, the results are tabulated below in table 5.5.

Table 5.5: Compressive strength test results

SAMPLE	Graphene %	Failure load (P) kN	fc	Average fc	Change %
1	Control	354	45.07	45.1	0.0
2	0.03	389	49.53		
3		544	69.26	59.4	31.8
4	0.05	360	45.84		
5		355	45.20	45.5	1.0
6	0.1	391	49.78		
7		342	43.54	46.7	3.5

5.3.1 Calculations

$$f_c = \frac{P}{A}$$

$$A = \frac{\pi \times D^2}{4}$$

Therefore

$$f_c = \frac{4 \times P}{\pi \times D^2}$$

f_c = Compressive strength, in megapascals

P = maximum applied force indicated by the testing machine, in newtons

D = 100mm = average diameter of sample, in millimetres

The maximum load indicated in the test machine for the control sample was 354 kN

$$f_c = \frac{4 \times 354000}{\pi \times 100^2}$$

$$f_c = 45.07\ MPa$$

The same method was used to calculate the compressive strength of the sample containing 0.03%,0.05% and 0.1% of graphene by weight of cement.

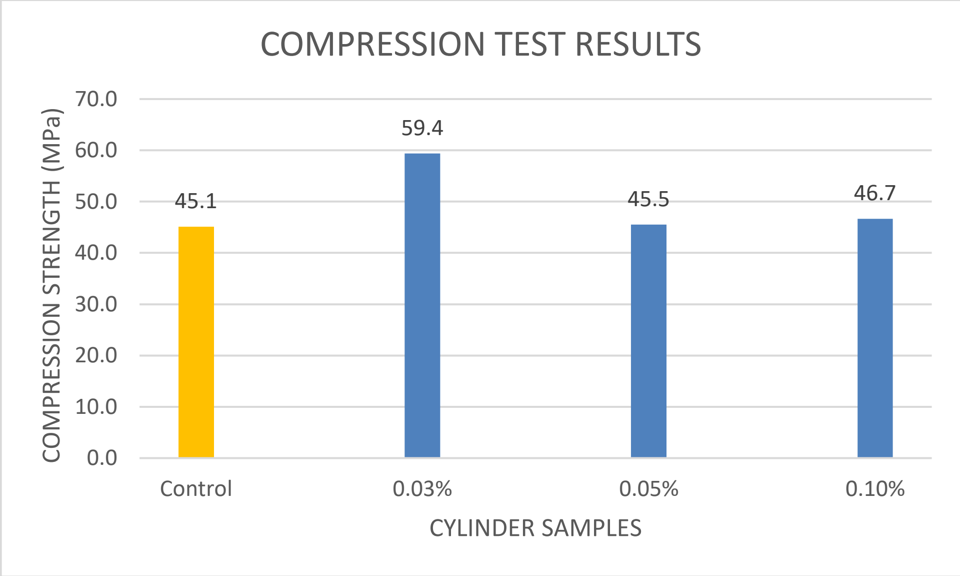


Figure 5.8: Compressive strength results

Results are shown in table 5.5 and figure 5.7 show that there was an improvement in the compressive strength of the sample containing 0.03% of graphene of 31.8% while 0.05% showed an improvement of only 1% and 0.1% showing an improvement of 3.5%. The results for 0.05% and 0.1% are not consisted with what was expected as there is a little improvement shown, this might be due to some inconsistency in the mixing of the concrete material as manual mixing method was used. It was expected that the results would follow the same trend as the flexural results whereby 0.05% and 0.1% results will be reducing from the 0.03% optimum but by no more than 15%. A picture of the failed sample can be found in figure 5.8, more of the failed samples can be review in Appendix D

Figure 5.9: Compressive strength sample after rapture load

5.4 Indirect tensile test results

There were two samples per graphene percentage to test for indirect tensile strength and one control sample to compare the results with, the results are tabulated below in table 5.6.

Table 5.6: Indirect tensile test results

SAMPLE	Graphene %	Failure load (P) kN	f_{cf}	Average f_{cf}	Change %
1	Control	98.10	3.123	3.12	
3	0.03	109.96	3.500		
4		97.97	3.118	3.31	6.0
7	0.05	88.53	2.818		
8		74.60	2.375	2.60	-16.9
11	0.1	97.55	3.105		
12		90.55	2.882	2.99	-4.1

5.4.1 Calculations

The indirect tensile strength of the sample was calculated as follows:

$$T = \frac{2000P}{\pi LD}$$

where

T = indirect tensile strength, in megapascals

P = maximum applied force indicated by the testing machine, in kilonewtons

L = length, in millimetres

D = diameter, in millimetres

The maximum load indicated in the test machine for the control sample was 98.1 kN

$$T = \frac{2000 \times 98.1}{\pi \times 200 \times 100}$$

$$T = 3.12\ MPa$$

The same method was used to calculate the compressive strength of the sample containing 0.03%,0.05% and 0.1% of graphene by weight of cement.

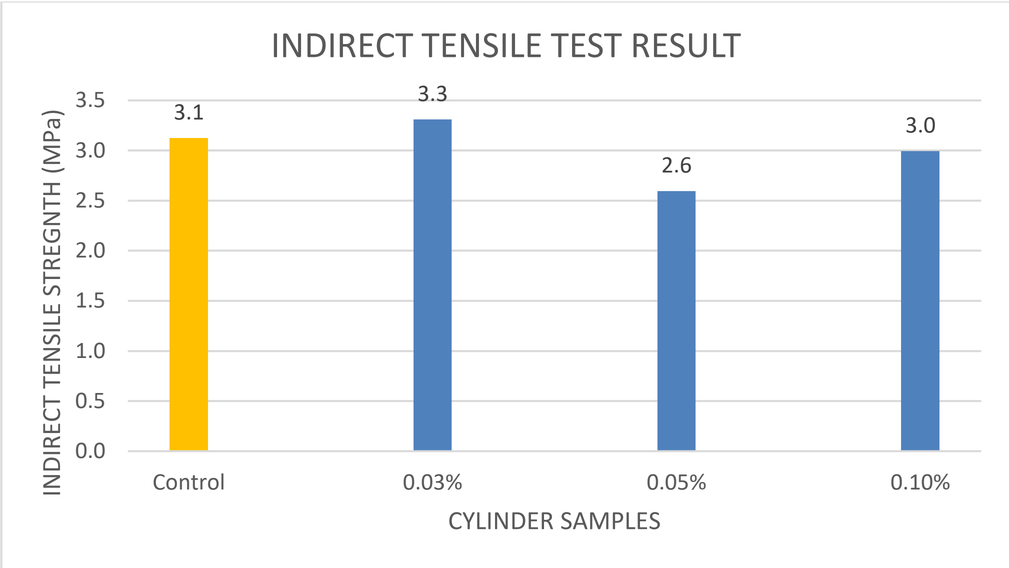


Figure 5.10: Indirect tensile test results

The results of the indirect tensile test are not as expected, with only 0.03% showing an improved tensile result while 0.05% and 0.1% show a reduction the indirect tensile strength. The results for 0.03% of graphene by weight of cement, shows a 6% increase in indirect tensile strength, 0.05% graphene by weight of cement, showed a decrease in strength of 16.9% and 0.1% graphene by weight of cement, showed a decrease in strength of 4.1%. I believe that the control sample came from a batch that was well made and well compacted which resulted in a much stronger concrete, this has distorted the results. With more control sample and more graphene added samples, we could have had better and more accurate average results. A picture of the failed sample can be found in figure 5.11, more of the failed samples can be review in Appendix D.

Figure 5.11: Indirect tensile test sample after rapture load

5.5 Modulus of elasticity

A load of about 40% of the compressive strength was applied to the test samples, and the results of the deflection with the corresponding load were recorded at increments of 10kN. The deflection, stress and strain test results are shown in Table 5.7

Table 5.7: Stress, strain and deflection results

load (kN)	stress (MPa)	Deflection (mm)	strain	Deflection (mm)	strain	Deflection (mm)	strain	Deflection (mm)	strain
		control	x10^-4	0.03% Graphene	x10^-4	0.05% Graphene	x10^-4	0.1% Graphene	x10^-4
0	0.00	0	0	0	0	0	0	0	0
10	1.27	0.006	0.3	0.009	0.45	0.011	0.55	0.015	0.75
20	2.55	0.014	0.7	0.018	0.9	0.022	1.1	0.025	1.25
30	3.82	0.024	1.2	0.026	1.3	0.032	1.6	0.035	1.75
40	5.09	0.033	1.65	0.036	1.8	0.042	2.1	0.046	2.3
50	6.37	0.044	2.2	0.047	2.35	0.052	2.6	0.056	2.8
60	7.64	0.055	2.75	0.057	2.85	0.063	3.15	0.066	3.3
70	8.91	0.063	3.15	0.067	3.35	0.073	3.65	0.075	3.75
80	10.19	0.073	3.65	0.077	3.85	0.084	4.2	0.087	4.35
90	11.46	0.084	4.2	0.088	4.4	0.095	4.75	0.097	4.85
100	12.73	0.095	4.75	0.098	4.9	0.105	5.25	0.107	5.35
110	14.01	0.103	5.15	0.107	5.35	0.116	5.8	0.118	5.9
120	15.28	0.112	5.6	0.117	5.85	0.125	6.25	0.129	6.45
130	16.55	0.122	6.1	0.128	6.4	0.134	6.7	0.14	7
140	17.83	0.133	6.65	0.139	6.95	0.145	7.25	0.149	7.45
150				0.149	7.45	0.156	7.8	0.16	8

5.5.1 Calculations

$$Stress\ (MPa) = \frac{Load\ (kN)}{Cross\ sectional\ area\ (m^2) \times 1000}$$

$$Cross\ sectional\ area = \frac{\pi \times D^2}{4}$$

Therefore

$$Stress\ (MPa) = \sigma = \frac{4 \times Load\ (kN)}{\pi \times D^2 \times 1000}$$

Sample calculations for a load of 80kN

$$Stress\ (MPa) = \sigma = \frac{4 \times 80}{\pi \times 0.1^2 \times 1000}$$

$$\sigma\ (MPa) = 10.19\ MPa$$

$$Strain = \varepsilon = \frac{Change\ in\ length}{Length}$$

Cylinder height is the length = 200mm

Change in length is the reading taken from the dial gauge as the sample was subjected to load.

Sample calculations for a load of 80kN

$$Strain = \varepsilon = \frac{0.073}{200}$$

$$Strain = \varepsilon = 3.65\ \times 10^{-4}$$

Table 5.8: Modulus of elasticity calculated results

		Control	0.03% Graphene	0.05% Graphene	0.1% Graphene
Compression load fc	kN	354	466.5	357.5	366.5
	MPa	45	49.5	45.8	49.8
33% of fc (kN)		116.82	153.945	117.975	120.945
Stress (σ) (MPa)		15.279	19.099	15.279	15.279
Strain (ε)		0.00056	0.000745	0.000625	0.000645
Calculated E (MPa)		27284	25636	24446	23688
Final E (MPa)		27300	25650	24450	23700
Change %		0	6.4	11.7	15.2

Modulus of elasticity was calculated using stress and strain:

$$Modulus\ of\ elasticity = \frac{stress\ at\ 33\%\ of\ f_c(MPa)}{Strain\ at\ 33\%\ of\ f_c}$$

Calculating modulus of elasticity at 0.03% of graphene by weight of cement.

$$Modulus\ of\ elasticity = \frac{19.099}{0.000745}$$

$$Modulus\ of\ elasticity = 25636\ MPa$$

Final modulus of elasticity taken to the nearest 50

$$Modulus\ of\ elasticity \cong 25650\ MPa$$

The results for modulus of elasticity are lower than expected even for the control sample, with our characteristic compressive strength of normal concrete (control) at 32 MPa we expected the modulus of elasticity to be 30,100 MPa as shown in AS3600-2009, table 3.1.2 (figure 5.10) and yet the results show 27,300 MPa which is about 10% less than the expected Modulus of elasticity. The results show a reduction in modulus of elasticity as more graphene is added to the concrete mix. Results for 0.03% show a modulus of elasticity of 25650 MPa, which is a 6.4% reduction in the modulus of elasticity when compared to the control sample. Results for 0.05% show a modulus of elasticity of 24450 MPa, which is a 11.7 % reduction in the modulus of elasticity when compared to the control sample. Results for 0.1% show a modulus of elasticity of 23700 MPa, which is a 15.2 % reduction in the modulus of elasticity when compared to the control sample.

f'_c (MPa)	20	25	32	40	50	65	80	100
E_c (MPa)	24,000	26,700	30,100	32,800	34,800	37,400	39,600	42,200

Figure 5.12: Concrete properties at 28 days

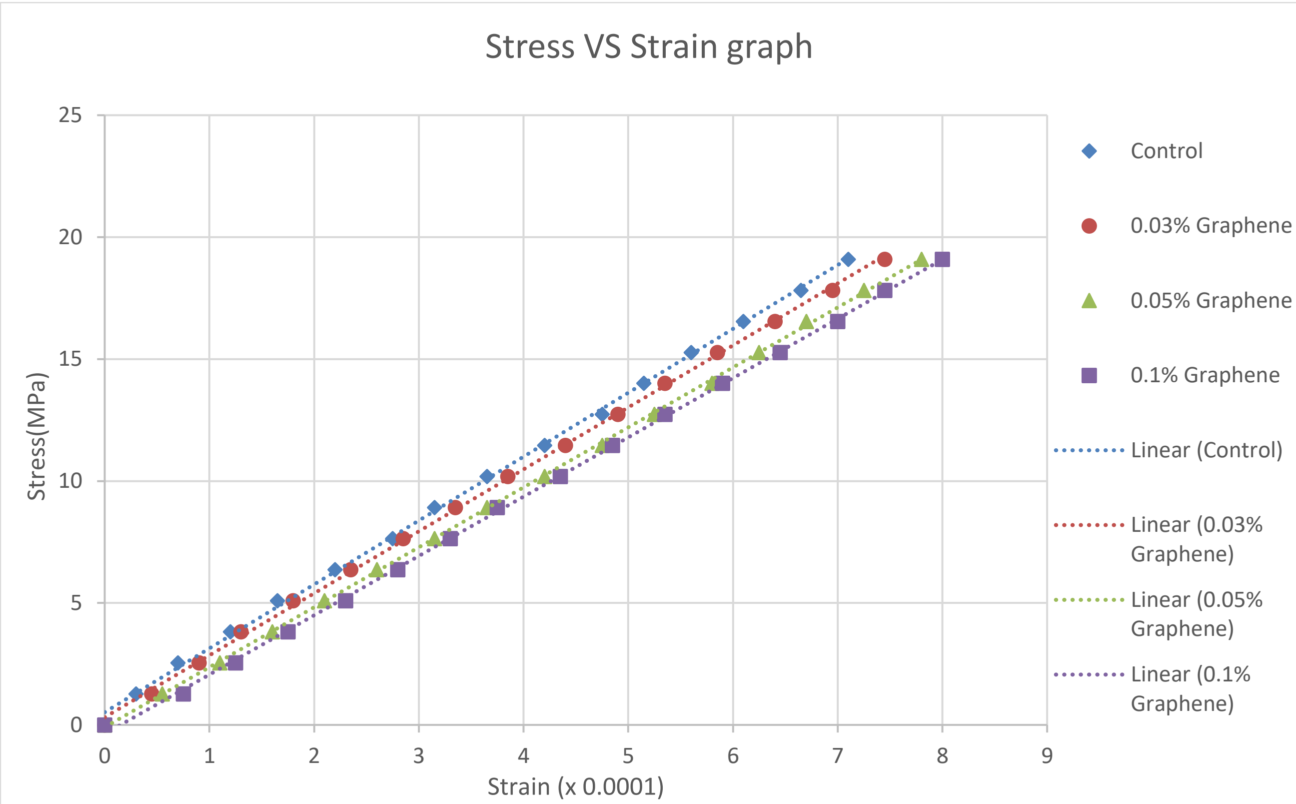


Figure 5.13: Stress VS Strain graph

5.6 Combined results analysis

With literature review, we expect the results of the flexural and tensile tests to be about 10% of the compressive strength f_c shown in table 5.5. The results for the flexural test show better reading than those of indirect tensile test, with a calculated flexural strength of 3.38 MPa to 3.79 MPa at 6.4% to 7.9% of the compressive strength. While the indirect tensile test shows lower readings of 2.6 MPa to 3.31 MPa at 5.6% to 6.9% of the compressive test result. The reason for these lower results could be that the compressive strength results were a little higher than the calculated target strength of 40 MPa. The compressive results on table xxx show all calculated readings above 45 MPa with the one for 0.03%, showing the highest test result of 59.4 MPa.

Table 5.9: Compressive strength compared to flexural and tensile

Graphene %	fc (MPa)	Average fc (MPa)	Flexural (MPa)	fraction of fc %	Tensile (MPa)	fraction of fc %
Control	45.07	45.1	3.38	7.5	3.12	6.9
0.03	49.53					
	69.26	59.4	3.79	6.4	3.31	5.6
0.05	45.84					
	45.20	45.5	3.62	7.9	2.60	5.7
0.1	49.78					
	43.54	46.7	3.54	7.6	2.99	6.4

6 Conclusion and further work

6.1 Summary

Through the literature review, it was clear that not much research has been conducted, in understanding the effects of graphene in concrete, particularly in Australia. This project aimed to analyse the effects of graphene on the flexural strength, compressive strength, indirect tensile strength, modulus of elasticity and slump of fresh concrete. The results for this project, unfortunately, are not as conclusive as we had hoped. Even though we got a good reading on some of our tests, the slump test results we quite good and consistent with what was expected. Therefore, I would conclude that the slump test was successful.

The results for flexural strength were mixed with the results for the beams with 40mm of graphene concrete mix at the bottom of the beam showing excellent trend and aligned with expected results while the results for beams with full graphene show improvement when compared with the control sample but with a low percentage of improvement and different to the 40mm beams as 0.03% had the highest strength while the 40mm beams showed 0.05% as the graphene percentage by weight of cement with the highest improvement. I would conclude that the flexural test was successful even though I would suggest further investigations with more sample.

Compressive strength results were mixed with 0.03% showing expected results with a significant improvement in the compressive strength when compared to the control sample, but the other two graphene percentages showed low improvements and not within the expected trend as 0.05% was the lower of the two percentage. We expected the compressive strength to improve to a certain level then gradually decrease as more graphene is added. I would conclude that the compressive test results are were successful in showing that graphene improves the compressive strength, but the trend of the results was inconclusive.

The results for the indirect tensile test were not as expected as we had two of the graphene percentages 0.05% and 0.1% by weight of cement showing a decrease in strength when compared with the control sample. 0.03% showed a modest improvement in strength of 6% when compared to the control sample, the results for this test are inconclusive. There was only one control sample per test, so if the control sample was an unusual result, we could not tell as there was nothing to compare it to except theoretical information. Therefore, I would recommend that the experiment be repeated on a separate project with the number of samples increased even for the control sample to ensure that the result outliers are eliminated from the results and not used as they may distort the results.

6.2 Slump

Assumptions that can be drawn from the slump test results is that with an increase in graphene, in the concrete mix, reduces the fluidity of fresh concrete. This means that the graphene sheets make a good bond with cement paste or chemical reaction with cement paste in the concrete creates a stronger fresh concrete mix. The takeaway from this test result is that as fresh concrete is stronger, normal curing time for concrete could be reduced.

6.2.1 Future work

Further investigation into slump test is warranted as we might not have to wait 28 days before the concrete with graphene is fully loaded, with higher sample numbers and testing the compressive strength of graphene concrete at 7,14,21 and 28 days we could find out the precise time that graphene concrete reaches the characteristic and target strength.

6.3 Flexural strength

All the results for flexural strength showed, even though the results for full graphene beams were a bit disappointing, with the improvements in the flexural strength for 0.03%, 0.05% and 0.1% of graphene by weight of cement showing 12%,7% and 5% respectively when compared with control sample results. The results for beams with 40mm of graphene concrete mix at the bottom of normal concrete beam showed more positive and expected results with 0.03% showing a 29.8%, 0.05 showing a 44.7% and 0.1% showing a 44% improvement in the flexural strength when compared with the control sample results. Based on these results, we can conclude that graphene does increase the flexural strength of concrete with an optimum amount of graphene at around 0.03% and 0.5%.

6.3.1 Future work

Further investigation needs to be completed focussing purely on the flexural test. I believe further investigations should have more sample numbers as well as increasing the number of graphene amounts perhaps having 0.02 %, 0.03 %, 0.04 %, 0.05 %, 0.06 %, 0.07 %, 0.08 %, 0.09 %, and 0.1 %, as the graphene quantities by weight of cement. Another separate investigation after the above would be to look at the layer of graphene at the bottom of the beams, with maybe about 4 thicknesses of 20 mm, 30 mm,40 mm and 50mm layers of graphene concrete mix to find out the optimum thickness that yields the best results by percentage.

6.4 Compressive strength

Compressive strength results in this project showed that graphene added to concrete does increase the compressive strength, particularly the results for 0.03% of graphene by weight of cement. The results for 0.05% and 0.1% of graphene by weight of cement were lower than expected. Compressive strength of concrete with 0.03% of graphene by weight of cement showed a 31.8% improvement, while 0.05% and 0.1% of graphene by weight of cement showed modest results of 1% and 3.5% respectively. Clearly something did not go right with the tests for 0.05% and 0.1% of graphene by weight of cement, this could be due to inconsistencies in the concrete mixing as manual mixing was utilised instead of the automatic mixer.

6.4.1 Further work

In this project we had only two samples per graphene percentage which, does not give enough data to conclusively form an opinion on how much graphene improves the compressive strength of concrete. This test for compressive strength I believe should be a stand-alone project, on which more samples per graphene percentage could achieve better results. My suggestion is to have minimum of four samples per percentage of graphene, but of course the more sample, the better. I would also suggest that more graphene percentages be investigated perhaps from 0.02% to 0.1% with 0.01% increments.

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8 Appendices

8.1 Appendix A

8.1.1 Project specification

ENG4111/4112 RESEARCH PROJECT

PROJECT SPECIFICATION

For: Pako Maruping

Title: Flexural behaviour of graphene-reinforced concrete beams

Major: Civil engineering

Supervisors: Dr. Weena Lokuge
Professor Karu Karunasena

Enrolment: ENG4111 – EXT S1, 2019
ENG4112 – EXT S2, 2019

Project Aim: To investigate flexural behaviour of graphene-reinforced concrete beams, as per Australian standards.

Programme: Version 1, 20th March 2019

1. To analyse evidence based research on graphene, industrial use of graphene and concrete graphene mix design.

2. Design and plan testing of graphene reinforced concrete. Test variables include:

    - Full graphene reinforced concrete mix beams and 40mm layer of graphene reinforced concrete layer at the bottom of 110mm of normal concrete beam.
    - Graphene content of the samples will be 0.1%, 0.05%, and 0.03%.

3. Testing of the graphene reinforced beams will as per AS 1012 and relevant tests will be conducted for mechanical properties.

4. Analysis and evaluation of experimental results and draw conclusions on the use of graphene reinforced concrete.

5. Organise content to prepare dessertation.

If time and resources permit:

6. Evaluate the practicality and cost effectiveness of using graphene reinforced concrete beams on large scale projects

8.2 Appendix B

8.2.1 Mix Design Spreadsheet

Pako Maruping Batch Concrete Mix Design

Target Strength (MPa):	40 MPa
Compressive Strength (MPa):	32 MPa
Target Slump (mm):	80
Slump Tolerance (mm):	± 40
Target Air Content (%):	-
Air Content Range (%):	-
Max W/C :	0.5

Sand Moisture Content (%):	3.5

MIX DESIGN PROPORTIONS (2		
7mm Stone	560	kg
10mm Stone	560	kg
Sand	560	kg
Cement	480	kg
Water	240	L
Graphene	2250	kg

Sample Number	Tests and Test Size	Concrete/Graphene Thickness	Graphene Percentage	Concrete/Graphene Sample Size	Final Concrete Sample Size	7mm Stone	10mm Stone	Sand	Total Aggregate Weight	Water	Cement	Total Concrete Weight	Graphene
	m	m	%	m3	m3	kg	kg	kg	kg	L	kg	kg	Total kg
	Beams (0.15 x 0.15 x 0.5)												
1	Flexural tests	0.15	0.03	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923	0.001620000
2		0.15	0.05	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923	0.002700000
3		0.15	0.1	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923	0.005400000
4		0.04	0.03	0.003000	0.011250	1.6800	1.6800	1.7388	5.0988	0.6591	1.4400	7.1979	0.000432000
		0.11	0	0.008250	0.011250	4.6200	4.6200	4.7817	14.0217	1.8126	3.9600	19.7943	0.000000000
5		0.04	0.05	0.003000	0.011250	1.6800	1.6800	1.7388	5.0988	0.6591	1.4400	7.1979	0.000720000
		0.11	0	0.008250	0.011250	4.6200	4.6200	4.7817	14.0217	1.8126	3.9600	19.7943	0.000000000
6		0.04	0.1	0.003000	0.011250	1.6800	1.6800	1.7388	5.0988	0.6591	1.4400	7.1979	0.001440000
		0.11	0	0.008250	0.011250	4.6200	4.6200	4.7817	14.0217	1.8126	3.9600	19.7943	0.000000000
	Cylinders (0.1D x 0.2H)	**Volume m3**											
1	Compressive test	0.001570796	0.03	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000226195
2		0.001570796	0.05	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000376991
3		0.001570796	0.1	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000753982
4	MOE	0.001570796	0.03	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000226195
5		0.001570796	0.05	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000376991
6		0.001570796	0.1	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000753982
7	Split Tensile Test	0.001570796	0.03	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000226195
8		0.001570796	0.05	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000376991
9		0.001570796	0.1	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	0.000753982
	Control	**Volume m3**											
10		0.005498	0.03	0.005498	0.005498	3.0789	3.0789	3.1866	9.3444	1.2080	2.6390	13.1914	0.000791712
11		0.005498	0.05	0.005498	0.005498	3.0789	3.0789	3.1866	9.3444	1.2080	2.6390	13.1914	0.001319520
12		0.005498	0.1	0.005498	0.005498	3.0789	3.0789	3.1866	9.3444	1.2080	2.6390	13.1914	0.002639040
7	Control Sample	0.15	0	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923	
8	Control Sample 40mm	0.15	0	0.011250	0.011250	6.3000	6.3000	6.5205	19.1205	2.4718	5.4000	26.9923	
10	cylinder control	0.001570796	0	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	
11	cylinder control	0.001570796	0	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	
12	cylinder control	0.001570796	0	0.001571	0.001571	0.8796	0.8796	0.9104	2.6697	0.3451	0.7540	3.7688	

Total single sample		1.08	0.0981	0.1591	70.1924	70.1924	72.6491	213.0339	27.5397	60.1649	300.7385	0.0211
Total second sample incl		2.16	0.1963	0.3182	140.3848	140.3848	145.2983	426.0678	55.0795	120.3298	601.4771	0.0423
Total incl 20% wastage			**0.2355**	**0.3818**	**168.4617**	**168.4617**	**174.3579**	**511.2814**	**66.0954**	**144.3958**	**721.7725**	**0.0507**

8.3 Appendix C

8.3.1 Risk management plan

University of Southern Queensland Print View

USQ Safety Risk Management System

Version 2.0

Safety Risk Management Plan

Risk Management Plan ID:	*Status:*	Current User:	Author:	Supervisor:	Approver:
RMP_2019_3687	*Approve*	lokuge	i:0#.w|usq\w0030132	i:0#.w|usq\lokuge	i:0#.w|usq\lokuge

Assessment Title:	Casting and testing of graphene reinforced concrete	Assessment Date:	15/08/2019
Workplace (Division/Faculty/Section):	204060 - School of Civil Engineering and Surveying	Review Date:	31/07/2020 (5 years maximum)

Approver:	*Supervisor: (for notification of Risk Assessment only)*
Weena Lokuge	*Weena Lokuge*

Context

DESCRIPTION:

What is the task/event/purchase/project/procedure?	Casting and testing of graphene reinforced concrete
Why is it being conducted?	BENG(Civil) Research project work
Where is it being conducted?	P3 lab, P11 lab
Course code (if applicable)	ENG4111/ENG4112
Chemical Name (if applicable)	Graphene

WHAT ARE THE NOMINAL CONDITIONS?

Personnel involved	Pako Maruping, Piumika Ariyadasa
Equipment	Wheel barrow, shovel, trowel, concrete mixer,Flexural test machine, Compressive test machine
Environment	laboratory, (room temperature with dry condition)
Other	

Briefly explain the procedure/process	The procedure is to prepare a normal concrete mixture and a concrete mixture with graphene in a standard process for compressive and flexural strengths tests. Cast cylindrical concrete specimens and beam specimens.

Assessment Team - who is conducting the assessment?

Assessor(s):	Professor Karu Karunasena, Weena Lokuge, Piumika Ariyadasa
Others consulted: (eg elected health and safety representative, other personnel exposed to risks)	

Risk Matrix

Probability	Consequence: Insignificant No Injury 0-$5K	Minor First Aid $5K-$50K	Moderate Med Treatment $50K-$100K	Major Serious Injury $100K-$250K	Catastrophic Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1,000	L	M	H	H	H
Unlikely 1 in 10,000	L	L	M	M	M
Rare 1 in 1,000,000	L	L	L	L	L

Recommended Action Guide

Extreme:	**E** = Extreme Risk – Task ***MUST NOT*** proceed
High:	**H** = High Risk – Special Procedures Required (Contact USQSafe) Approval by VC only
Medium:	**M** = Medium Risk - A Risk Management Plan/Safe Work Method Statement is required
Low:	**L** = Low Risk - Manage by routine procedures.

Risk Register and Analysis

	Step 1	Step 2	Step 2a	Step 2b	Step 3			Step 4				
	Hazards: **From step 1 or more if identified**	***The Risk:*** **What can happen if exposed to the hazard without existing controls in place?**	***Consequence:*** **What is the harm that can be caused by the hazard without existing controls in place?**	***Existing Controls:*** **What are the existing controls that are already in place?**	***Risk Assessment:*** **Consequence x Probability = Risk Level**			***Additional Controls:*** **Enter additional controls if required to reduce the risk level**	***Risk assessment with additional controls:*** **Has the consequence or probability changed?**			
					Probability	*Risk Level*	*ALARP*		*Consequence*	*Probability*	*Risk Level*	*ALARP*
	Example											
	Working in temperatures over 35^{0} C	*Heat stress/heat stroke/exhaustion leading to serious personal injury/death*	*catastrophic*	*Regular breaks, chilled water available, loose clothing, fatigue management policy.*	*possible*	*high*	*No*	*temporary shade shelters, essential tasks only, close supervision, buddy system*	*catastrophic*	*unlikely*	*mod*	*Yes*
1	Manual liftin...	Back or spinal injury	Minor	Lab safety induction provided, Wear personal protective equipment (steel cap safety shoes, heavy duty gloves). and using proper manual handling procedure according to USQ safety manual. The action is taking place under the supervision of technical staff.	Unlikely	Low	☑					☐
2	Exposure to ...	Skin irritation and breathing problems	Minor	Wear personal protective equipment (Safety steel cap shoes, dust masks, safety goggles and safety gloves)	Unlikely	Low	☑					☐
3	Spillage of w...	Slipping causing injury	Minor	Ensure use proper water pressure, Clean up spillage, Wear PPE	Unlikely	Low	☑					☐
4	Rotating mac...	Material can fly from the mixer causing body injuries	Minor		Unlikely	Low	☑					☐

				Lab safety induction given, wear appropriate PPEs [steel cap safety shoes, eye protection safety goggles and heavy duty gloves], the activity is happening under supervision, Refer to SOP for the emergency stops attached to the mixer.								
5	Cleaning and...	Trip Hazzard	Minor	Wear PPE including safety boots.	Unlikely	Low	☑					☐
6	Handling, shi...	Specimen can fall on the feet	Minor	Wear personal protective equipment (steel cap safety boots) follow proper techniques in USQ safety manual. The action taking place under supervision.	Unlikely	Low	☑					☐
7	Setting up of...	Crushing of fingers, physical injury due to falling parts	Minor	Lab safety induction provided, Wear personal protective equipment, The action is taking place under supervision of trained person, make sure fixtures are undamaged, Seek second person help for heavy items	Unlikely	Low	☑					☐
8	Fixing jaws o...	Hand and head injuries	Minor	Wear personal protective equipment (Safety helmet, Steel caps safety shoes, Safety gloves, safety goggles) Lab safety induction provided, The action is taking place under the supervision of well trained person.	Unlikely	Low	☑					☐
9	Projectile fra...	Material can fly from Sans machine causing Body injuries	Minor		Unlikely	Low	☑					☐

				Lab safety induction provided, Wear personal protective equipment (steel cap safety shoes, heavy duty gloves,safety goggles and safety helmet). The action is taking place under the supervision. maintain clear distance while the machine is running. Refer to SOP for the emergency stops attached to the sans machine.								
...	Lifting heavy ...	Back and shoulder pain	Minor	Lab safety induction provided. follow proper techniques in USQ safety manual. Wear PPE. Use the help Trolly, Forklift for heavy loads.	Unlikely	Low	☑					☐
...	Testing of m...	Physical injury from flying broken specimen, crushing fingers from moving parts	Minor	Lab safety induction provided, Wear personal protective equipment. Use safety screen and eye protection, keep clear during testing from moving parts, The action takes place under trained person. use gloves when handling broken specimen, adopt to safety work procedure attached to the machine.	Unlikely	Low	☑					☐
...	Switching on...	Electrical shock	Minor	Lab safety induction provided. Wear PPE. Use of leather gloves, Trained personnel operates machine,emergency procedures are in place.	Unlikely	Low	☑					☐

Step 5 - Action Plan (for controls not already in place)

	Additional Controls:	Exclude from Action Plan: (repeated control)	Resources:	Persons Responsible:	Proposed Implementation Date:

Supporting Attachments

File Attachment

Graphene SDS.pdf
Adobe Acrobat Document
142 KB

Concrete SDS.pdf
Adobe Acrobat Document
119 KB

Step 6 – Request Approval

Drafters Name:	*Pako Marupimg*	*Draft Date:*	*15/08/2019*
Drafters Comments:			

Assessment Approval: **All risks are marked as ALARP**

Maximum Residual Risk Level: **Low - Manager/Supervisor Approval Required**

Document Status:	*Approve*

Step 6 – Approval

Approvers Name:	*Weena Lokuge*	*Approvers Position Title:*	*Senior Lecturer/Project supervisor*
Approvers Comments:	*We have discussed this with the technical staff*		

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

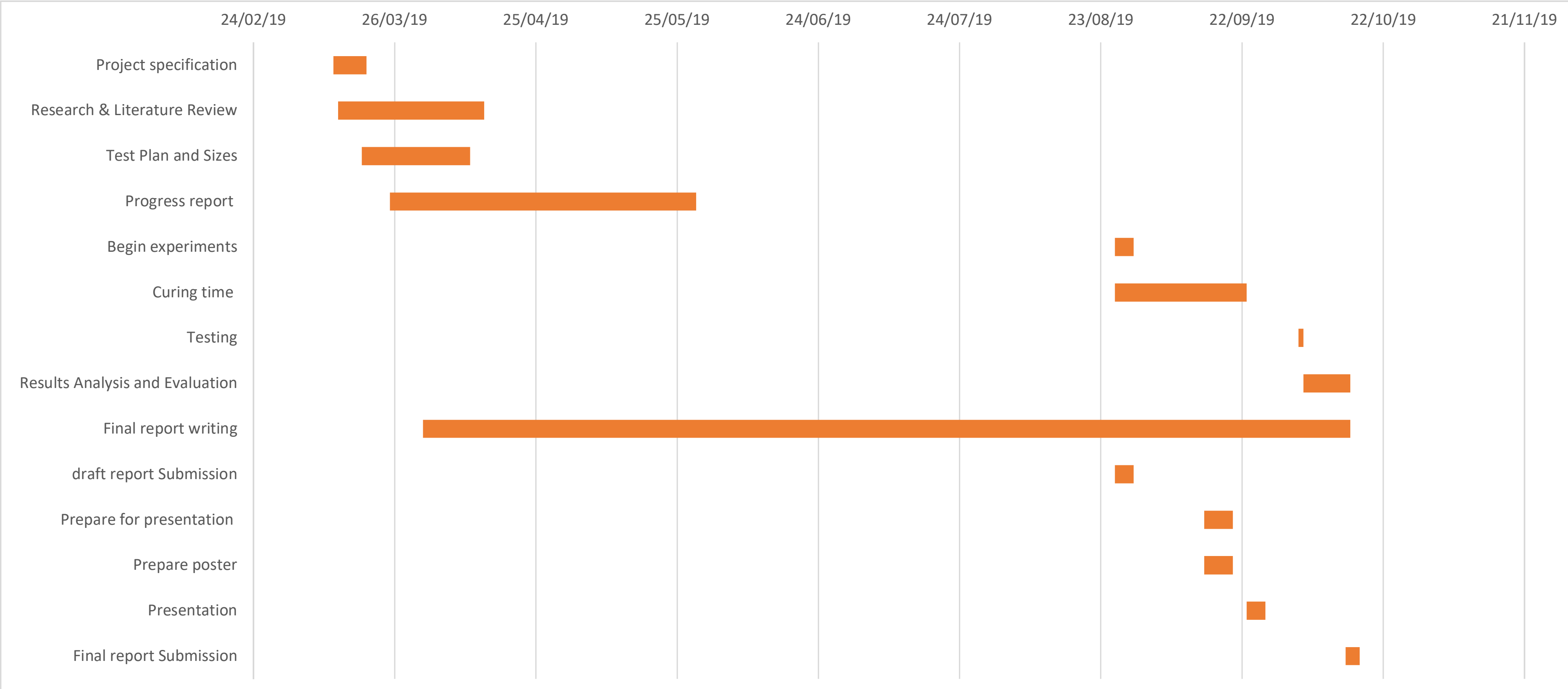
Approval Decision: *Approve*	*Approve / Reject Date:* *26/08/2019*	*Document Status:* *Approve*

8.3.2 Project Schedule

PAKO MARUPING USQ FINAL YEAR PROJECT

Flexural behaviour of graphene reinforced concrete beams

START DATE	END DATE	DESCRIPTION	DURATION (days)
13/03/19	20/03/19	Project specification	7
14/03/19	15/04/19	Research & Literature Review	31
19/03/19	12/04/19	Test Plan and Sizes	23
25/03/19	30/05/19	Progress report	65
26/08/19	30/08/19	Begin experiments	4
26/08/19	24/09/19	Curing time	28
04/10/19	05/10/19	Testing	1
05/10/19	15/10/19	Results Analysis and Evaluation	10
01/04/19	18/10/19	Final report writing	197
26/08/19	30/08/19	draft report Submission	4
14/09/19	20/09/19	Prepare for presentation	6
14/09/19	20/09/19	Prepare poster	6
23/09/19	27/09/19	Presentation	4
14/10/19	17/10/19	Final report Submission	3



8.3.1 Graphene Safety Data Sheet.

Graphene Manufacturing Australia

Safety Data Sheet

Version 1.0 Rev date 25.10.2017

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name: Multilayer Graphene nanoplates

Recommended Use: Manufacture of substances

Supplier: Graphene Manufacturing Australia Pty Ltd (GMA)

ABN: 83 614 164 877

Street Address: 90 Staghorn Street, Enoggera, 4051, Queensland, Australia

Telephone Number: +61 434 432 002

Emergency Telephone: +61 0434 432 002

2. HAZARDS IDENTIFICATION

GHS Classification – Not a hazardous substance or mixture

GHS Label elements, including precautionary statements

Pictogram:	none
Signal word:	none
Hazard statement(s):	none
Precautionary statement(s):	none

Not a hazardous substance or mixture

Other hazards – none

3. COMPOSITION/INFORMATION ON INGREDIENTS

Components / CAS Number Proportion Risk Phrases

Substances

Formula	:	C
Molecular weight	:	12.01 g/mol
CAS-No.	:	7782-42-5
EC-No.	:	231-955-3

4. FIRST AID MEASURES

If inhaled

If breathed in, move person into fresh air. If not breathing, give artificial respiration.

In case of skin contact

Wash off with soap and plenty of water.

In case of eye contact

Flush eyes with water as a precaution.

If swallowed

Never give anything by mouth to an unconscious person. Rinse mouth with water.

Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in section 11.

Indication of any immediate medical attention and special treatment needed

No data available

5. FIRE FIGHTING MEASURES

Extinguishing media

Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

Special hazards arising from the substance or mixture

No data available

Advice for fire-fighters

Wear self-contained breathing apparatus for fire fighting if necessary

Further Information

No data available

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

Avoid dust formation. Avoid breathing vapours, mist or gas. For personal protection see section 8.

Environmental precautions

No special environmental precautions required.

Methods and materials for containment and cleaning up

Sweep up and shovel. Keep in suitable, closed containers for disposal.

Reference for other sections

For disposal see section 13

7. HANDLING AND STORAGE

Precautions for safe handling

Provide appropriate exhaust ventilation at places where dust us formed. For precautions see section 2.

Conditions for safe storage, including any incompatibilities

Store in a cool place. Keep container tightly closed in a dry and well-ventilated place.

Specific end use(s)

Apart from the uses mentioned in section 1, no other specific.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

Occupational Exposure Limits

Component	CAS-No.	Value	Control parameter	Basis
Graphite	7782-42-5	TWA	3 mg/m3	Australia. Workplace Exposure Standards for Airborne Contaminants.
	Remarks	See Chapter 14 National Commission documentation available for these values containing no asbestos and <1% crystalline silica, all forms except fibres		
		TWA	3 mg/m3	Australia. Workplace Exposure Standards for Airborne Contaminants
		Containing no asbestos and <1% crystalline silica		

Exposure controls

Appropriate engineering controls

General industrial hygiene practice

Personal protective equipment

Respiratory protection: Protect against inhalation by using type N95 (US) or type P1 (EN 143) dust masks. A respiratory protection program that meets applicable OHSA requirements should be maintained in the workplace.

Eye protection: Protect against contact with eyes by wearing suitable safety eyeglasses or chemical protective goggles or other face protection.

Skin protection: Protect against skin contact by wearing protective gloves. Protect against skin contact by wearing suitable clothing.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state and appearance:	Solid.
Odor:	Odorless.
Taste:	Tasteless.
Molecular Weight:	12.01 g/mole
Color:	Black
pH (1% soln/water):	Not applicable.
Boiling Point:	Not available.
Melting Point:	3650°C (6602°F)
Critical Temperature:	681°C (1257.8°F)
Specific Gravity:	Not available.
Vapor Pressure:	Not applicable.
Vapor Density:	Not available.
Volatility:	Not available.
Odor Threshold:	Not available.
Water/Oil Dist. Coeff.:	Not available.
Ionicity (in Water):	Not available.
Dispersion Properties:	Not available.
Solubility:	Insoluble in cold water.

Other safety information

No data available

10. STABILITY AND REACTIVITY

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Excess heat, incompatible materials.

Incompatibility with various substances: Highly reactive with oxidizing agents.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:

Reacts vigorously with liquid potassium, and potassium peroxide. If graphene contacts liquid potassium, rubidium or caesium at 300 C, intercalation compounds may be formed.

Special Remarks on Corrosivity: Not available. Polymerization: Will not occur.

Chemical stability: Stable under normal conditions of use.

Conditions to avoid: Avoid contact with foodstuffs. Avoid exposure to heat, sources of ignition, and open

flame.

Incompatible materials: Incompatible with oxidising agents.

Hazardous decomposition products:

Hazardous decomposition products formed under fire conditions – Carbon oxides

Other decompositions products – No data available

11. TOXICOLOGICAL INFORMATION

Routes of Entry: Inhalation. Ingestion.

Toxicity to Animals:

LD50 (oral, rat): >2000mg/kg (OECD Test Guideline 423)

LC50 (inhalation, rat): 4h – 2,000mg/m3 (OECD Test Guideline 403)

Serious eye damage/eye irritation

Eyes – Rabbit

Result: No eye irritation (OECD Test Guideline 405)

Skin corrosion/irritation

Skin – Rabbit

Result: No skin irritation (OECD Test Guideline 404)

Respiratory or skin sensitisation

- Mouse; Did not cause sensitisation on laboratory animals (OECD Test 429)

Germ cell mutagenicity

In vitro assay

S. typhimurium

Results: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC

Reproductive toxicity

No data available

Specific target organ toxicity – single exposure

No data available

Specific target organ toxicity – repeated exposure

No data available

Aspiration hazard: No data available

Additional information

To the best of our knowledge, the chemical, physical and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

Toxicity

Toxicity to fish: Semi-static test LC50 – Danio rerio (Zebra fish) - > 100 mg/l – 96 h (OECD Test Guideline 203)

Toxicity to daphnia and other invertebrates: Static test EC50 - Daphnia magne (Water flea) - > 100 mg/l – 48 h (OECD Test Guideline 202)

Toxicity to algae: Static test EC50 – Pseudokirchneriella subcapitata - > 100 mg/l – 72 h (OECD Test Guideline 201)

BOD5 and COD: Not available.

Persistence and degradability: Not available

Mobility in soil: No data available

Other adverse effects

No data available

13. DISPOSAL CONSIDERATIONS

Waste treatment methods

Product

Offer surplus and non-recyclable solutions to a licensed disposal company

Contaminated packaging

Dispose of as unused product

14. TRANSPORT INFORMATION

UN number

ADR/RID: - IMDG: - IATA-DGR: -

UN proper shipping name

ADR/RID:	Not dangerous goods
IMDG:	Not dangerous goods
IATA-DGR:	Not dangerous goods

Transport hazard class

ADR/RID: - IMDG: - IATA-DGR: -

Packaging group

ADR/RID: - IMDG: - IATA-DGR: -

Environmental hazards

ADR/RID: no IMDG Marine pollutant: no IATA-DGR: no

Special precautions for user

No data available

15. REGULATORY INFORMATION

Safety, Health and environmental regulations/legislation specific for the substance or mixture

Standard for the Uniform Scheduling of medicines and poisons

No data available

Carcinogen classification under the WHS REguation 2011, Schedule 10

Not listed

16. OTHER INFORMATION

Safety Data Sheet – Graphene Manufacturing Australia Pty Ltd (GMA); 25/10/2017

This material safety data sheet has been prepared by GMA.

This SDS summarises to our best knowledge at the date of issue, the chemical health and safety hazards of the material and general guidance on how to safely handle the material in the workplace. Since GMA cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, assess and control the risks arising from its use of the material.

If clarification or further information is needed, the user should contact their GMA representative at the contact details on page 1.

GMA responsibility for the material as sold is subject to the terms and conditions of sale, a copy of which is available upon request.

8.3.2 Concrete Data Sheet.

MINI SDS

HAZARDOUS CHEMICAL. NON-DANGEROUS GOODS. According to the WHS Regulations and the ADG Code.

Boral Concrete (Boral Cement)

INGREDIENTS	CAS NO	%	8HR OEL
portland cement	65997-15-1	<30	10 mg/m3
chromium(VI) ion	18540-29-9	<0.1	0.05 mg/m3
Calcium Sulfate Solution	10034-76-1	<10	10 mg/m3
limestone	1317-65-3	<5	10 mg/m3

GHS

DG

UN No: **Not Applicable**
Hazchem Code: **Not Applicable**
DG Class: **Not Applicable**
Subsidiary Risk: **Not Applicable**
Packing Group: **Not Applicable**
Poisons Schedule: **Not Applicable**

HEALTH HAZARD INFORMATION

Signal word:	**Danger**	
Hazard statement(s):	**H315**	Causes skin irritation.
	H318	Causes serious eye damage.
	H317	May cause an allergic skin reaction.
	H341	Suspected of causing genetic defects.
	H350	May cause cancer.
	H335	May cause respiratory irritation.

PRECAUTIONS FOR USE

Appropriate engineering controls:	Local Exhaust Ventilation recommended.
Glasses:	Consider chemical goggles.
Respirator:	Particulate. (AS/NZS 1716 & 1715, EN 143:2000 & 149:001, ANSI Z88 or national equivalent)
Storage and Transportation:	Store in cool, dry, protected area. Dispose of this material and its container at hazardous or special waste collection point. Keep out of reach of children.
Fire/Explosion Hazard:	Toxic smoke/fumes in a fire. Dispose of this material and its container at hazardous or special waste collection point.
	Toxic to aquatic organisms.Use appropriate

PROPERTIES

Solid. Alkaline.Does not burn.

EMERGENCY

FIRST AID

Swallowed:	Give water (if conscious). Seek medical advice.
Eye:	Wash with running water (15 mins). Medical attention.
Skin:	Remove contaminated clothing. Wash with soap & water.
Inhaled:	Fresh air. Rest, keep warm. If breath shallow, give oxygen. Medical attention.
Advice To Doctor:	Deferoxamine is preferred chelator. Supportive care. Irrigate eyes with saline. Supportive care. Ipecac emesis. Chrome ulcers respond to CaNa2EDTA. Treat symptoms NOT history. Emesis. Deferoxamine may be antidotal.
Fire Fighting:	Keep surrounding area cool. Water spray/fog.
Spills and Disposal:	Avoid dust. Sweep shovel to safe place. Dispose of this material and its container at hazardous or special waste collection point. This material and its container must be disposed of in a safe way. To clean the floor and all objects contaminated by this material, use water and detergent.

SAFE STORAGE WITH OTHER CLASSIFIED CHEMICALS

+	x	+	o	+	+	+

x — *Must not be stored together*
0 — *May be stored together with specific preventions*
+ — *May be stored together*

8.4 Appendix D

8.4.1 Picture of samples after rapture load

8.4.1.1 Flexural


Bottom
0.05 Full Graphene


0.03 40mm Graphene

8.4.1.2 Compressive


0.1Gra
0.05
Gra


0.1
Gra
0.05
Gra

8.4.1.3 Indirect Tensile


Control
Control
0.05
40 mm


0.05
40 mm


0.05 Gra
0.1Gra
Control.


0.1 Gra
0.05 Gra