University of Southern Queensland

Faculty of Health, Engineering and Sciences

Optimal Mix Design for Epoxy Resin Polymer Concrete

A Dissertation Submitted By

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ENG4112 Research Project Part 2

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Abstract

Concrete is one of the most widely used materials in the construction industry, being well known for its high compressive strength. However it is known to be weak in tensile strength, flexural strength and often requires reinforcement. There is a solution to this problem, polymer concrete. Polymer concrete has many improved qualities compared to that of normal concrete which have been thoroughly investigated in previous research. However, one gap in the research that does exist is the use of coarse aggregate in the polymer concrete mix. This project will concentrate on finding the ideal mix design for epoxy resin polymer concrete with the addition of coarse aggregate.

To achieve this objective there were three minor objectives created, which will be used as the three studies for the project. The first of these was to find the ideal resin to filler ratio that provides the best distribution of the coarse aggregate for the least amount of air voids. Then, using the resin to filler ratio from Study One, Study Two varies the amount of aggregate to investigate the strength properties of the specimens. Finally, using the strongest mix from Study Two, an Empirical Prediction Formula will be formed relating the tensile strength to compressive strength.

Study One shows that the ideal resin to filler ratio is 60% resin to 40% filler. Using this ratio in Study Two, it was found that the mix design with no aggregate in the mix was the strongest for all strength tests. It was determined that this is due to the addition of aggregate to the mix causing air voids, therefore reducing the strength. However, for all three tests, it was observed that the maximum strength varied little between the four mix designs confirming that the addition of aggregate and how much is added does not have a large impact on the strength of the sample. It can also be seen that the Young's Modulus for all the compressive samples is quite low, therefore showing excellent elasticity of the mix designs which was a desired property.

As the amount of aggregate added to the mix does not have a notable effect on the strength or elasticity of polymer concrete, course aggregate can be added to the mix to reduce the cost of the epoxy resin concrete allowing the product to be more cost competitive in the general construction sector.

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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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1 Introduction

1.1 Background

The most common type of concrete is comprised of three main ingredients; water, aggregate and cement, which are combined with different ratios depending on the characteristics required (Australia, Cement Concrete and Aggregates, 2015). Normal concrete is known to be weak in tensile strength, brittle and easily erodible by chemicals and high velocity water flow. This is becoming an ever growing problem in today's society with the need for the least amount of maintenance and longer lasting structures. In early 1950 research into a different form of concrete was discovered, polymer concrete (Aravinthan, 2013). Polymer concrete has increased strength characteristics, as well as improved resistance to environmental factors and a faster curing time.

With such improved properties, polymer concrete became a fast growing area of research. Moving forward to 2015 and polymer concrete is widely used across the world. The only set back is that it is quite expensive to produce, and therefore is only used for smaller projects such as drainage pipes and coatings over other structural components. Polymer concrete is also commonly used for projects that require a quick curing time, such as bridge repair. There are many different types of polymer concrete, depending on the characteristics required. This report focuses on the development of epoxy based polymer concrete, which is a relatively new area of research and there is still much to learn about the properties and how the specimens will react under different conditions.

The main area that hasn't been researched is the use of aggregates in polymer concrete. Aggregates are being added to the polymer concrete to find if this will have an effect on the strength characteristics of the specimen. There are so many different factors effecting polymer concrete already that the use of course aggregate has not been investigated, therefore there is no standard to follow. This is why it is important to carry out further research into what effect aggregates have on epoxy resin polymer concrete.

Scope and Limitations

The scope of this project is to investigate how coarse aggregate performs in epoxy resin polymer concrete. This will consist of three separate studies and will utilize a range of different materials and procedures. The materials required will be epoxy resin, hardener, fly ash, fire retardant filler, hollow microsphere filler and coarse aggregate. There will be three strength tests completed for study two, these are compression, flexural and tensile.

The limitations for this project include the restricted amount of epoxy resin, the types of filler that are available and the type of aggregate. Also, the investigation of the properties is limited to physical observation, flexure, compression and indirect tensile strength.

1.2 Study Objectives

1. Determination of the optimum filler to resin ratio for a consistent polymer concrete mix.
2. Investigate the physical properties of the polymer concrete mix with different filler to resin ratio
3. Determine the physical and mechanical properties of the epoxy resin polymer concrete with different amounts of coarse aggregates.

4. Develop an empirical prediction formulae to describe the properties of epoxy based polymer concrete.
5. Further research into how aggregates effect normal concrete compared to polymer concrete.
6. Writing and submission of project dissertation.

2 Literature Review

2.1 Introduction

Polymer concrete, although it has been around for many years, is still quite a new area of research. Therefore finding as many resources on the different types of polymer concrete and the different uses is very important to ensure the best choice of ingredients. This section critically reviews the studies conducted related to polymer concrete.

2.2 Polymer Concrete

Research into the use of polymer concrete has been seen as early as the 1950's, it was first conducted by the ACI committee (Erp, 2014). Polymer concrete can be defined as “concrete in which the binder is an organic polymer; a construction and structural material that is a solidified mixture of macro molecular substance with a mineral aggregate” (System i Technologie, 2009). Polymer concrete is known for its high strength characteristics, resistance to chemicals and water absorption, is much more durable in comparison to normal concrete and has excellent adhesion properties. As can be seen in Figure 2.1, polymer concrete performs much better in all of the tested characteristics compared to traditional concrete. This makes polymer concrete excellent for use for drainage systems, due to the lack of moisture absorption, and for the use of tanks to hold corrosive materials, due to its chemical abrasion resistance. Although, these characteristics are only applicable for a certain mix of polymer concrete, they can be varied greatly depending on the materials used in the mix.

Comparison of properties of polymer concrete and traditional B30 class concrete

	Polymer concrete	B30 concrete
compressive strength Rc [MPa]	80 - 110	30
bending tensile strength Rg [MPa]	22 - 35	2 - 4
splitting tensile strength Rr [MPa]	8 - 12	1,5 - 2
abrasion resistance [cm]	0,1 - 0,2	0,6
moisture absorption [mm]	0	4 - 8

Figure 2.1 - Comparison of Mechanical Properties of Polymer Concrete to Normal B30 Concrete

Polymer concrete is comprised of three major parts; aggregate, synthetic resin and other additives. The most commonly used resins for polymer concrete include unsaturated polymer resin, methyl methacrylate, epoxy resins, furan resins and polyurethane resins (System i Technologie, 2009). Aggregate used in the mix is either coarse aggregate, greater than 5mm, or fine aggregate, less than 5 mm (America's Concrete Manufacturer, 2015).

The use of polymer concrete is all attributed to its rapid curing, it reaches more than 70% of its final strength within one day of curing which can be seen in Figure 2.2 (Choi, 2012). This particular study was done using polyester resin, however it can be assumed that epoxy resin will cure in the same fashion. This is much quicker than that of normal concrete, which only reaches 20% within the first day of curing (Singh, 2013).

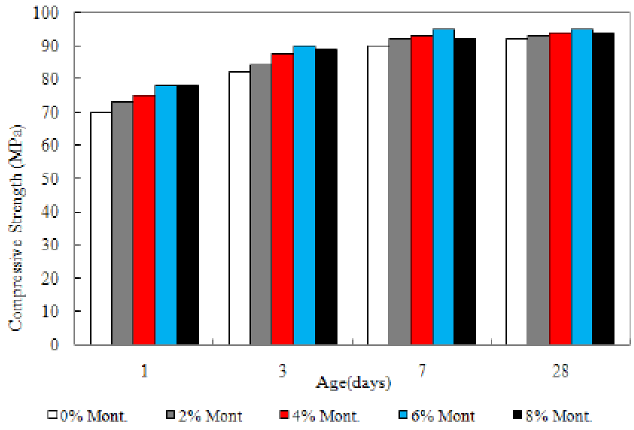

Figure 2.2 - The Compressive Strength of Polymer Concrete over Time

Full strength can be reached even quicker if the polymer concrete goes through high temperature curing, however this is only done if completely necessary. This is due to the curing temperature not having a large effect on the overall strength of the materials, as can be seen in Figure 2.3 (Choi, 2012). For this project the specimens will be cured at room temperature for 7 days, in that time the samples will have reached full strength. This is also a cost effective method and would replicate field casting.

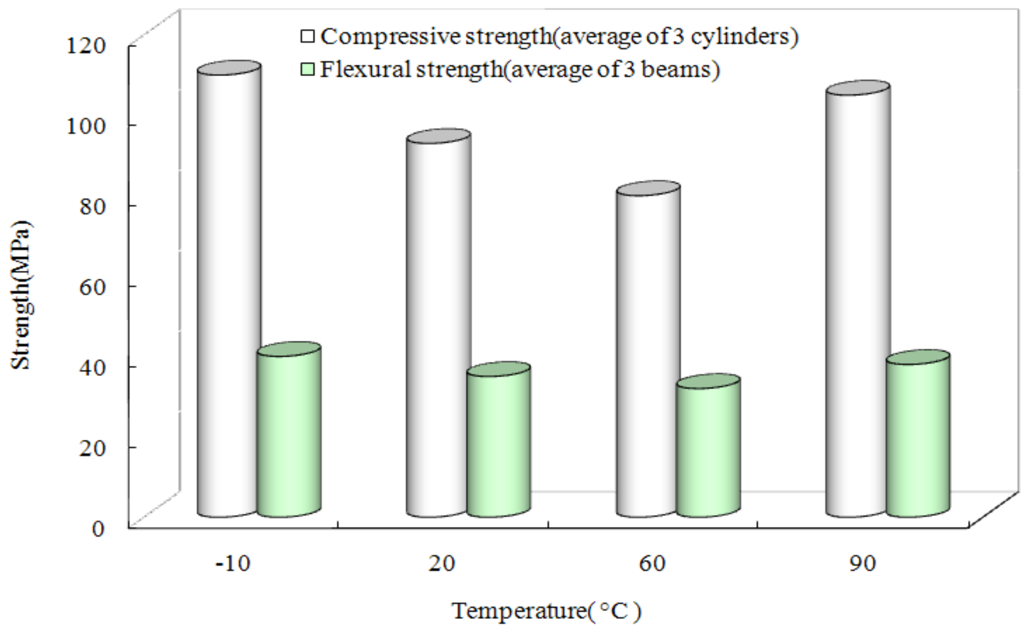

Figure 2.3 - The effect curing temperature has on the strength of concrete

Although Polymer Concrete clearly has better properties than that of normal concrete, the uptake of its use in the construction industry is slow. This is mainly due to the lack of knowledge about the product and the cost. As it's so expensive the mix will need to be optimized before use in major construction projects. The price of polymer concrete is the main issue most constructors have with using the material, and therefore the minimum amount of resin and the cheapest curing option should be taken. Therefore this study will investigate the optimal resin to filler ratio, with the main focus of the project being on the use of Epoxy Resin in the mix.

2.3 Properties of Polymer Concrete

2.3.1 Compressive Strength

It has been shown through comparisons of different studies done that the mix design of the specimen will have a large effect on the strength characteristics of the sample. As can be seen in Figure 2.4 the composition of materials can affect the compressive strength up to 40MPa, which is a significant difference (M. Golestaneh, 2010). As discussed earlier, the compressive strength of polymer concrete is expected to be upwards of 80MPa. However, as also shown in Figure 2.5 that is not always the case. This shows that the resin mix with no radiation applied during curing only reaches a compressive strength of 40Mpa.

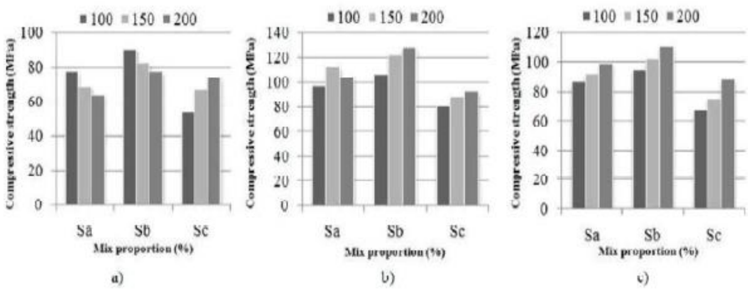

Figure 2.4 - Compressive Strength Comparison of different mix designs

It can be seen in Figure 2.5 that, depending on the type of polymer chosen the compressive strength can vary significantly. It is shown that the resin polymer concrete produces the highest compressive strength. However, this study was done to see the effect of gamma radiation (G. Martínez-Barrera 1*, 2011), therefore the value of compressive strength is greatly improved. It can be seen that with no radiation the compressive strength of the resin polymer concrete is 40MPa, which is low compared to that of others.

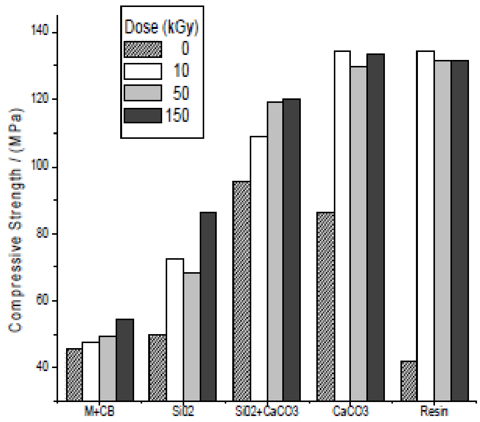

Figure 2.5 - Compressive Strengths of different mix designs subjected to radiation

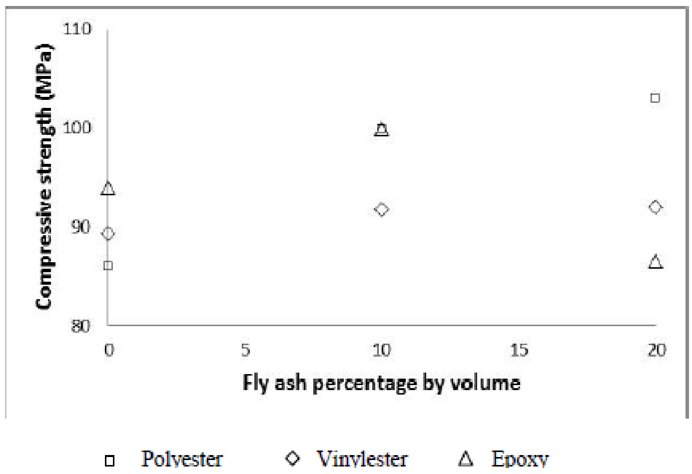

Figure 2.6 - Comparison of Compressive Strength of Polymer Concrete with Different Resins

As can be seen in Figure 2.6, three different types of polymers are being compared with increasing fly ash percentage. It can be seen that, with no fly ash added at all, the epoxy resin is the strongest of the mixes. However, it can be seen that with the addition of 20% fly ash the epoxy resin is the weakest. This shows that the three resins have a similar compressive strength, only varied by 20MPa at maximum (Aravinthan, 2013).

2.3.2 Tensile Strength

As stated earlier, the tensile strength is also expected to be much higher than that of normal concrete. Once again the choice of materials will affect the strength characteristics significantly. It can be seen in Figure 2.7 that the tensile strength doesn't only increase with the amount of resin percentage but also with the amount of filler added to the mix, this is due to the fillers being used to add stability to the mix (M. Golestaneh, 2010). This shows that a higher resin percentage will be desirable, while having enough filler for stability.

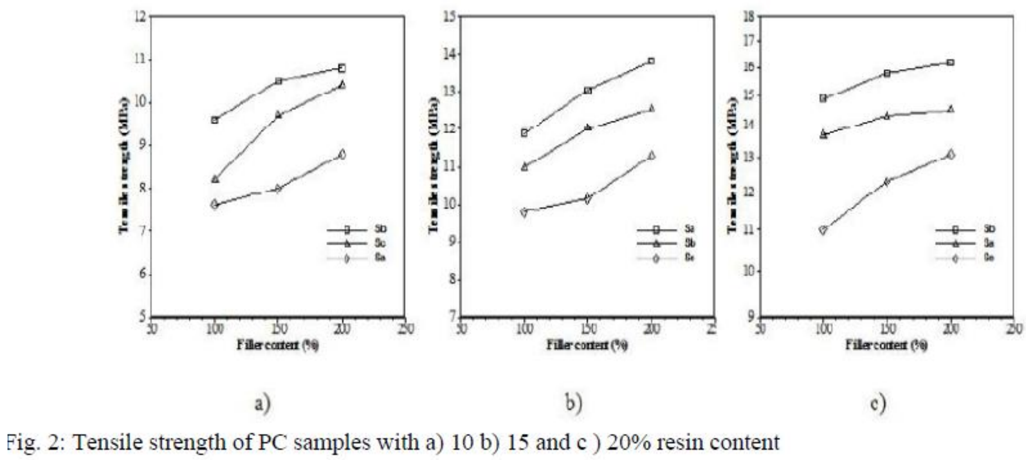

Figure 2.7 - Tensile Strength of Samples with varying resin and filler content

It can also be seen in Figure 2.8 the difference between three types of resin for the tensile strength. This shows that there is not a significant difference between the three resin types, however epoxy resin is the strongest for all three resin contents analysed. It can also be seen, from this particular study, that the maximum tensile strength is achieved with no fly ash. This is due to air voids in the mix with the addition of fillers (Aravinthan, 2013). These studies show that the expected

Tensile Strength of the specimens should range between 10MPa and 20MPa depending on mix design.

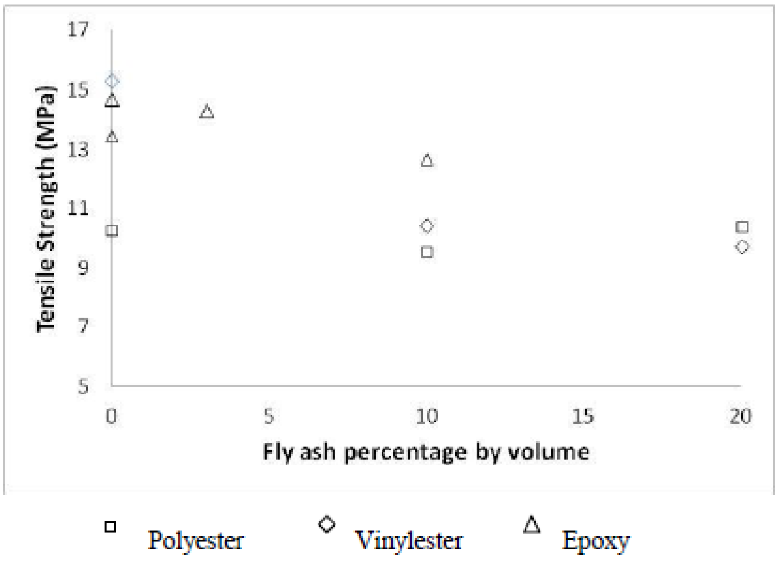

Figure 2.8 - Tensile Strength Comparison of Polymer Concrete with Different Resins

2.3.3 Flexural Strength

The final test that will be completed for this project will be flexural strength testing. As stated earlier this is also expected to be much greater than that of normal concrete. Epoxy resin is also expected to provide a higher flexural strength than other resins in polymer concrete, which is demonstrated in Figure 2.9. With low concentrations of fly ash the epoxy resin polymer concrete has a much greater flexural strength than the Vinylester polymer concrete. It can also be seen that the expected flexural strength of the sample will be greater than 20MPa. This is also supported in Table 2.1 (M. Golestaneh, 2010), showing the flexural strength can range from 8MPa to 22MPa depending on the mix design.

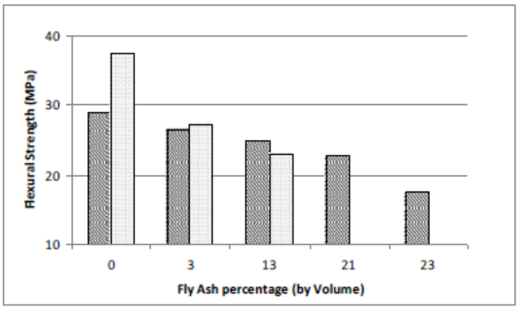

Figure 9. Flexural strength

Figure 2.9 - Flexural Strength comparison of vinylester (Dark Grey) and epoxy (White) resins with increasing fly ash percentage.

Table 2.1 - Flexural Strength Comparisons for different mix designs

PC type	Flexural Strength (MPa)	PC type	Flexural Strength (MPa)	PC type	Flexural Strength (Mpa)
EP$_{10}$-Sa$_{100}$	8.50	EP$_{15}$-Sa$_{100}$	13.12	EP$_{20}$-Sa$_{100}$	14.3
EP$_{10}$-Sa$_{150}$	9.25	EP$_{15}$-Sa$_{150}$	16.30	EP$_{20}$-Sa$_{150}$	15.5
EP$_{10}$-Sa$_{200}$	11.70	EP$_{15}$-Sa$_{200}$	14.30	EP$_{20}$-Sa$_{200}$	18.5
EP$_{10}$-Sb$_{100}$	14.00	EP$_{15}$-Sb$_{100}$	18.17	EP$_{20}$-Sb$_{100}$	16.5
EP$_{10}$-Sb$_{150}$	10.50	EP$_{15}$-Sb$_{150}$	20.10	EP$_{20}$-Sb$_{150}$	17.5
EP$_{10}$-Sb$_{200}$	11.20	EP$_{15}$-Sb$_{200}$	22.50	EP$_{20}$-Sb$_{200}$	11.3
EP$_{10}$-Sc$_{100}$	11.30	EP$_{15}$-Sc$_{100}$	12.30	EP$_{20}$-Sc$_{100}$	13.3
EP$_{10}$-Sc$_{150}$	8.71	EP$_{15}$-Sc$_{150}$	11.40	EP$_{20}$-Sc$_{150}$	14.5
EP$_{10}$-Sc$_{200}$	6.48	EP$_{15}$-Sc$_{200}$	10.13	EP$_{20}$-Sc$_{200}$	16.1

2.3.4 Elasticity

Young’s Modulus is a material property that describes a specimen’s stiffness. This is done using the gradient of the stress strain curve. The Young’s Modulus is important when dealing with concrete as it defines the flexibility of the material. This is directly related to the compressive strength of the specimen, using the stress strain curves to calculate the Young’s Modulus. The Young’s Modulus of normal concrete is between 20GPa and 40GPa (ERMCO, 2006).

The lower the Young’s Modulus is the more flexible the material is, hence glass has a Young’s Modulus of 100GPa with rubbers having 0.1GPa. There haven’t been any studies conducted looking specifically at the Young's Modulus of epoxy resin polymer concrete, however in other studies the Young's Modulus is tested along with other properties. One study shows that values can range anywhere between 3GPa to 20GPa (G. Martínez-Barrera 1*, 2011), other studies support this conclusion.

It can be seen from these studies that the Young's Modulus is heavily affected by the materials chosen for the mix design. In Figure 2.10, it can be seen that depending on what type of polymer is used and the dosage of kGy given has a large impact on the Young's Modulus. The Resin mix has the lowest elastic modulus.

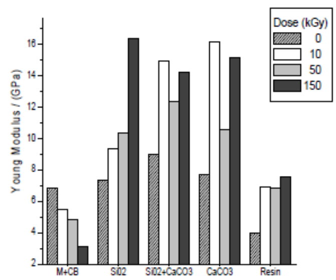

Figure 10. Young's Modulus of polymer concrete elaborated with different mineral

Figure 2.10 – Variation of Young's Modulus for different types of polymers with radiation.

The main reason epoxy resin was chosen for this study is due to its elastic properties, although epoxy is more expensive than the other resins and doesn't provide the highest compressive strength, it does have superior elastic characteristics. This can be seen in Figure 2.11, where for the lower concentrations of fly ash it is shown that Epoxy Resin Polymer Concrete has the lower modulus of elasticity (Kazmierczac, 2004). This shows that it will be more flexible than the Vinylester and therefore more suitable for this study.

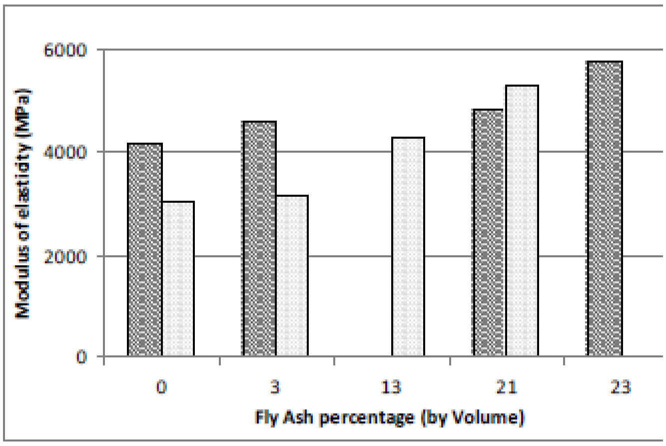

Figure 2.11 – Comparison of Young's Modulus for vinylester (Dark) and epoxy (Light) resins with increasing fly ash.

2.4 Epoxy Resin

The choice of resin is dependent on the availability, cost, desired properties and the application. The most commonly used types of resin are epoxy resin and polyester resin, this is due to the high strength and resistance to chemical deterioration (Aravinthan, 2013). For this study, epoxy resin was chosen, this is due to its durability and mechanical properties. Epoxy Resin is desirable due to its superior chemical resistance, excellent structural ability, and minimum shrinkage during curing, excellent fatigue resistance and it has low water absorption (Aravinthan, 2013).

There are many different types of epoxy resins available, for this study the use of EPON828 was selected, it will be referred to as Resin-A. This is a clear resin, that when hardened with appropriate curing agents, has very good mechanical, adhesive, dielectric and chemical resistance properties, these properties are shown in Table 2.2 (Hexion, 2009). For the resin to cure, it is required to mix it with a hardener. For this study the hardener chosen is D-230 PEA. This was chosen due to its fantastic properties as an epoxy curing agent, also due to the fact that it is completely miscible with a range of different materials.

Property	Test Method	Unit	Value
Epoxide Equivalent Weight [1]	ASTM D1652	g/eq	185-192
Viscosity @ 25°C [2]	ASTM D445	P	110-150
Color	ASTM D1544	Gardner	1 max.
Pounds per Gallon @ 25°C (77°F)		lbs/gal	9.7
Density @ 25°C (77°F)		g/ml	1.16
Physical form			Clear liquid
Vapor pressure @ 77°C (170°F)		mm Hg	0.03
Refractive index @ 25°C (77°F)			1.573
Specific heat		BTU/lb/°F	0.5

[1] ASTM D1652 (Epoxy Content of Epoxy Resins – Perchloric Acid Method)

[2] ASTM D445 (Kinematic Viscosity - Determinatin of the Viscosity of Liauids by Ubbelohde Viscometer).

Table 2.2 - Epoxy Resin Characteristics

2.5 Filler Selection

The selection of the fillers came down to previous research done in this area. The different types of fillers used in epoxy resin have been well documented, the ones specifically chosen for this study are Fire Retardant Filler, Hollow Microsphere and Fly Ash.

2.5.1 Fire Retardant Filler

Polymers are known to readily burn in oxygen, therefore it is important to ensure that this does not occur during testing. Fire retardant filler is used to reduce the flammability of the mix, which is important in a situation where a large amount of heat is being applied to the mix. The filler influences the resistance to ignition and the smoke and toxic gas emission of products. Fire Retardant Filler can also effect heat capacity, thermal conductivity and emissivity. This is very important when dealing with epoxy resins and hardener as there is thermal heat involved in the curing process, therefore using Fire Retardant Filler to combat this is necessary.

Fire Retardant Filler works by the simple dilution of the combustible fuel source, slowing the diffusion rate of oxygen and flammable pyrolysis and changing the melt rheology of the polymer which will slow the drip. This is most important when the proposed design is being used in enclosed, difficult to escape places. Fire Retardant Filler is not completely inert to fire, however it will offer flame retardant and smoke supressing qualities, which will give enough time to react to the situation before any damage occurs (Hornsby, 2007).

2.5.2 Hollow Microsphere Filler

In general, Hollow Microsphere (HM) is used to increase volume while reducing density of the mix. The HM do not absorb the resin into their internal cavities, rather they displace the resin. There are many advantages to using HM fillers, such as low density, improved dimensional stability, greater thermal insulation and many others. There are a number of different types of HM fillers to choose from, depending on the desired properties of the mix will depend on the type of HM fillers chosen. For this study the Glass Hollow Microsphere Filler (GHMF) was chosen, this is due to the properties required of the mix and the availability. GHMF can also be manufactured in many different ways, often the chemical composition is varied along with the wall thickness and the particle size and shape.

Density and crush strength is also important properties of HM fillers, these characteristics are mainly influenced by the potential to reduce weight and wall thickness. These characteristics vary dramatically across product lines, therefore checking with the manufacturer is important. Potential to reduce weight mainly effects the density, which in turn effects the crush strength as the density and crush strength are directly related. Wall thickness is an important characteristic, the thicker the wall the stronger the material will be. Although the wall thickness is also dependent on the chemical composition of the material and the manufacturing process used. The particle size of the HM effects the relative density and the survival rate of the filler (Gruit, 2002).

Depending on the mechanical characteristics, the type of finish and the desired cost of the mix will depend on the manufacturer and type of HM filler chosen for the mix.

2.5.3 Fly Ash

Fly Ash is the by-product of burning coal in power plants. It is a fine grey powder mostly consisting of glassy particles (Australia, Fly Ash, 2010) and is commonly used as a supplementary material in concrete as it significantly improves the concrete's mechanical properties. The use of fly ash as a filler in normal concrete is well documented, hence why it is also quite popular for use in polymer concrete. It was found that, in comparison to other fillers, that fly ash has the best performance in almost all strength testing (Aravinthan, 2013). Fly Ash is known to improve the workability of the mix which leads to an excellent surface finish. It also improves the chemical resistance, this is due to its small particle size and roundness of the particles which reduces the mean pore size which blocks penetration of the material.

As can be seen in Figure 2.12, fly ash improves the compressive strength of the mix (K. S. Rebeiz, et al., 2004), also note that fly ash performs much better than Silica Fume in compression which is shown in Figure 2.13. Also, shown in Figure 2.14, the tensile strength is improved with the addition of fly ash then it can be seen in Figure 2.15, that once again fly ash performs better than silica flume. These are very important characteristics for creating the ideal mix for polymer concrete, as strength is one of the most important properties.

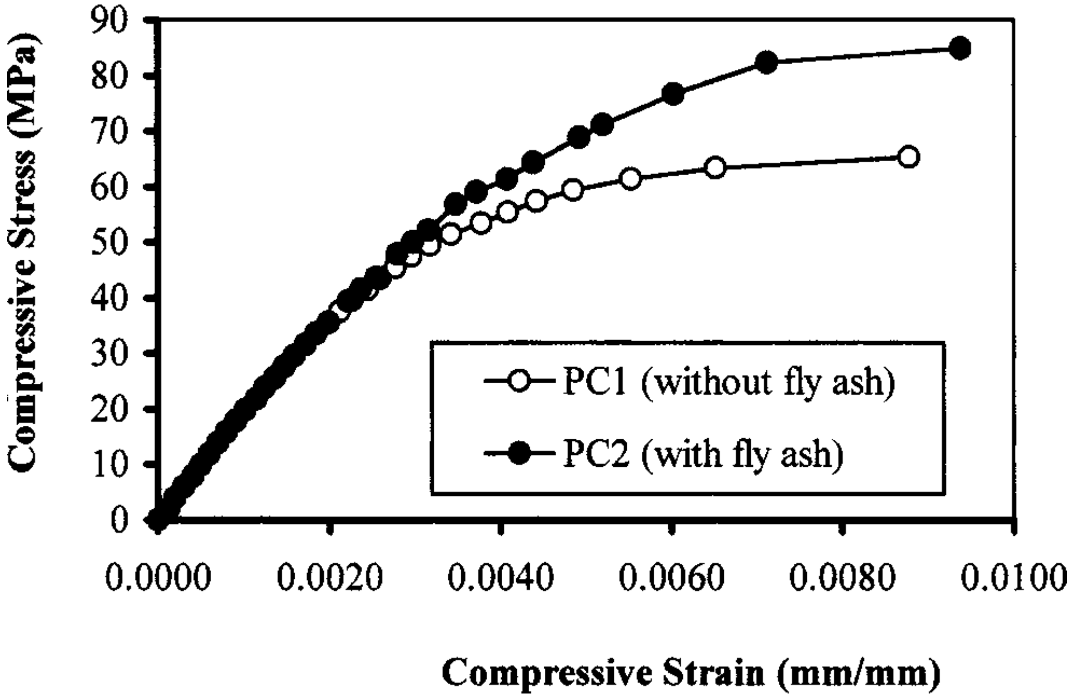

Figure 2.12 - The comparison of polymer concrete with and without fly ash

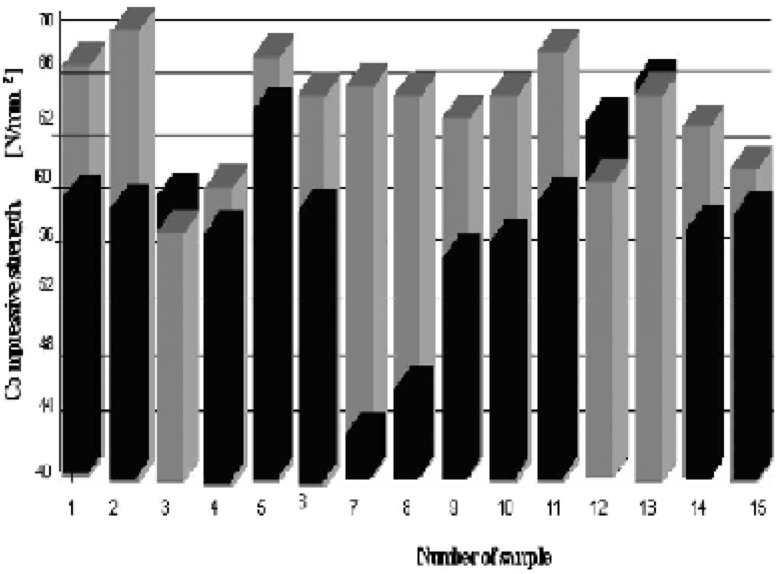

Figure 2.13 - Compressive strength of epoxy resin polymer concrete with fly ash (grey) and silica fume (black).

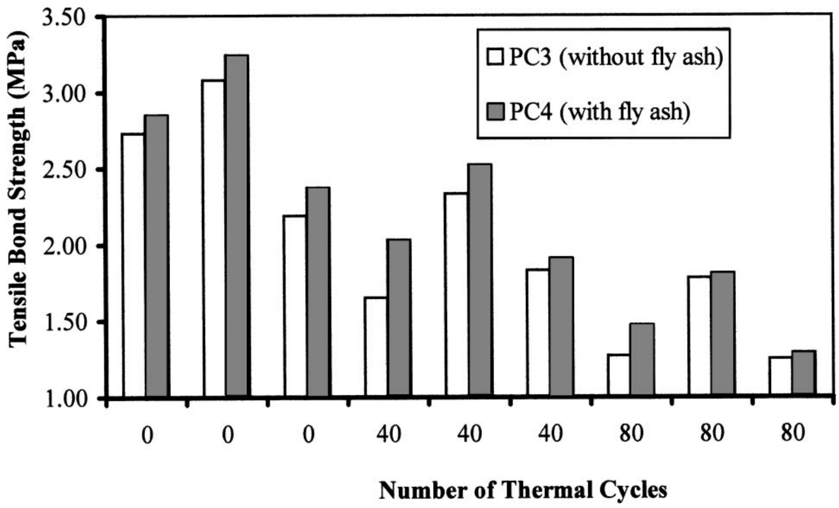

Figure 2.14 - Comparison of Polymer Concrete Tensile Strength with and without fly ash.

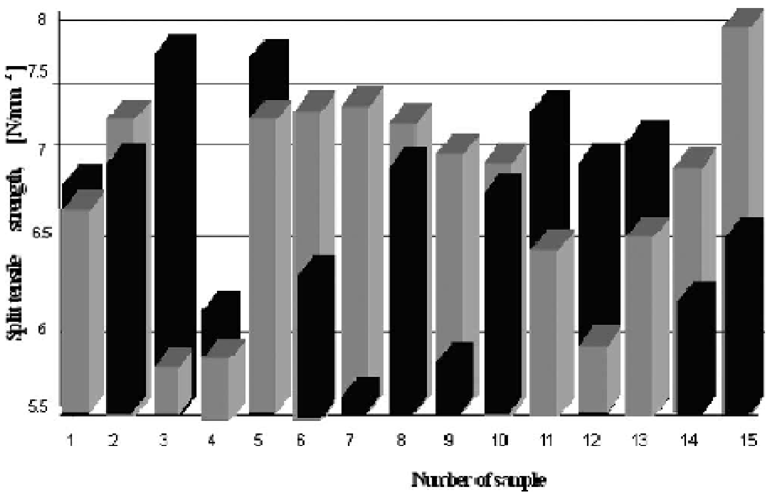

Figure 2.15 - Tensile Strength of Epoxy Resin Polymer Concrete with fly ash (grey) and silica fume (black)

Another major part of this study is examining Young's Modulus, this is defined as the tendency of an object to deform along a certain axis when opposing forces are applied along that axis. It has been shown in studies that as the amount of fly ash in a mix increases, as does the elastic modulus, reaching a peak of 29GPa (Kazmierczac, 2004). Therefore it would be wise to keep the amount of fly ash to a minimum so as to keep as much elasticity in the specimen as possible.

2.6 Aggregate

As there is no standard for the use of aggregate in polymer concrete, this is where the gap in research lies and what this project will be investigating. The effect of coarse aggregate on normal Portland Concrete will be investigated to indicate how the addition of coarse aggregate will behave in polymer concrete. It was decided to use 10mm coarse basalt aggregate for the study as there were already experiments conducted on the use of fine aggregates, such as sand, in polymer concrete mixes already.

Aggregates are used in concrete mixes to improve strength characteristics, it will generally make up 70%-80% of the weight of a concrete mix (Penn State University, n.d.). Aggregates are required to be clean, hard and strong, this is to ensure that they are free of materials that could cause damage to the concrete. There are two main categories of coarse aggregate, gravels and crushed stone. For this study it was decided to use crushed stone, this can be obtained from quarry rocks which are then crushed, washed and screened for cleanliness and gradation. There are many different types of aggregates with many different properties, the main properties of coarse aggregate are grading, durability, abrasion and skid resistance, unit weights and voids, particle shape and surface texture, absorption of surface moisture. All of these factors are important when selecting the type of aggregate used in the ideal mix.

Particle shape and surface texture have a sizeable impact on the workability of the mix, the most desirable is smooth, rounded and compact aggregate as it mixes through well. This also has an effect on the void content of the mix, it is highly desirable to keep the void content as low as possible, therefore smooth aggregates are desired as the more angular the aggregate the greater the amount of voids in the mix (Voelker, 1990). The surface texture of the mix has a direct effect on the workability also, if the aggregate is smooth the workability of the mix will be improved. However, if the surface texture is rough, the aggregate has a stronger bond with the mix therefore giving a higher strength. Grading and size distribution of the aggregate is the most important as this determines the amount of paste required, which is the main factor affecting the cost of the mix. The more expected voids in the mix the more paste is required, therefore it is of important to get a mixture of different sizes of aggregate to assist in filling the voids (Penn State University, n.d.).

Moisture content varies depending on what type of aggregate is being used, it can be anywhere from <1% for crushed gravels to 40% for sands (M. H. Mohammed1, 2012). There are four states of moisture content; oven dry, air dry, saturated surface dry and wet. Oven dry and Saturated Surface Dry can be used for specific moisture state, therefore can be used as reference states for moisture content. To find the moisture content of an aggregate it is necessary to find the absorption capacity, effective absorption and surface moisture. The density of aggregate is required to find the weight volume relationship of the mix, this is done so the weight of the aggregate can be calculated from the volume of aggregate required (Penn State University, n.d.).

Specific gravity of the aggregate can be separated into two categories, absolute and bulk. Absolute specific gravity refers to the solid material of the aggregate, this is excluding the pores. Bulk specific gravity refers to the whole of the aggregate, including the pores. The mixture proportioning is calculated using the bulk specific gravity of the aggregate, this is also used to satisfy the minimum density requirements. Finally the bulk unit weight, which refers to the graded aggregate will occupy in the concrete mix, is also used for mixture proportioning (Penn State University, n.d.).

2.7 Testing Procedures

2.7.1 Compression Testing

Compression testing is done to find the compressive strength of a sample. This is one of the most common tests when analysing a concrete sample as concrete is used for its excellent compressive strength. The compression test is done by applying crushing load until failure, the standard procedure for compressive testing can be found in appendix 3. It can be seen that this is a fairly simple test with the results being easily evaluated. However there are many standards to ensure consistency when testing.

The first standard refers to the size of the specimens, there can either be cylindrical or square samples. Cylinder samples are much more common than the square alternative in Australia and America (Building Research Institute, 2015). Depending on the type of project and testing will determine the size of the cylinder, however it is important to ensure that the specimen maintains a slenderness ratio of 2. The most common sizes of samples for concrete testing are either 100mm diameter by 200mm height or 150mm diameter by 300mm height (WebTechTix, 2014). The compressive strength of these two sizes have been compared as can be seen in Figure 2.16 (J.R. del Viso, n.d.). Figure 2.16 shows that the D3, which is the smaller sample, has a very similar strength to that of the larger sample. This shows that the size of the sample does not have a great effect on the compressive strength values. Seeing as this project will be using epoxy resin polymer concrete a small specimen size will be ideal to minimise costs. Therefore, while keeping a slenderness ratio of two, a specimen size of 50mm diameter by 100mm height was chosen.

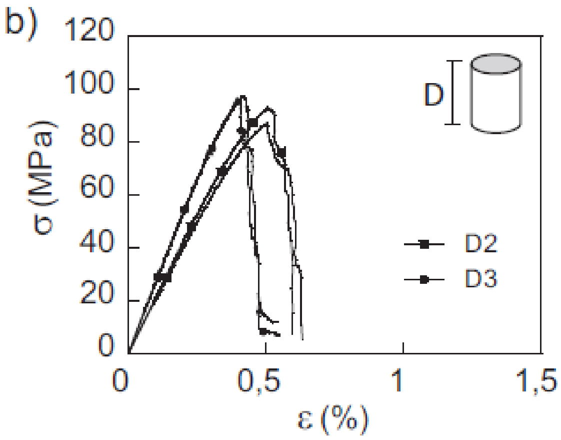

Figure 2.16 - Comparison of Compressive Strength of Different Sized Cylindrical Specimens

It is quite common for the specimen to be compacted using a tamping stick, this is done to remove air voids in the mix (NRMCA, 2014). However, for this particular study, this will not be done. Being due to the first study specifically looking for air voids in the mix and therefore it would affect the results. Another common aspect of compressive strength tests is using three samples for each mix design. This is done to ensure that the results are consistent, also if one of the samples produces a strength significantly different to that of the other samples it can be discarded.

Therefore, through research, for the compression testing there will be three cylindrical samples of 50mm diameter by 100mm height made for the compression testing. The testing will follow the procedure stated in appendix 3 with the results being recorded by the testing machine.

2.7.2 Tensile Testing

The Tensile Strength Test is conducted to determine the splitting failure of the specimen. This test is not as common as the compressive strength test, however it is still important as concrete structures are highly vulnerable to tensile cracking (Building Research Institute, 2015). The tensile strength will be found using the split cylinder test. For convenience it was determined that the same size cylinders would be used for the tensile test as for the compression testing.

The issue with this type of splitting tensile testing is that it can cause slight compressive loads where the load is directly applied on the sample. It is assumed that 1/6 of the sample depth is subjected to compressive stress, however the remaining 5/6 of the depth is affected by tensile stress (Building Research Institute, 2015). However, this will not greatly affect the results as the action of the compressive strength is quite small. Once again this is for normal concrete, not polymer concrete so the effect could be different.

2.7.3 Flexural Testing

Flexural testing is done to find the specimens resistance to bending. There are two main types of flexural testing; third point loading and centre loading as is demonstrated in Figure 2.17. For this particular study centre point loading was chosen, this is due to the size of the beam being tested.

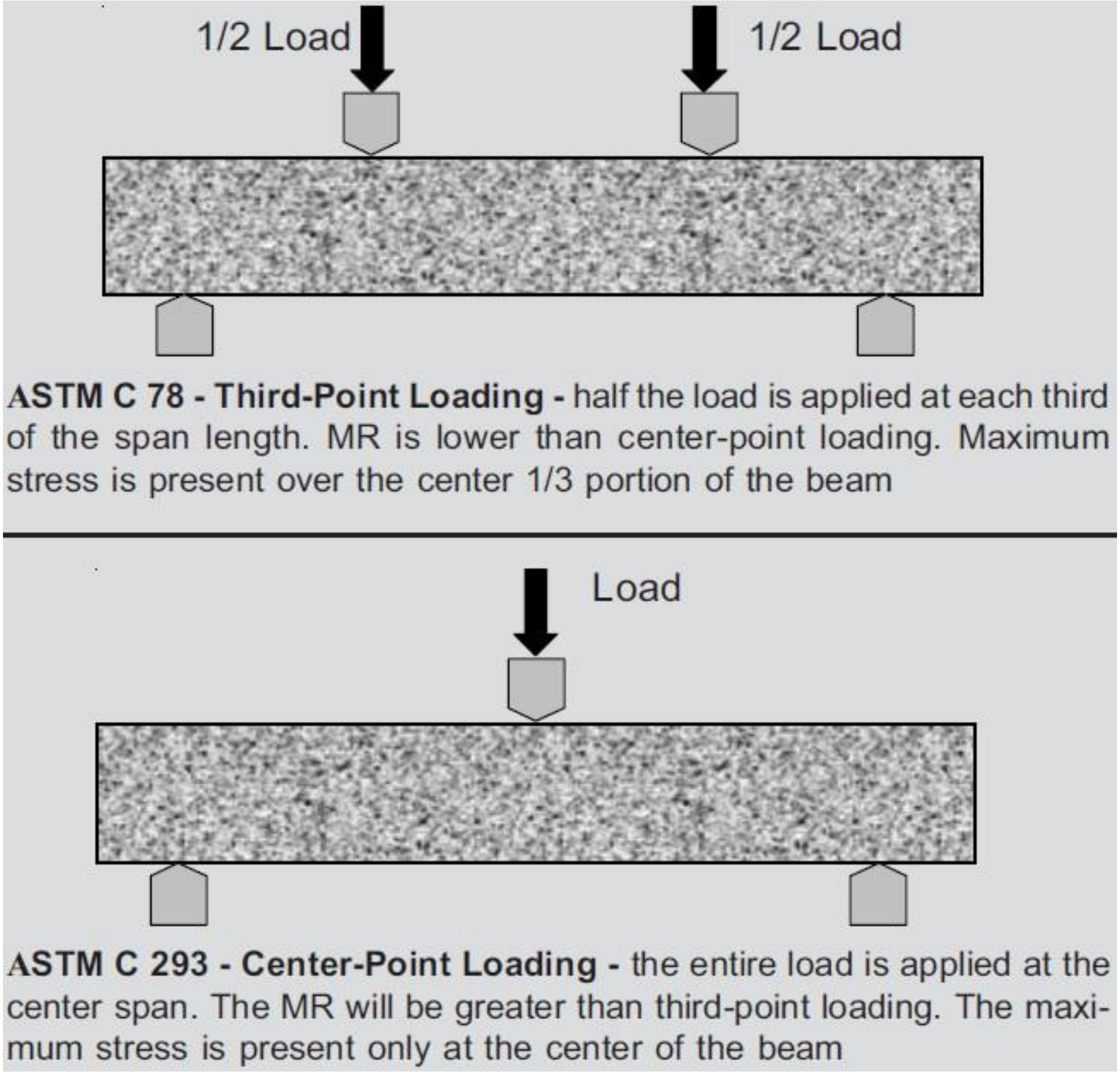

Figure 2.17 - Two different methods of flexural testing set up

This is typically done using a beam, depending on the type of concrete specimen is being tested will affect the beam size. Seeing as epoxy resin polymer concrete is expensive to produce, it was decided to use small beams. The only constraint that the span needs to be a minimum of three times the depth of the specimen. Therefore it was decided to use beams 25mm depth by 20mm width by 200mm length.

2.8 Summary

The use of aggregates in polymer concrete is currently ungraded, therefore there is no standard as to what level of aggregate should be used. This is where the project hopes to fill this gap in research and find how coarse aggregate performs in polymer concrete. Finally there is the use of fillers, there are many different types of fillers that could be used in polymer concrete, and this study will focus on the use of Fire Retardant Filler, Hollow Microsphere Filler and Fly Ash. Depending on the combination of these three major parts, the mixture could be used for completely different projects and could have completely different characteristics. This study will focus on the use of Epoxy Resin with the fillers Fire Retardant Filler, Hollow Microsphere Filler and Fly Ash along with coarse aggregate.

3 Methodology

3.1 Introduction

This project will consist of three major studies:

- Study 1 – Finding the optimum filler to resin ratio
- Study 2 – Finding the optimum amount of aggregate
- Study 3 – Finding the Empirical Equation

Study 1 and 2 will be done in quick succession to each other, due to the quick curing and testing nature of the studies. On completion of testing in Study 1 and 2, Study 3 will be completed after the results from Study 1 and 2 have been analysed.

Study 1 will consist of a visual inspection only. The optimum filler to resin ratio will be chosen by observing how well the aggregate is distributed throughout the specimens and how many air voids are present within the specimens. Study 2 will then proceed with the creation of moulds to form standard sized specimens to complete compression, flexural and tensile testing of the mix designs. The results from these tests will then be used to find the optimum amount of aggregate for the ideal mix design found in Study 1. Once the data from the testing has been analysed the results will be used to form an Empirical Prediction Formula for the mix.

3.2 Materials

Study 1 Requirements - The materials used for both studies are epoxy resin, hardener resin, hollow microsphere filler (HMF), fire retardant filler and fly ash (FA). These were chosen after research was conducted into probable uses for the material and it was concluded that these materials would create the ideal mix for the desired mechanical properties of the final product.

Study 2 Requirements - Other materials required included the specimen moulds, which are polyethylene pipes of 50mm internal diameter cut into 100mm lengths. There will also be flexural moulds constructed which will be 20mm width by 25mm depth by 200mmm length. This was done so that the specimens conformed to the standards required for compression, flexural and tensile testing. It was also required to obtain two different containers for the mixing of the materials as the fillers had to be mixed separately to the resins. All of these materials were available from either the CEEFC or on request from the University.

3.2.1 Resins

The two types of resin used for this project are Epoxy Resin, which will be referred to as Resin A and is shown in Figure 3.1. A Hardener Resin is required to "Cure" Resin A, this will be referred to as Resin B and is shown in Figure 3.2. It can be seen by comparing the two resins that Resin A is a much lighter colour than Resin B, also that Resin B has a much lower viscosity than Resin A.

Figure 3.1 - The epoxy resin used for the project (Resin A)

Figure 3.2 - Hardener resin used in the project (Resin B)

3.2.2 Filler

The three fillers chosen to be used in the mix are hollow microsphere filler (HM), fire retardant filler (FRF) and Fly Ash (FA). These are all shown in Figure 3.3, it can be seen the HM is on the right with the FRF in the centre and FA on the left. The HM filler is used to reduce the amount of air voids in the mix, this is important as voids will result in the loss of strength in the sample. FRF is used in the mix as resin is known to be flammable and it will reduce the risk of this occurring. Finally Fly Ash is used for its strength properties that were investigated in the literature review.

Figure 3.3 - Fillers used in the mix; (right to left) Hollow Microsphere Filler, Fire Retardant Filler and Fly Ash

3.2.3 Aggregate

The type of course aggregate used in this study is 10mm Crushed Basalt Aggregate. This was chosen due to the proven strength properties in cement based concrete and it is expected the strength properties will not change in the polymer concrete. The aggregate will be sourced from the CEEFC centre, ensuring it is washed and oven dried before use. The aggregate will be washed using a bucket and water, then dried using the aggregate drying oven provided in the CEEFC centre.

3.3 Specimen Details

3.3.1 Mixing Ratio for Study 1

There were 7 different mix designs to be made, the list below shows the weight of each ingredient required for each mix.

1. 100% resin to 0% filler

100/0		
Ingredients	**Weight, gms**	**With 5% Extra**
Resin A	113.9	**119.5**
Resin B	36.4	**38.3**
FRF	0.0	**0.0**
HM	0.0	**0.0**
FA	0.0	**0.0**
CA	172.4	**181.1**

2. 90% resin to 10% filler

90/10		
Ingredients	**Weight, gms**	**With5% Extra**
Resin A	102.5	**107.6**
Resin B	32.8	**34.4**
FRF	19.2	**20.2**
HM	2.1	**2.2**
FA	5.8	**6.1**
CA	172.4	**181.1**

3. 80% resin to 20% filler

80/20		
Ingredients	**Weight, gms**	**With5% Extra**
Resin A	91.1	**95.6**
Resin B	29.1	**30.6**
FRF	38.5	**40.4**
HM	4.3	**4.5**
FA	11.5	**12.1**
CA	172.4	**181.1**

4. 70% resin to 30% filler

70/30		
Ingredients	**Weight, gms**	**With5% Extra**
Resin A	79.7	**83.7**
Resin B	25.5	**26.8**
FRF	57.7	**60.6**
HM	6.4	**6.7**
FA	17.3	**18.2**
CA	172.4	**181.1**

5. 60% resin to 40% filler

60/40		
Ingredients	**Weight, gms**	**With 5% Extra**
Resin A	68.3	**71.7**
Resin B	21.9	**23.0**
FRF	76.9	**80.8**
HM	8.5	**9.0**
FA	23.1	**24.2**
CA	172.4	**181.1**

6. 50% resin to 50% filler

50/50		
Ingredients	**Weight, gms**	**With 5% Extra**
Resin A	56.9	**59.8**
Resin B	18.2	**19.1**
FRF	96.2	**101.0**
HM	10.7	**11.2**
FA	28.9	**30.3**
CA	172.4	**181.1**

7. 40% resin to 60% filler

40/60		
Ingredients	**Weight, gms**	**With 5% Extra**
Resin A	45.5	**47.8**
Resin B	14.6	**15.3**
FRF	115.4	**121.2**
HM	12.8	**13.5**
FA	34.6	**36.4**
CA	172.4	**181.1**

Table 3.1 shows the total amount of each material required for study 1.

Ingredients	Weight
Resin A	585.8
Resin B	187.5
FRF	424.2
HM	47.1
FA	127.3
CA	1267.5

Table 3.1 - Ingredient weights required for study 1.

3.3.2 Mixing Ratio for Study 2

The purpose of Study 2 is to determine the ideal amount of aggregate to achieve the best possible strength characteristics. This will be done by using the ideal resin to filler ratio found in study one, 60/40, with the amount of coarse aggregate added to each mix will being varied. There will be three types of tests performed on the mix designs for this study; compression, tensile and flexural strength tests. The results will be analysed to find the ideal mix of aggregate and to help standardise the use of coarse aggregate in polymer concrete.

There will be 4 different mix designs used for this study, these will be defined in the ratio of resin to filler to aggregate and are:

- 1 : 1.2 : 0
- 1 : 1.2 : 1
- 1 : 1.2 : 2
- 1 : 1.2 : 3

Table 3.2 shows the amount of each type of material required to complete the testing in Study 2. The table also shows the amounts of individual components required for each of the mix designs. All quantities have been increased by 10% to ensure the mix is adequate to fill the moulds completely.

Calculation for 6 Cylinders and 3 Beams (with 10% extra)					
Resin:Filler (by volume) =	60:40	60:40	60:40	60:40	
Resin-Filler:Coarse aggregate (by volume)	100:0	81.69:18.31	69.05:30.95	59.80:40.20	
Resin: Filler: Coarse aggregate (by volume)	1:0.67:0.00	1:0.67:0.37	1:0.67:0.75	1:0.67:1.12	
Resin: Filler: Coarse aggregate (by weight)	1:1.20:0.00	1:1.20:1.00	1:1.20:2.00	1:1.20:3.00	**Total**
Weight of Part A	900.5	735.6	621.8	538.5	**2796.4**
Weight of Part B	288.2	235.4	199.0	172.3	**894.9**
Weight of FRF	1014.3	828.6	700.4	606.6	**3149.9**
Weight of HM	112.7	92.1	77.8	67.4	**350.0**
Weight of FA	304.3	248.6	210.1	182.0	**945.0**
Weight of coarse aggregate	0.0	971.2	1641.6	2132.2	**4745.0**

Table 3.2 - Study 2 material calculations and weights of materials required.

3.4 Specimen Preparation

3.4.1 Weight and Density Measurements for the Ingredients

The first step of preparation will be to calculate the amount of each material required for the mix design. This will be completed by finding the densities of each material and using this to calculate the weight of each material required. The resins will only work together if they are mixed at 100g Resin A: 32g Resin B, therefore when designing the different mixes for Study One this ratio needs to stay constant. This is done by finding the percent by volume required of resin and dividing it between the two resins using this ratio. The fillers also require a ratio, this was decided upon after conducting research and aiming for certain mechanical characteristics. This ratio is 90g of FRF: 10g HM: 27g FA.

For the fillers and resins the densities were given, however for the aggregate the density needed to be found. This was completed using the multipycnometer shown in Figure 3.4.

Figure 3.4 - Multipycnometer used to measure the density of the aggregate.

Which gave the constants for the following equation, which was given:

$V_s = V_c - V_r \, [P_1 \; P_2 - 1]$

Where P_1 and P_2 are readings from the machine, V_c and V_r are constants, and V_s is the volume of the sample.

$P_1 = 16.955$

$P_2 = 7.360$

$V_c = 149.3968$

$V_r = 88.4522$

Using these values, that gives the volume of the specimen to be 34.087 mm^2. This can then be used to calculate the density of the aggregate.

Density= $W_g \; V_s$

Where:

Wg = 99.84 g

Vs=34.087 mm^2

Therefore, giving a density of 2.982g.cm^3. Using this value the weight of aggregate required for the mix can be found. This is done by calculating the percentage by volume of aggregate required, which for Study 1 is 30% for all 7 specimens, and for Study 2 can be averaged as 30% for all 24 specimens, which equates to 2862 cm^3 . Multiplying the density of the aggregate by the volume required will give the weight of aggregate required, which is calculated to be 8.3kg. This will be rounded up to 9kg to provide extra aggregate if required. The aggregate was then thoroughly washed, to ensure no unwanted materials were added into the mix, and placed in the oven to dry. Once the density of each material has been obtained, the weight required can be calculated using the percent by volume of the materials used in each study, which are listed in Appendix 1.

3.4.2 Preparation Study 1

The first step to preparing the specimens will be to prepare the moulds. The mould consisted of a PVE pipe with duct tape used to cover the base, this will be used as it is the most cost effective way to create a smooth base for the mould. The moulds are also designed so that they can be removed easily. It was very important that there are no creases in the duct tape on the ends of the moulds as this will cause a non-uniform surface which could affect the testing results. Once again, this is not important for Study one, however all the moulds will be prepared together and therefore will be taken into consideration. When dealing with epoxy resins it is very important to wear protective equipment, therefore before any preparation could begin it will be necessary to obtain the protective equipment. The protective equipment required consisted of a full body protective suit, safety glasses, breathing masks and rubber gloves. It was also a requirement that steel cap safety boots be worn within all sections of the laboratory P9 shown in Figure 3.5.

Figure 3.5 - Protective material used during the creation process.

The materials can all be obtained from the CEEFC laboratory, all of the materials will be obtained and brought to the resin room to begin mixing. Once this is done the mixing of the first sample can begin. Firstly all of the fillers will be combined in a separate container. It is incredibly important to carefully weigh out each material as this project is quite sensitive, as is shown in Figure 3.6. It was important to ensure the mix was consistent as any irregularities in the mix could have an effect on the results achieved in final testing.

Figure 3.6 - Materials were carefully weighed using the scales in P9.

Following mixing of the fillers the resins were mixed in a separate container. It is very important to mix the resins thoroughly or inconsistencies in the curing process may occur which will weaken the specimens. There were some problems with the Resin A material, as can be seen in Figure 3.1 it is quite lumpy and inconsistent. To resolve the issue the epoxy Resin A will need to be strained before being mixed with the hardener to ensure a high quality product free of lumps in the mix. The two resins can then be mixed thoroughly and the fillers were then added to the mixture as shown in Figure 3.7 and then mixed further until there was a smooth and consistent mix. Finally the aggregate is added and the mix was poured into the moulds and they were left to cure in the resin room as seen in Figure 3.8. This process was completed for all of the mix designs except for the 100% resin to 0% filler, as this specimen did not require any filler, just the aggregate.

Figure 3.7 - Adding the fillers to the resins and combining well.

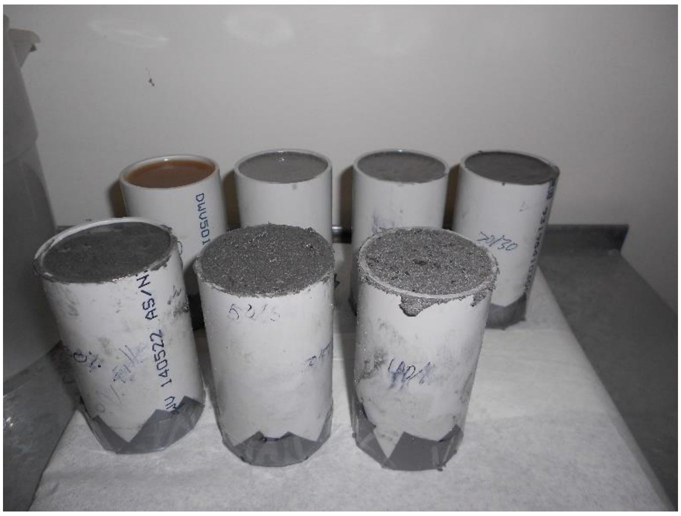

Figure 3.8 - Study 1 specimens straight after pouring

The specimens will be left over night to cure. This is due to polymer concrete gaining 70% of its strength within the first 24 hours, it is acceptable practice to remove the specimens from the moulds the very next day. This will be done by cutting along the edge of the PVE and prying the mould off the specimen. This process will be completed for all 7 specimens and then the specimens will be returned to the resin room to finish curing for the remainder of the 7 days.

3.4.3 Preparation Study 2

For Study 2 there will be 6 cylinders and 3 beams required to be made for each mix design. Three of the cylinders will be used for compression testing, the other three will be used for tensile testing with the three beams being used for flexural testing. The 6 cylinders will be the same PVE moulds used in Study One, however the beams will be cast in plywood moulds. All of the moulds were made with the correct dimensions and ratios to be appropriate for use in standard testing procedures. The quantities of materials required for Study 2 have already been discussed previously, being shown in Table 3.2

As can be seen in Table 3.2, there is more of each material required than what was used in Study One. For Study One there was only 5% allowance for extra material calculated and it was found to be insufficient as some of the moulds weren't completely filled. Therefore it has been decided to increase the extra material allowance to 10% to ensure all moulds will be compliant with the standards for testing.

The specimens will be left to cure for one day before having the moulds removed. The process will be done in the same way as Study 1 for the cylinder moulds. The flexural testing beams will have their moulds removed by carefully taking apart the moulds and removing the specimen. Once all specimens have had their moulds removed, the specimens will be labelled and left for the remainder of the 7 days to complete the curing process prior to testing.

On completion of the curing process it will be necessary to ensure the top and bottom of the specimens to be used for compression testing are smooth and even so the results of the testing are not distorted by imperfections in the loaded surface. Sand paper cannot be used to achieve this as the coarse aggregate is far too coarse to be sanded back. Therefore it will be required to cut the specimens. This will be a difficult task as if too much height is removed from the cylinder it will no longer meet the standardised size used for the testing. It was decided that the wet saw will once again be used, as it will give a smooth finish and it has already been established that it will cut through the polymer concrete mix. Once this is completed the specimens will be prepared for testing.

3.5 Test Set up and Procedure

3.5.1 Study 1

For Study One the testing procedure is quite simple as only a visual inspection is required. The specimens will cut along the longitudinal axis using the wet saw in Z1.101 at the university which is shown in Figure 3.9. It will be required to book the use of the machine and to be supervised while using the machine. The specimens will need to be moved from the CEEFC lab to Z1.101 where the specimens will be and cut in half along the longitudinal axis. There will be no testing required, only a visual inspection to determine the specimen with the best course aggregate distribution throughout. This will completed by lining up the 7 specimens next to each other and checking for distribution of aggregate and amount of visible air voids.

Figure 3.9 - Wet Saw in Z1.101 used to cut the samples.

3.5.2 Compressive Test

The compression testing is to be conducted first. Before the test is conducted it is important that the dimensions and weight of the specimens are measured so that the data can be analysed correctly. To ensure that there are no unwanted point loads applied to the specimens, all of the testing will be conducted with small rubber mats on the top and bottom of the samples. The samples will be carefully placed in the machine and it will be lowered so it will almost touch the top of the sample as can be seen in Figure 3.10. It is important to wear protective equipment; glasses, gloves and safety boots, while operating this machine. Once the specimen is in position the machine can be started, the load will be continuously added to the specimen until crushing failure. The data recorded will be the load on the specimen and the deflection for the whole test.

Figure 3.10 - How a Cylindrical Sample is positioned in a Compressive Testing Machine (Federal Highway Administration Research and Technology, 2006)

The data recorded will be the loading in Newtons and the deflection in millimetres. To analyse this data these outputs will need to be converted into compressive strength and strain. The compressive strength will be calculated by dividing the given load by the cross sectional area of the specimen, this is why it is essential to record the exact size of the specimen. The strain will be calculated using the below equation:

$$Strain = \frac{Abs(Height - Deflection) - Height}{Height}$$

Once the compressive strength and strain of the specimens are found, the stress strain curves can be formulated. The stress strain curves will be used to find the Young's Modulus of the mix design. This is done by finding the gradient of the elastic deformation section of the stress strain curve. This can be seen in Figure 3.11 (Tinius Olsen, n.d.), referring to the proportional limit and modulus line, the gradient of this section of the stress strain curve will give the elastic modulus.

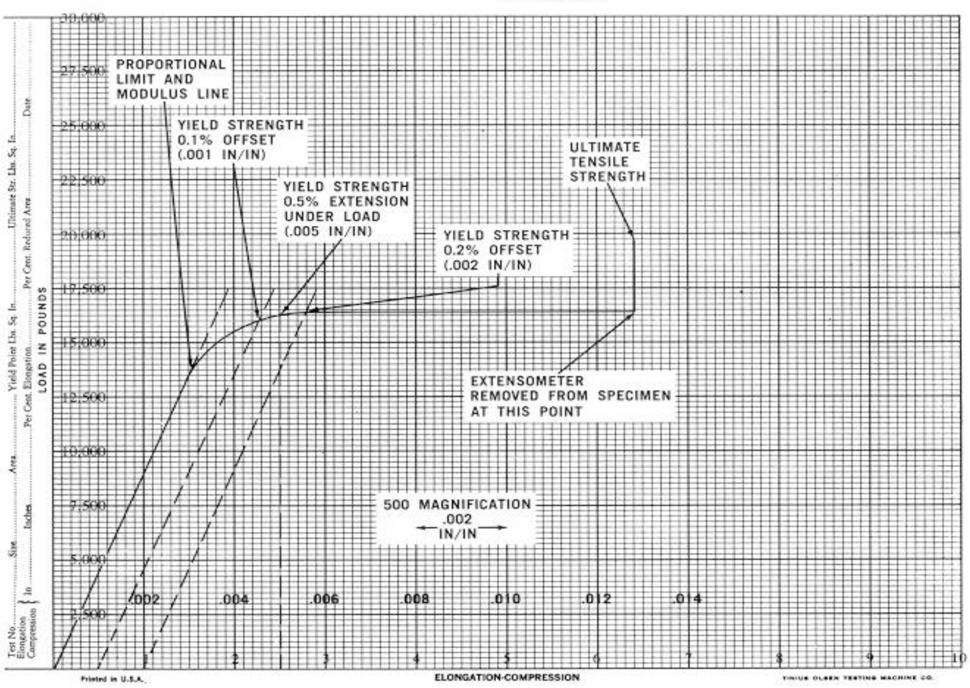

Figure 3.11 - A typical stress strain curve

3.5.3 Splitting Tensile Test

This test will be finding the ultimate load for splitting tensile strength. This will be done using the same sized cylindrical samples as the compression testing, however they will have the force applied to the longitudinal edge of the specimen rather than the top of the specimen as can be seen in Figure 3.12. As can be seen there will be no restraints on the sides of the specimens, this is to allow for movement in that direction of the sample. It is important to wear protective equipment; glasses, gloves and safety boots, while operating this machine.

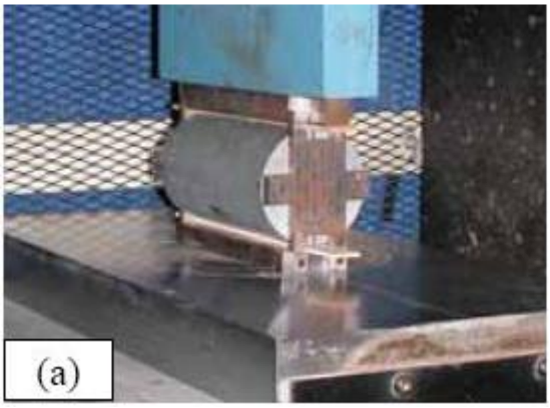

Figure 3.12 - Splitting Tensile Cylindrical Specimen Position in the Machine

The Splitting Tensile Test will be very similar to that of the compression test, the data collected will be the load and deflection of the sample. This data will be used to calculate the Tensile Strength and Strain so a stress strain diagram can be formed to find the Young's Modulus of the sample. The tensile strength is once again found by dividing the load by the cross sectional area, which now refers to the long edge of the specimen and therefore will be much greater than the compressive strength specimens cross sectional area. The Strain will be calculated in the same way as compressive strength, however the diameter will be used as the height due to the orientation of the specimen. Finally the Young's Modulus will be found in the same way as compressive strength.

3.5.4 Flexural Test

As stated in the literature review, the flexural strength of the specimens will be conducted using the centre point loading. This will be done using the 25mm depth by 20mm width by 200mm length beams constructed earlier. The machine that will be used for the test is shown in Figure 3.13, it can be seen that there will be a point load applied to the centre of the beam with the supports slightly in from the end of the beam.

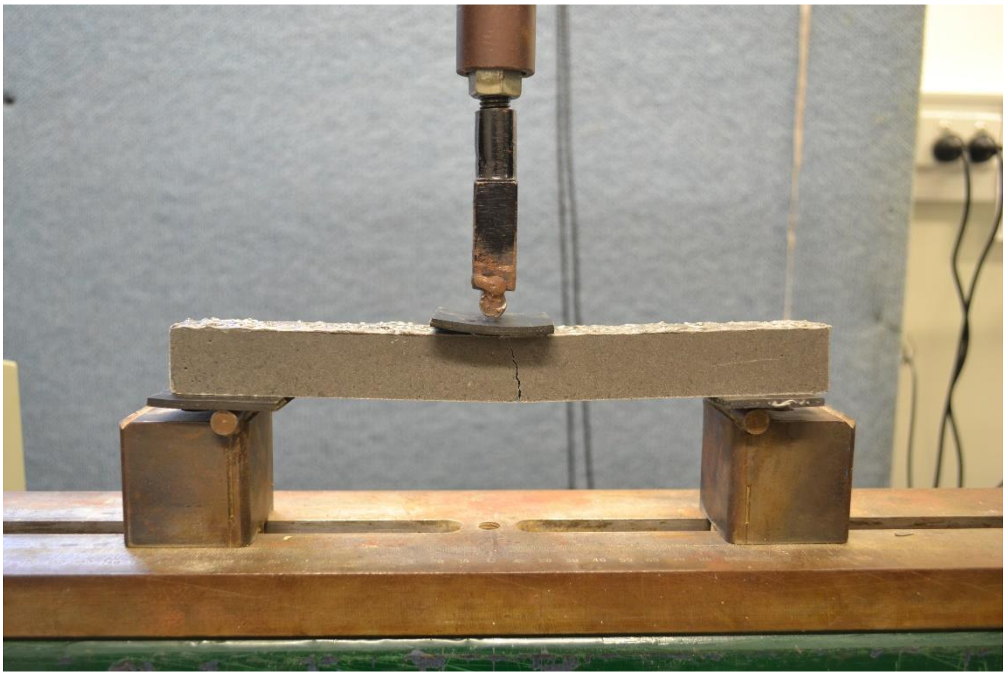

Figure 3.13 - The Flexural Testing Set Up

For this test it will be required to document the exact size of the beam, as this will be an input into the machine. This machine will do all the calculations required to find the flexural strength and the strain percentage, therefore it will not be required to calculate the strength manually. For this particular test only the maximum strength of each specimen will be found, the stress strain curve and elastic modulus will not be analysed. It is important to wear protective equipment; glasses, gloves and safety boots, while operating this machine.

3.6 Study 3 - Empirical Prediction Formula

The definition of Empirical is based on or guided by experience, experiment or observation, as distinct from theory (Heinemann, 1999). Therefore an Empirical Prediction Formula will be finding the relationship between the tensile strength and the compressive strength from the analysis of study two results. This will be done by plotting the results from the two tests against each other and find the relationship. A power trend line will then be applied to the data to find the line of best fit and the equation that matches this line. This is the simplest of the three studies and will require the least amount of time to complete. However, it will depend on the analysis of the data from study 2.

3.7 Summary

Above is stated all of the materials required and the methodologies for each study. As each study is dependent on the results from the previous one these will need to be completed in succession. All of the materials will be sourced from the CEEFC, with the only program required being Microsoft Excel.

4 Results

4.1 Study 1

On inspection of the Resins prior to mixing, it was seen that there were inconsistencies in Resin A in the forms of lumps and thickened sections. This could lead to the specimen having unwanted voids and therefore weakness where the resin hasn't mixed thoroughly with the other materials. To resolve this problem Resin A was strained to remove the lumps and thickened sections prior to adding it to the mix.

It could easily be seen on the day of mixing and moulding the specimens that certain mix designs were not going to be the ideal selection. These were the 100/0, 90/10 and 80/20 mix designs. This was due to the low viscosity of the mix designs therefore all of the aggregate settled at the base of the mould. This meant that these would not provide the best distributed aggregate. It was also observed that the 40/60 mix had a very low workability, therefore the mix would contain a significant amount of air voids. Therefore this mix would not be desirable, although the aggregate seemed to be well distributed throughout the mix, the air voids would make it quite weak. Another problem with this study was that mix 50/50 was compacted using a tamping stick, this was done by suggestion however not what was required. This could affect the air voids in the 50/50 mix significantly. For the initial observations on the day of moulding it was suspected that the 70/30 or 60/40 mix would be ideal.

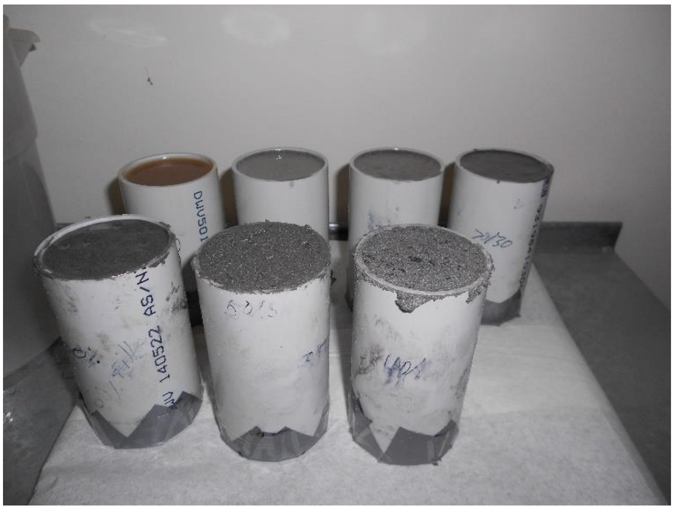

Figure 4.1 - Study 1 specimens on the day of pouring.

Once the specimens were cut open it could be seen that the initial observations were mainly correct, however it can be seen in Figure 4.2. Figure 4.2 for the 70/30 specimen that the aggregate also settled to the base of the mould. This left the best mix designs being 60/40 and 50/50. As discussed earlier the 50/50 mix was compacted therefore there would be fewer air voids in the mix. However, it could be seen that 50/50 had slightly more air voids than the 60/40 mix, even with the compaction, therefore the 60/40 mix was decided upon for the ideal mix.

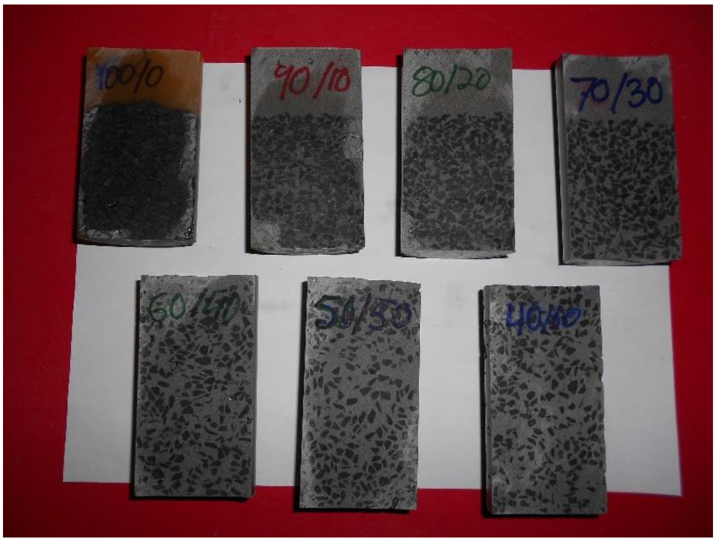

Figure 4.2 - Study 1 results, showing the aggregate distribution within the different mixes

4.2 Study 2

Study two consisted of three testing methods; compression, tensile and flexural. These were done to find the strength characteristics of the mix designs.

4.2.1 Compressive Strength

For compression testing there are many different ways the data can be analysed. For this project it was chosen to look at the maximum strength and stress strain curves. This is done to show how the specimen will fail during the whole loading process, also so the Young's Modulus can be calculated.

There were three samples for each mix design, this was done to ensure consistent and accurate results. It was important to the results that all three samples were quite similar, if not the test will need to be redone to get a better reading. As seen in Table 4.1, there are some irregularities between the samples, all of these were within tolerance and therefore did not affect the analysis. The average of the three samples was used to find the maximum compressive strength for each mix.

	Compressive Strength (Mpa)
0_1	41.784
0_2	41.577
0_3	43.529
1_1	36.520
1_2	38.198
1_3	27.527
2_1	38.876
2_2	36.237
2_3	32.901
3_1	41.221
3_2	39.834
3_3	38.577

Table 4.1 - Study two compressive strength of all samples.

It can be seen in Table 4.1 that the maximum compressive strength occurs in the mix with no aggregate. This is not the result that was expected, as in normal concrete the compressive strength increases with the amount of coarse aggregate. This could be caused by a number of different things. This could include the specimen failing in splitting instead of crushing or possibly the addition of aggregate caused voids in the mix, this is further discussed in the discussion chapter. From mix 1:1.2:1 onwards it follows the expected pattern of increasing compressive strength with the increase of aggregate. However it can be seen that the compressive strength does not vary significantly, with a maximum difference of 8MPa.

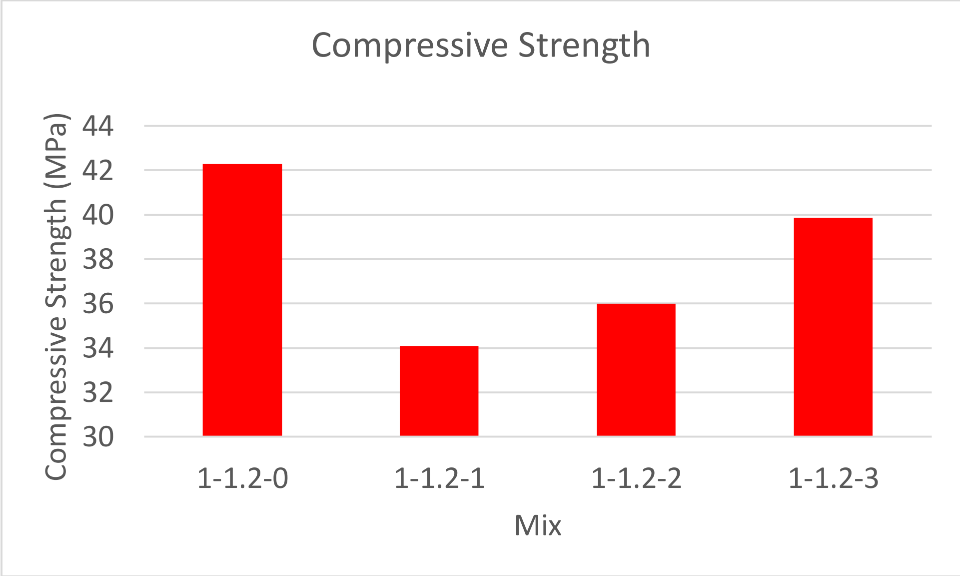

Figure 4.3 - The maximum compressive strength for the mix designs of study 2

Another way to analyse the data is by using a stress strain diagram. A stress strain diagram can be used to analyse a range of different things about the specimen, such as the modulus of elasticity, yield strength, proportional limit and elastic deformation. These are important forms of analysis as it will give an indication of how a specimen will fail.

4.2.1.1 Mix Design 1:1.2:0

The stress strain diagrams for the first mix, 1:1.2:0, is shown in Figure 4.4. The three samples were all plotted on the same graph as they were quite similar. It can be seen that the average yield strength occurs around 40MPa, the Yield Strength is how much the sample can deform before permanent deformation. The Ultimate Compressive Strength for the mix has already been determined in Figure 4.3 as 42MPa, this is the maximum strength of the mix.

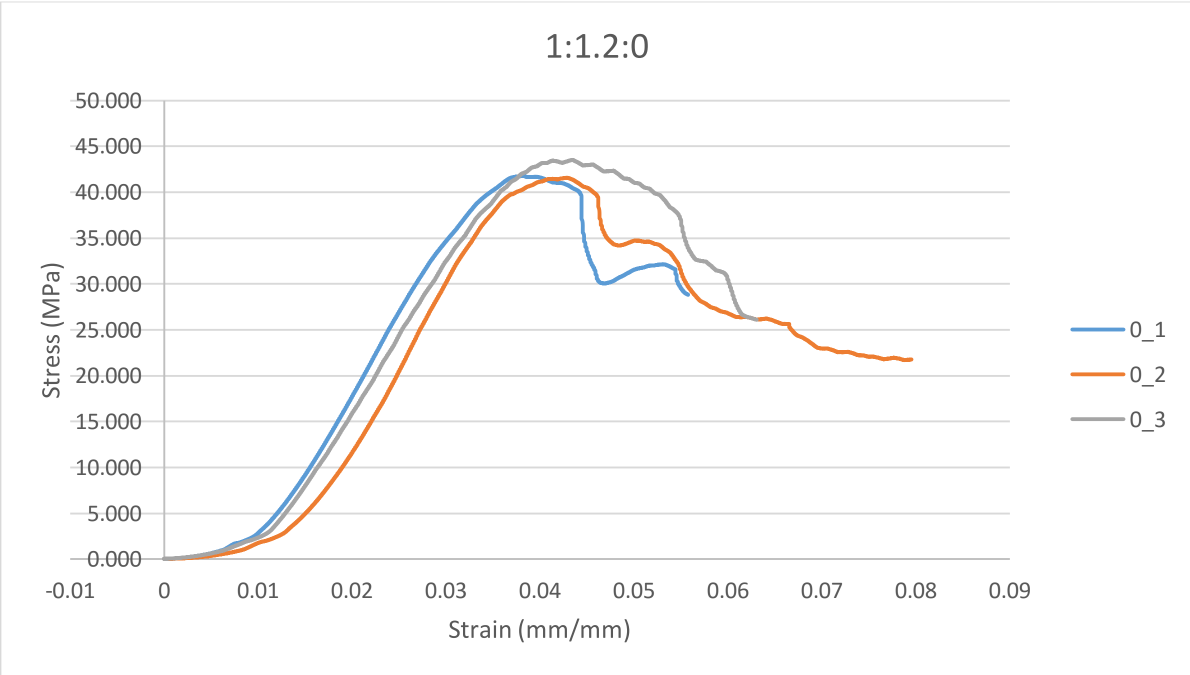

Figure 4.4 - The stress strain diagram for compressive strength of mix design 1:1.2:0

4.2.1.2 Mix Design 1:1.2:1

As was shown in Figure 4.3 the maximum compressive strength for this mix design is 34MPa. It can be seen from the stress strain diagram in Figure 4.5 that the third specimen has a much lower ultimate and yield strength, this could be due to a number of different factors. This will however effect the Young's Modulus calculation, therefore it was decided to only use sample one and two for this part of the analysis.

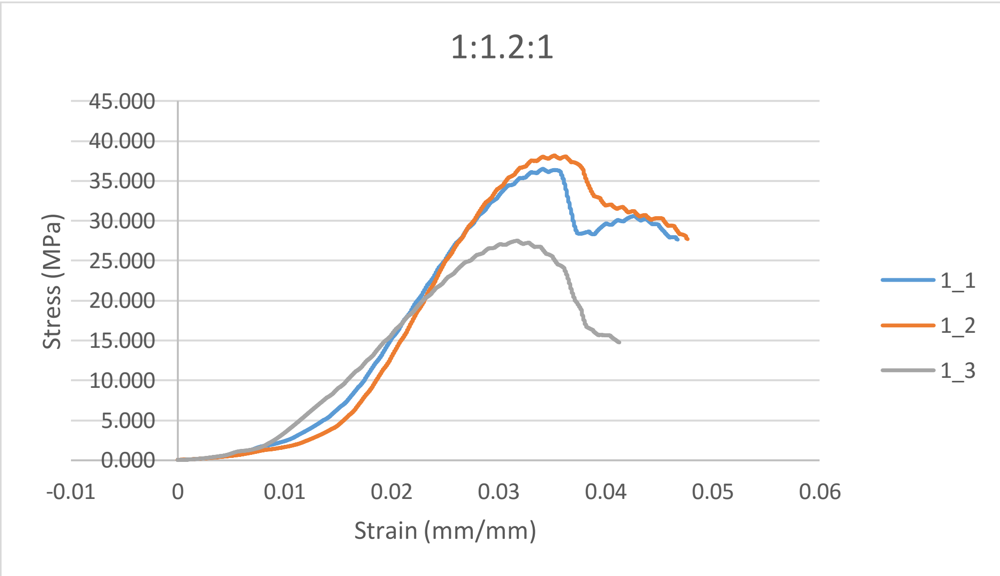

Figure 4.5 - The stress strain diagram for compressive strength of mix design 1:1.2:1

4.2.1.3 Mix Design 1:1.2:2

As shown in Figure 4.3, the maximum compressive strength for this mix design is 36MPa. It can be seen from the stress strain diagram in Figure 4.6 that even though the third sample peaks at a higher strain than the other two samples, that the gradient is still quite similar. Therefore data from all three samples can be used in the calculation.

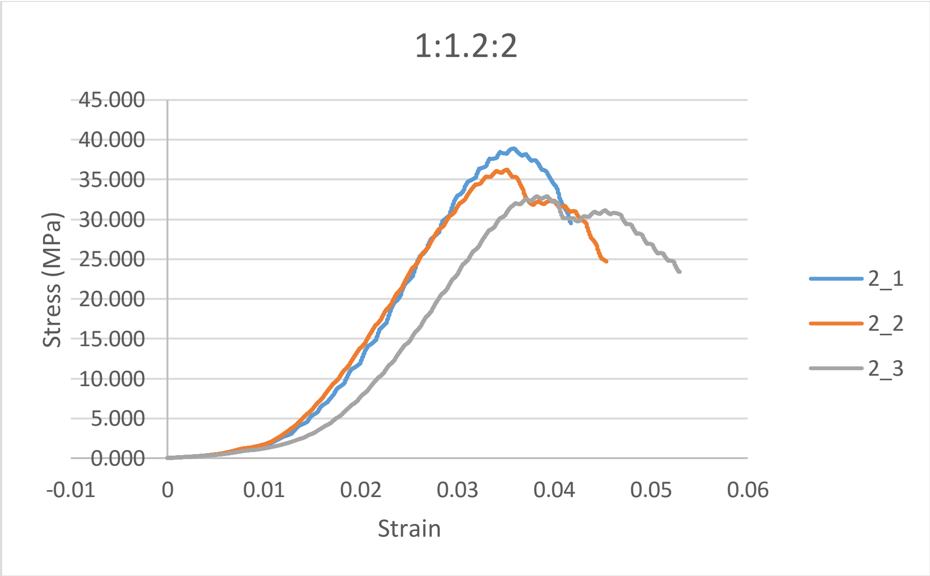

Figure 4.6 - The stress strain diagram for compressive strength of mix design 1:1.2:2

4.2.1.4 Mix Design 1:1.2:3

This is the final mix design tested, with a maximum compressive strength of 40MPa. Looking at Figure 4.7 it can be seen that sample one and three are quite similar, with the second sample peaking at a higher strain than the others. However it can be seen that the gradients are still similar and therefore all data can be included in the Young's Modulus calculations.

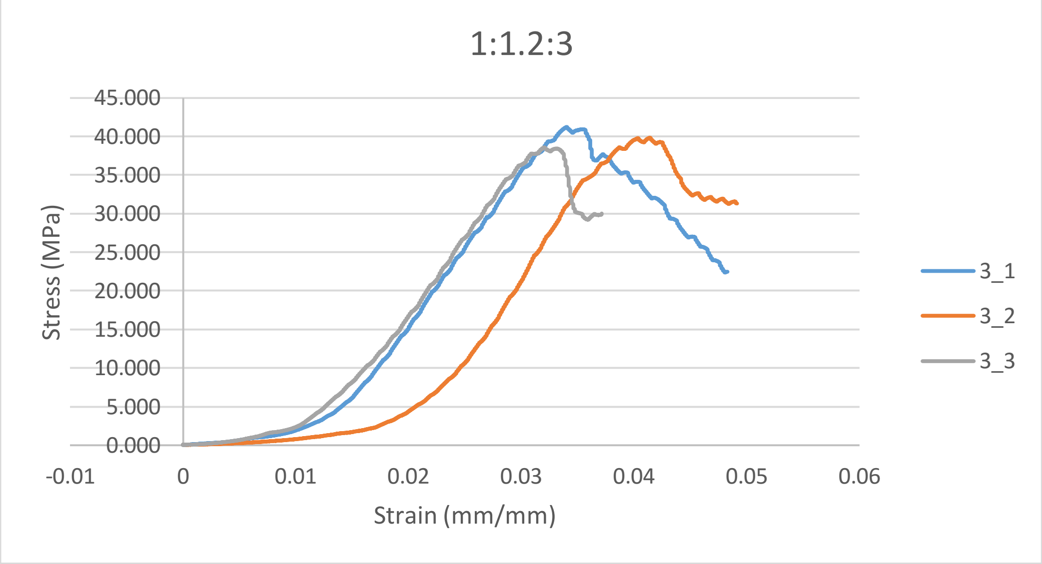

Figure 4.7 - The stress strain diagram for compressive strength of mix design 1:1.2:3

4.2.2 Tensile Strength

The tensile strength was analysed by finding the maximum values and also through analysis of the stress strain diagram for each mix design. Once again there were three samples for each mix design to ensure consistency of results. First all the results were analysed to ensure there were no discrepancies in the data, this is shown in Table 4.2. It can be seen that the values for the three specimens of each mix design are all very close and therefore the average of the three samples can be taken for the maximum tensile strength.

Specimen	f'st (MPa)
0_T_4	12.615
0_T_5	11.778
0_T_6	12.385
1_T_4	9.059
1_T_5	9.874
1_T_6	9.668
2_T_4	8.232
2_T_5	8.747
2_T_6	9.064
3_T_4	8.671
3_T_5	8.797
3_T_6	8.702

Table 4.2 - The tensile strength data for study 2

It can be seen in Table 4.2 that the tensile strength is highest in the mix with no aggregate, this was as expected. Then Figure 4.8 shows the tensile strength decreases, however mix 1:1.2:3 is slightly stronger than that of mix 1:1.2:2. This could mean the tensile strength has plateaued or just a discrepancy in the data, further testing on a mix with more aggregate again would need to be conducted to find the reasoning.

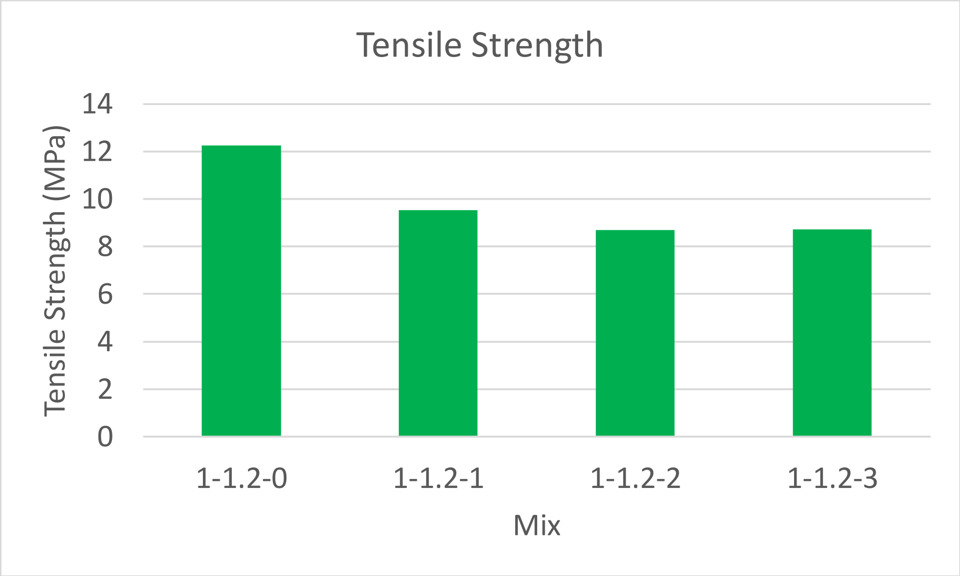

Figure 4.8 - Maximum tensile strength of each mix design for study 2

4.2.2.1 Mix Design 1:1.2:0

It can be seen in Figure 4.9 that the three samples are quite similar which shows that the three specimens for this mix design produces a consistent result. It can be seen that the 5th and 6th specimens are almost identical for the first section of the graph, which shows that they deformed the same over loading.

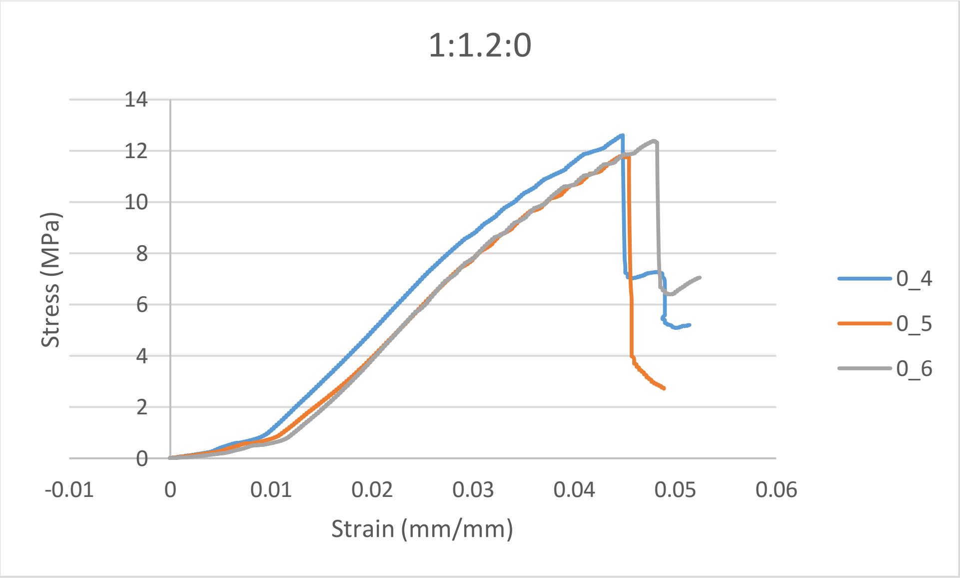

Figure 4.9 - The stress strain diagram for tensile strength for mix design 1:1.2:0

4.2.2.2 Mix Design 1:1.2:1

As can be seen in Figure 4.10 all three samples are again quite similar. However there is more of a difference between these specimens than that of the first mix design, showing variation as aggregate is added.

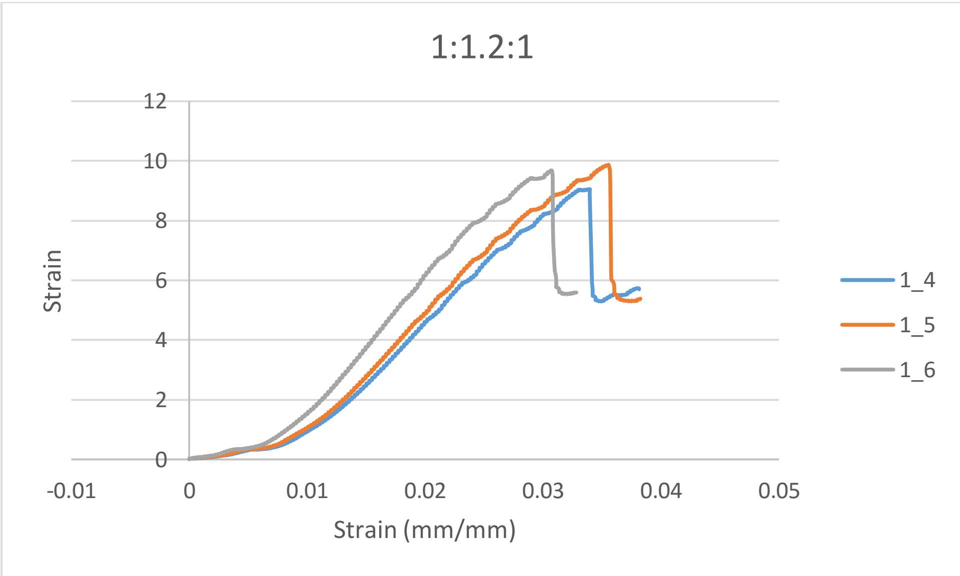

Figure 4.10 - The stress strain diagram for Tensile Strength of mix design 1:1.2:1

4.2.2.3 Mix Design 1:1.2:2

Figure 4.11 shows the stress strain diagram for the mix 1:1.2:2, all three of the samples are quite similar. Once again two of the samples are almost identical, just with different final strength values.

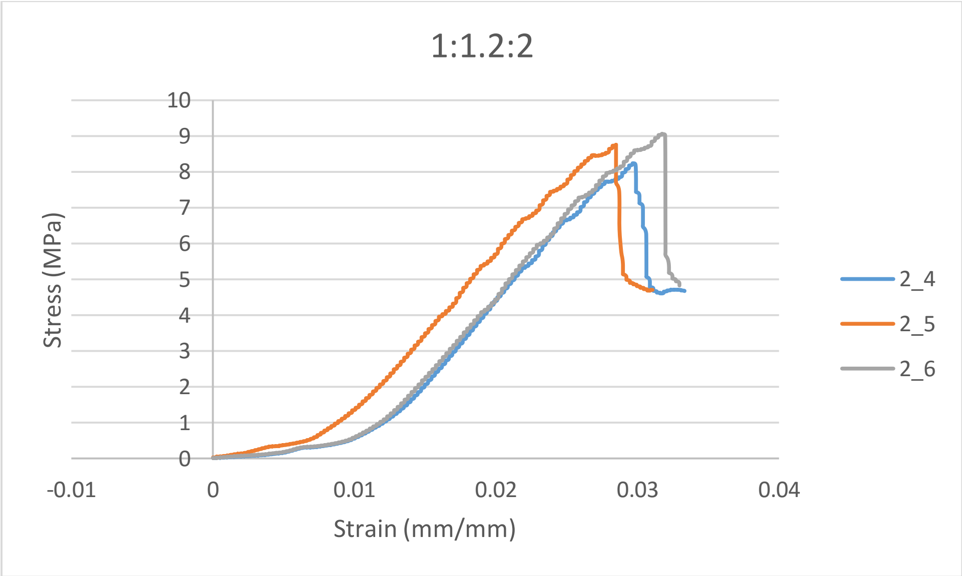

Figure 4.11 - The stress strain diagram for Tensile Strength for mix design 1:1.2:2

4.2.2.4 Mix Design 1:1.2:3

It can be seen that the samples are almost identical, showing good consistency throughout the three specimens.

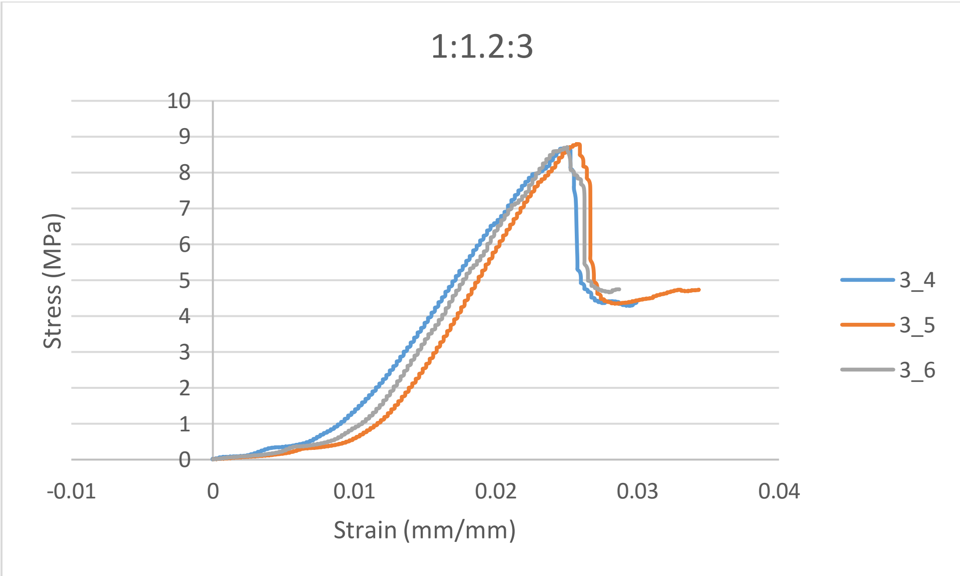

Figure 4.12 - The stress strain diagram for Tensile Strength of mix design 1:1.2:3

4.2.3 Flexural Strength

The flexural strength was found using three point bending testing. Once again there were three samples for each mix design, except for mix 1:1.2:3 as one was damaged while removing the specimens from the moulds. Table 4.3 shows the peak flexural stress for each sample, this was taken straight from the testing equipment. It can be seen that all of the peak flexural strengths are very similar, with only 3MPa difference between the lowest and highest. However a much better comparison is shown in Figure 4.13. It can be seen in Figure 4.13 that the maximum flexural strength occurs in the mix with no aggregate, with the second most occurring in the 1:1.2:3 mix. The other two mixes have similar flexural strength.

Specimen #	**Peak Flexural Stress MPa**
0_1	14.3
0_2	15.9
0_3	15.01
1_1	12.13
1_2	13.26
1_3	12.69
2_1	12.24
2_2	12.67
2_3	12.23
3_1	14.54
3_2	13.38

Table 4.3 - The peak flexural strength of all flexural specimens for study 2

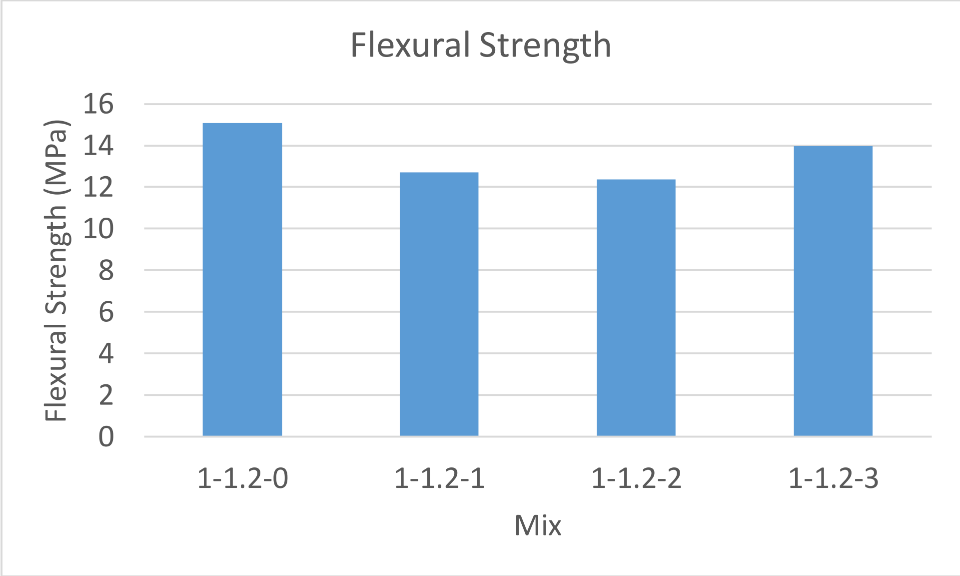

Figure 4.13 - Peak flexural strength of mix designs for study 2

4.3 Young's Modulus

As can be seen from the graphs below, the approximate elastic modulus for the samples is 2GPa. This is much lower than that of normal concrete, which usually ranges from 20GPa-30GPa. It was expected that the Young's Modulus would be low, however not this low. This is still a good result as it shows that the samples are quite flexible with high strength.

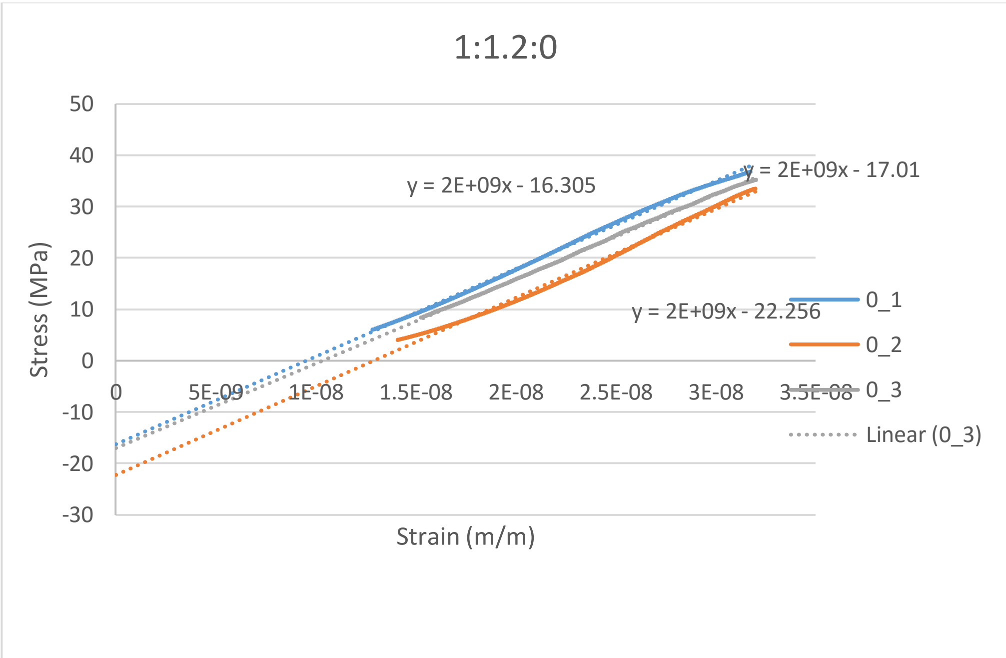

Figure 4.14 - Compressive Strength Young's Modulus for mix design 1:1.2:3

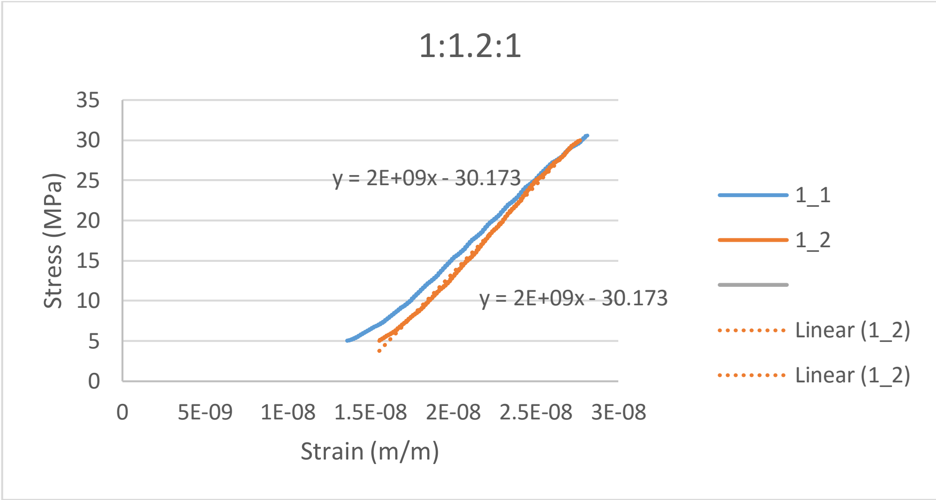

Figure 4.15 - Compressive Strength Young's Modulus for mix design 1:1.2:1

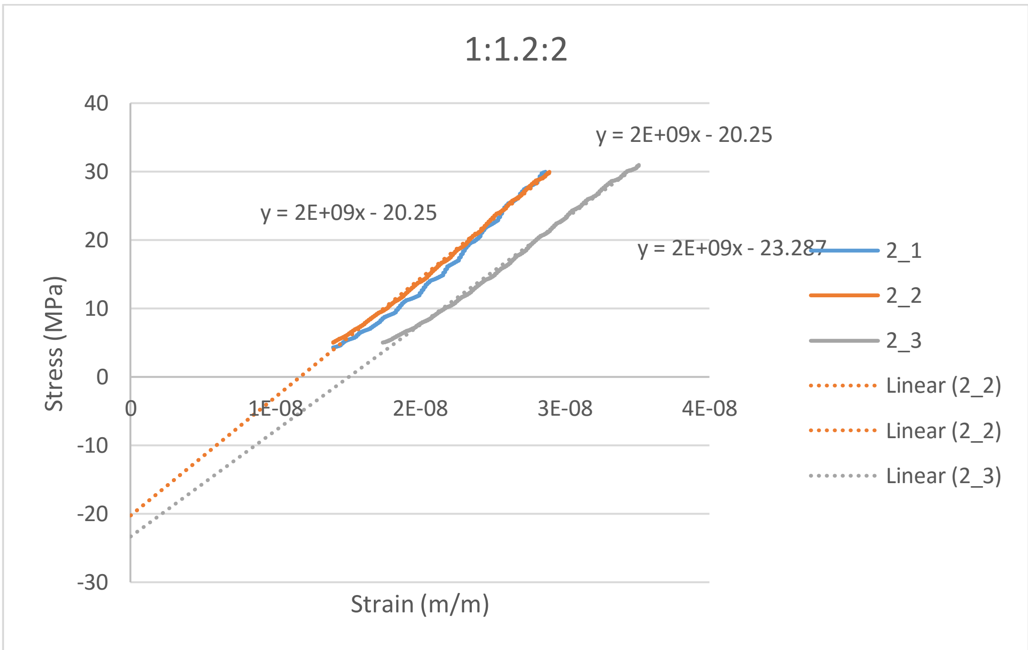

Figure 4.16 - Compressive Strength Young's Modulus for mix design 1:1.2:3

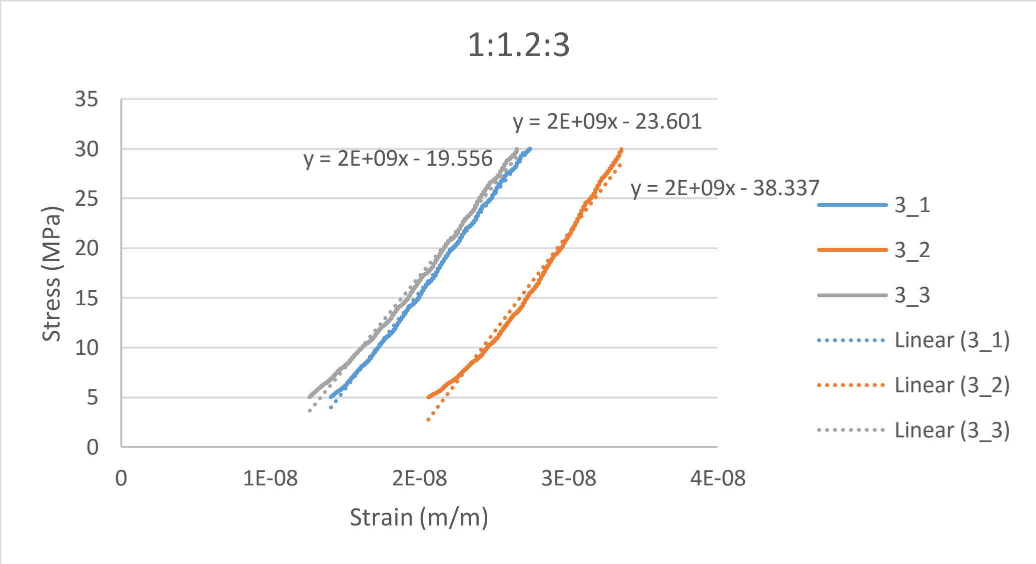

Figure 4.17 - Compressive Strength Young's Modulus for mix design 1:1.2:3

4.4 Study 3

Study three involves finding the relationship between the compressive and tensile strength of the ideal mix, giving the empirical prediction formula. From study two it was determined that the mix 1:1.2:0 was the strongest mix in all forms of testing. Therefore the relationship between the compressive and tensile strength of this mix design can be found. As can be seen in the graph below, three of the samples were compared to give an accurate reading. It was decided to compare the strongest compressive sample with the strongest tensile sample as this will yield a better comparison. It was decided to use the first two comparisons as they are the most similar. This gives an empirical prediction formula of:

$$f'_c = 4.5(f'_t)^{0.32}$$

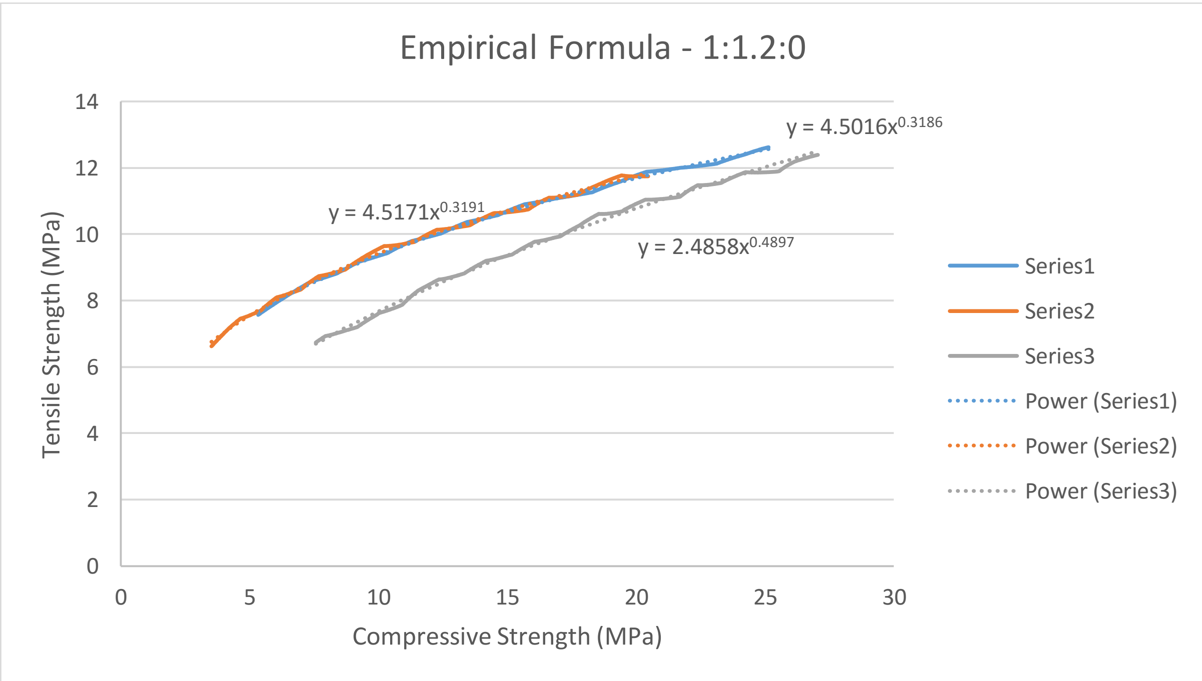

Figure 4.18 - Empirical Prediction Formula Mix 1:1.2:0

However, seeing as the other mix designs could still be used in certain cases they were also analysed. For the mix design 1:1.2:1, the equations were quite varied. Depending on which tensile samples were compared with which compression samples. However, there was assumed to be only slight discrepancies and therefore this was not checked. It can be seen below the comparisons of the three samples.

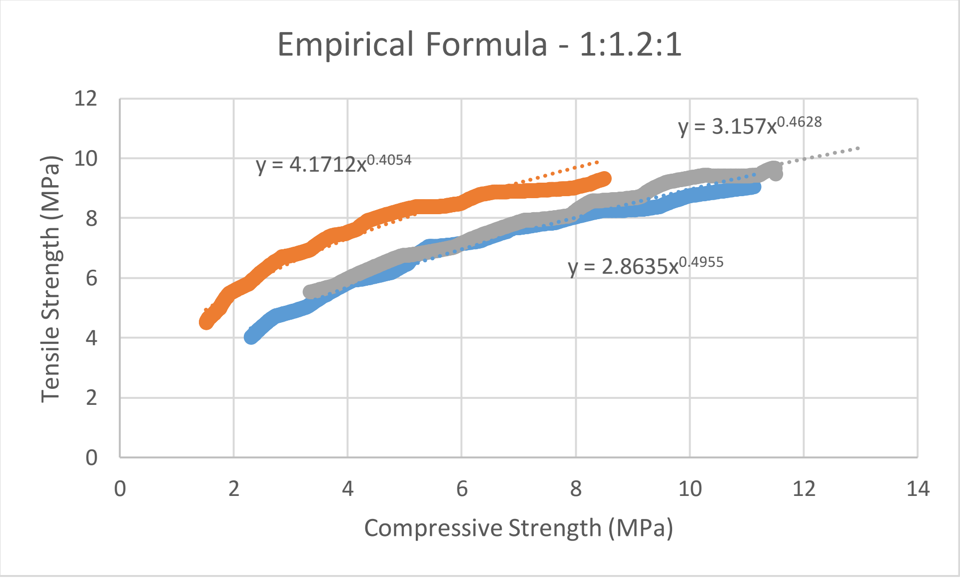

Figure 4.19 - Empirical Prediction Formula Mix 1:1.2:1

The formulas for mix design 1:1.2:2 can be seen below, it can be noted that these three comparisons are all quite different. It can also be seen that the relationship between compressive and tensile strength are not linear, which made it difficult to match the trend line to the data.

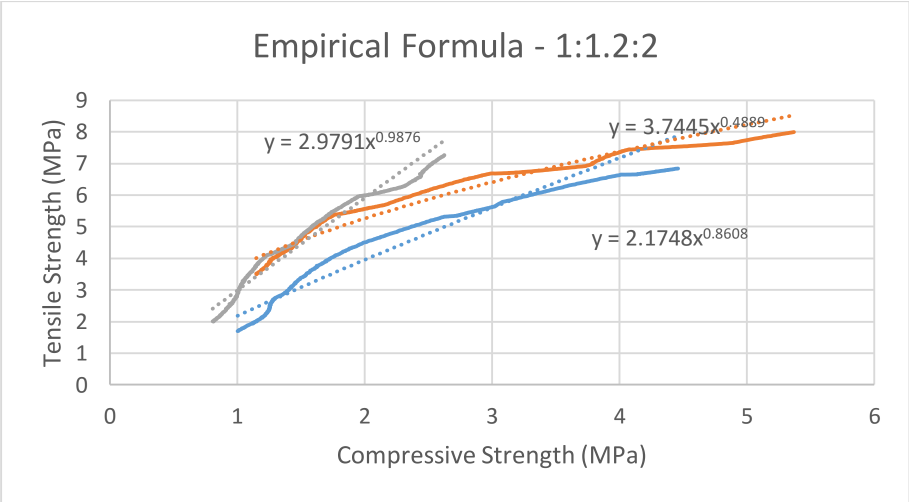

Figure 4.20 - Empirical Prediction Formula Mix 1:1.2:2

The final mix design, 1:1.2:3, doesn't show any relationship between the three formulas and therefore it would not be appropriate to use this mix design for an empirical prediction formula.

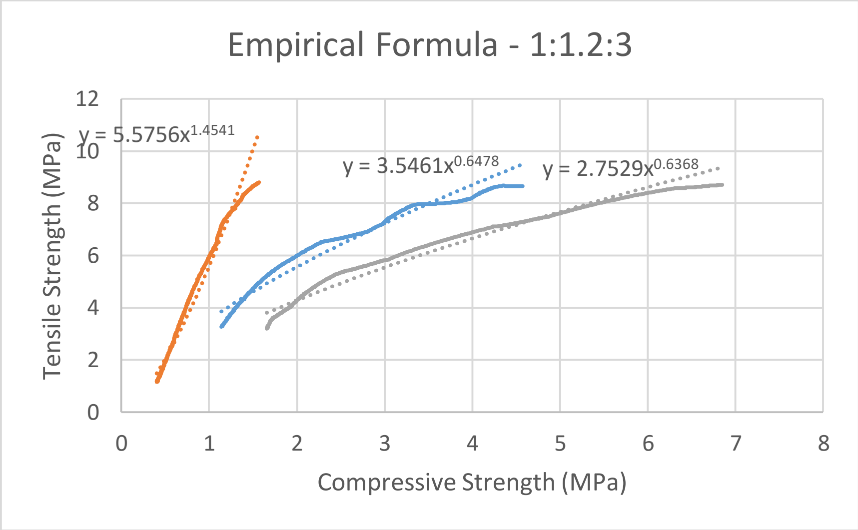

Figure 4.21 - Empirical Prediction Formula Mix 1:1.2:3

5 Discussion

5.1 Study 1

Study One results are based off a visual inspection of the specimens following the curing and cutting process. The initial thoughts were that either the 70/30 or 60/40 would be the best distributed mix. Initial observations were recorded in the mixing process showing some of the mixes viscosity was either too high or too low making the workability far too difficult. It can be seen in Figure 5.1 that the samples with the “glossy” looking surface have the lowest viscosity and the three mixes with higher viscosity have a rougher surface. This indicates that even the 70/30 mixes viscosity may be too low due to the glossy surface, also that the 40/60 mix will contain far too many air voids due to the high viscosity of the mix. Referring to Figure 5.1 it can be seen that there are air voids on the surface of the 50/50 and 40/60mix before curing had occurred.

Figure 5.1 - Study 1 specimens on the day of pouring

The next day the specimens were removed from their moulds and left to cure for a further 7 days before they were cut in half for visual inspection. Once the samples were cut open it was easy to see that the initial observations were slightly incorrect. The results determined that the ideal mix was 60% Resin 40% Filler. This was one of the predicted outcomes, however the previous studies did suggest that the 70% Resin 30% Filler mix could have been the ideal mix. As can be seen in Figure 5.2 the majority of the aggregate settled to the base of the sample, giving an uneven distribution of the course aggregate.

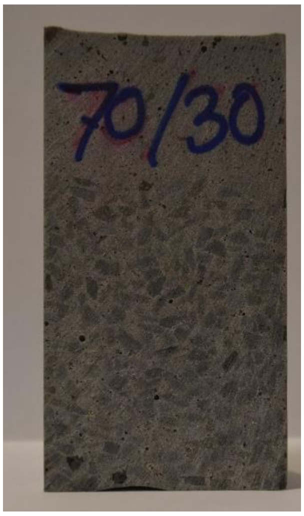

Figure 5.2 - The aggregate distribution of mix design 70/30.

It is shown in Figure 5.3 that the distribution of aggregate is similar for the first four samples, with the aggregate falling to the bottom and, then suddenly is well distributed through the sample in the 60/40 mix. It was expected that the aggregate level in the samples would gradually rise until the aggregate was fully distributed. This did not occur, as can be seen in Figure 5.3 it was a sudden jump between the 70/30 and 60/40 mix. It could be informative to see smaller intervals between the two mixes, to test how the aggregate is distributed throughout the samples and perhaps further refine the mix design.

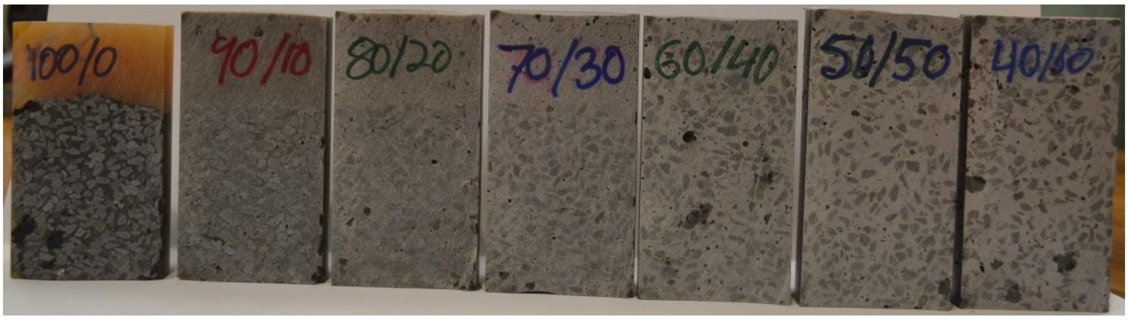

Figure 5.3 - Study 1 results; showing the aggregate distribution through all specimens

5.2 Study 2

5.2.1 Compressive Strength

The Study Two compressive strength results indicated that aggregate performs similarly in polymer concrete as it does in cement based concrete. However the variance between the highest and lowest average compressive strength is only 8MPa. This is quite a small variation in strength, which could mean that the aggregate did not have much of an effect on the compressive strength of polymer concrete at all. Looking at all of the values, the total difference between the lowest and highest compressive strength is 16MPa. The lowest value comes from the compression testing sample 1:1.2:1_3. It is approximately 10MPa weaker than the other two samples for this mix. This could be a fault in the sample, which would mean that the sample should be disregarded from the results. However, due to the tolerance being outside 15% of the average maximum compressive strength for the mix design, it can be discarded from the results. If this is done then the trend expected will not be followed, as can be seen in Figure 5.4.

Specimen	f'c
0_1	41.784
0_2	41.577
0_3	43.529
1_1	36.520
1_2	38.198
1_3	27.527
2_1	38.876
2_2	36.237
2_3	32.901
3_1	41.221
3_2	39.834
3_3	38.577

Table 5.1 - Maximum compressive strength of each specimen for study 2.

In Figure 5.4 it can be seen that the compressive strength of the different mixes follows no specific trend. This would conclude that the compressive strength is not overly affected by the addition of aggregate in the mix due to the already high strength of the polymer concrete mix. However, it can be seen that the strength is increasing in the final mix design. Further testing with more aggregate in the mix design will need to be conducted to see if the compressive strength continues to rise with the addition of aggregate.

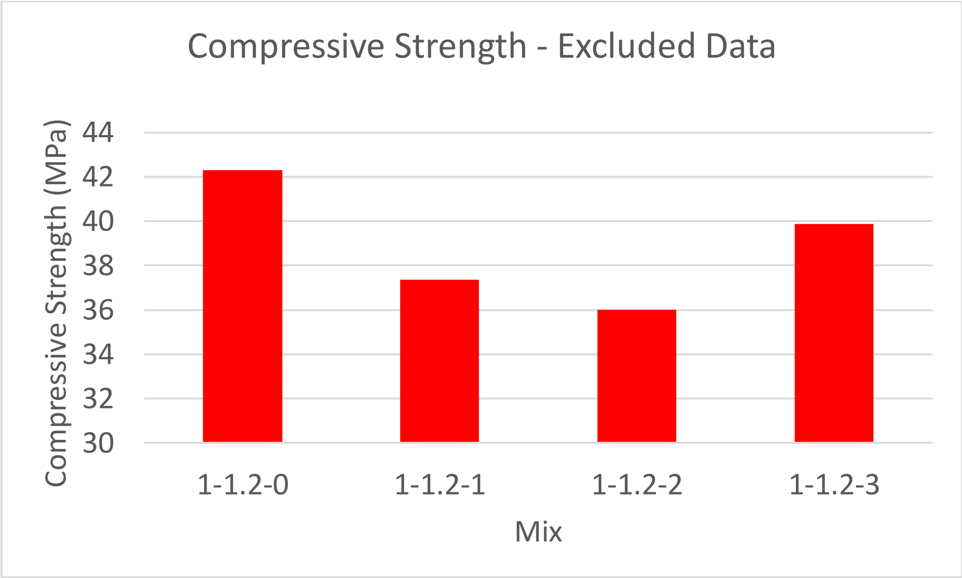

Figure 5.4 - The maximum compressive strength for each mix design excluding data.

It can also be seen that the mix without any aggregate is the strongest. This could be due to the sample having splitting failure rather than crushing, as has been discussed in the results and observations chapter. This is shown more clearly here in Figure 5.5, it can be seen that there is a crack running down the edge of the specimen. The crack could be due to the splitting failure, however it more likely due to cutting into the edge of the specimen when removing the mould. Considering the crack was not visible in the other two samples, it is assumed that this is not the cause of the high compressive strength achieved from the mix design.

Figure 5.5 - Possible splitting failure of specimen for mix design 1:1.2:0

The more likely explanation is that when aggregate was added to the mix voids were created, therefore making the specimens weaker. This can be analysed by looking at the densities of the mix designs. As shown in Table 5.2, the density of the mix design increases with the addition of aggregate which is expected. However when the density of the added aggregate is taken away from this value it can be seen that the mix with no aggregate actually has the highest density. Therefore showing that the addition of aggregate to the mix does create voids in the mix and therefore will affect the strength characteristics.

The aggregate density calculation was completed using the ingredient amounts and the density of the aggregate. Seeing as the six specimens were all mixed together and then poured into the separate moulds there is no way to say that each specimen received equal quantities of aggregate, however this is an assumption that needs to be made. This means that these densities might not be 100% accurate, however they are close enough to show the change in density.

	Average Density	Average Density minus Aggregate
1:1.2:0	1266.008	1266
1:1.2:1	1391.192	1083.060732
1:1.2:2	1649.998	1128.928869
1:1.2:3	1858.329	1181.436888

Table 5.2 - Average density for each mix design; first column including aggregates, the second removing the total aggregate density.

There is also a discrepancy in the data for mix 1:1.2:1, as discussed earlier, with sample 3 having a much lower compressive strength value than the other two samples. This could be due to a number of reasons, the most likely of which is there was a fault in the sample. The fault could have been due to an air void in the sample, inconsistencies in the resin or a number of other different reasons.

The remainder of the results were as expected for the compression tests even though there are still some ambiguities in the data. Finding the trend of compressive strength for the polymer concrete would be more conclusive if the Study was expanded to include more mix designs. If this was done it may more clearly define if there is a trend or not. For further study it would be suggested to do further mix designs, as was in the original project specifications, to conclude if the compressive strength continues to increase or if it stays around the 40MPa mark.

The compressive strength of polymer concrete should be around 80Mpa – 110MPa, however it can be seen from this project that the maximum compressive strength gained was 43.5MPa. This value is similar to that of high strength normal concrete, which means that the compressive strength of the polymer concrete is much lower than expected. The most likely cause of this is the material choices, as discussed previously in the literature review as this has the greatest impact on the characteristics of the cured sample. It was discovered in the literature review that the epoxy resin polymer concrete is not the strongest in compression, rather has excellent elasticity.

5.2.2 Tensile Strength

Tensile strength is the maximum load the sample can take before splitting failure occurs, although sometimes crushing can also occur in the testing. This can be seen in

, where shows that there is slight crushing failure present on the top of the sample before ultimate failure. This was expected as was discussed in the literature review, with one sixth of the sample experiencing crushing failure. It can also be seen by looking at the stress strain diagrams for the sample, which is sample 1 for mix design 1:1.2:0, this slight crushing has no effect on the results.

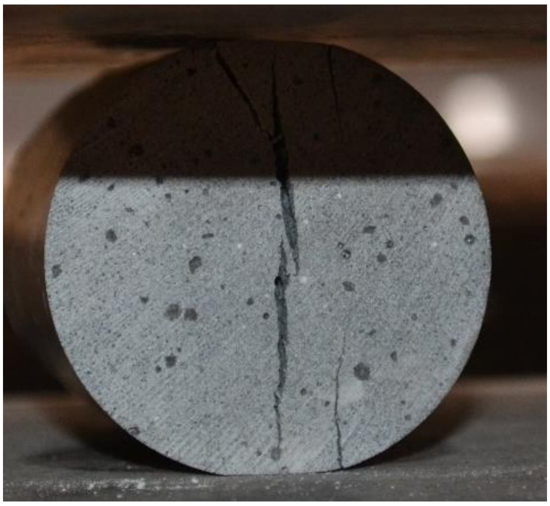

Figure 5.6 - Splitting failure of a tensile sample from study 2.

Figure 5.7 - Slight compression stress shown on specimen.

As can be seen from the analysis of the maximum tensile strength for the four mix designs, there was a total of 4MPa difference between the lowest and highest tensile strength. This was expected as tensile strength does not generally differ much between specimens. All the data fitted within the trend that was predicted, with the tensile strength decreasing with the amount of aggregate added. For each separate mix design there was only 1MPa difference between the three samples, which shows that the results are consistent. It can be seen from Table 5.3 that the mix 1:1.2:3 is slightly higher than the previous mix, but only by

0.04MPa which is practicably negligible. This could mean that the tensile strength has reached a plateau, or it could begin to increase. Once again further study on a mix with more aggregate would need to be completed to determine conclusively if there is a trend. However with the given data it can be said that the Epoxy Resin Polymer Concrete is strongest in tensile strength with no aggregate in the mix, with all the other mixes having similar tensile strengths.

Mix	f'st
1-1.2-0	12.25937
1-1.2-1	9.534037
1-1.2-2	8.681053
1-1.2-3	8.722964

Table 5.3 - Maximum Tensile Strength for the four mix designs from study 2

As discussed in the literature review, the tensile strength of normal concrete is between the ranges of 1.5MPa – 2MPa. It is shown in the results that the maximum tensile strength found from this study is 12MPa, which is 6 times that of normal concrete. This is an excellent result as this shows that polymer concrete is much stronger in tensile strength than normal concrete, which makes it useful for situations where high tensile strength is desirable. Although this outcome was indicated in the literature review, the results from this project are confirming the available information available.

5.2.3 Flexural Strength

From the literature review it was suggested that the flexural strength of the polymer concrete should be 22MPa-35MPa. The test results from this project yielded a maximum flexural strength of 15MPa, which is lower than expected. Once again this is most likely due to the materials chosen for this project. If different materials were chosen the flexural strength could be increased.

It can be seen in Table 5.4 that the total difference between the lowest and highest flexural strength is 4MPa, which once again is a very small variation. This can be interpreted as the coarse aggregate having little effect on the flexural strength of the polymer concrete. However, similar to tensile and compressive strength, the mix with no aggregate has a higher strength than the other three mix designs. Also similar to the tensile strength results, it is shown that the flexural strength increases in mix design 1:1.2:3. Another study should be done for a mix with more coarse aggregate in the future mix to determine if the flexural strength will continue to increase or if it will plateau.

Specimen #	Peak Flexural Stress MPa
0_1	14.3
0_2	15.9
0_3	15.01
1_1	12.13
1_2	13.26
1_3	12.69
2_1	12.24
2_2	12.67
2_3	12.23
3_1	14.54
3_2	13.38

Table 5.4 - Maximum flexural stress for each flexural specimen in study 2

5.2.4 Young's Modulus

As found in the results section, the Young's Modulus for four mix designs was found to be 2GPa on average. This is quite low for concrete, however it is not unheard of in polymer concrete with in the literature review showing there were some examples of low Young's Modulus values. A low Young's Modulus value means that the samples are very flexible, which is one of the desired properties. As can be seen in Figure 5.8, the elasticity is similar to that of woods and polymers (Engineering Materials, n.d.). This shows that the mix design can withstand a high amount of deflection before it is permanently deformed, which makes the material quite useful in components such as railway sleepers.

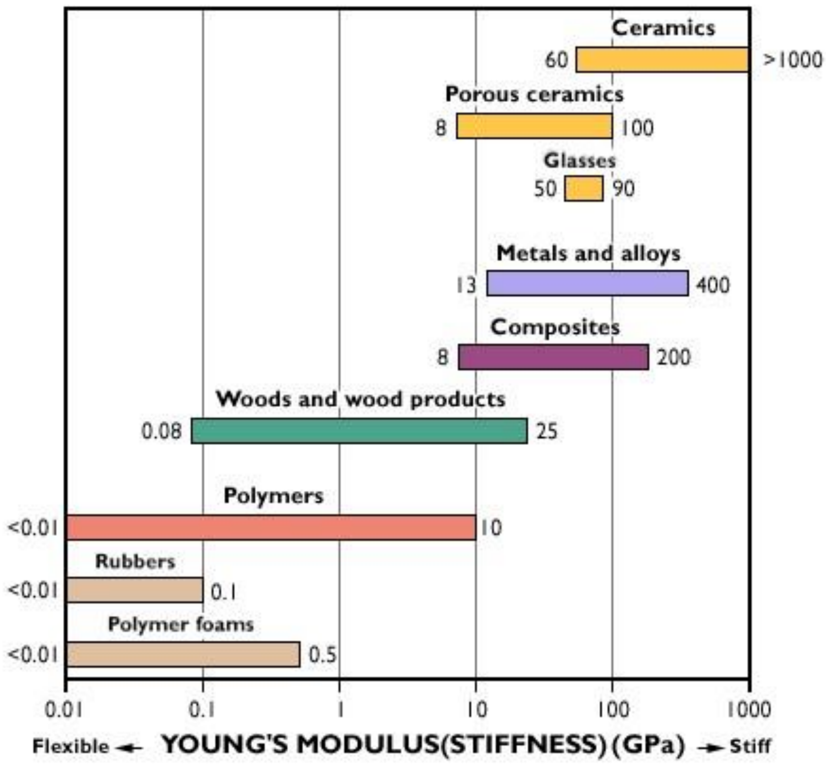

Figure 5.8 - Typical Young's Modulus Values for different materials.

The compressive strength testing results are similar to that of high strength concrete. Seeing as the Young's Modulus is directly related to that of compressive strength, the Young's Modulus was expected to be much higher. For normal concrete with similar strength the Young's Modulus would be 32.8GPa, which is much higher than the results from this project. Comparing this to the work done by Weena Lokuge and Thiru Aravinthan, where the Elastic Modulus values were between 8GPa and 11GPa for epoxy resin polymer concrete the values for this project are not unreasonable.

The findings from this section show that the samples have excellent elasticity, and can be used in situations where high strength and elasticity are both required.

This section of the project had a much better result than initially predicted, which does compensate for the lower values of compressive strength.

5.3 Study 3

As stated in the results, the empirical formula that best relates the tensile strength to the compressive strength for the mix design containing no aggregate is:

$$f'_c = 4.5(f'_t)^{0.32}$$

Therefore this is just for the resins and fillers as the aggregate had no effect on the mix design. From previous research, it was shown that for normal concrete the coefficient can range between 3 and 5, with the power coefficient usually being a square root. The formula derived doesn't quite match this, which is expected. This discrepancy is due to the tensile strength being much higher than that of normal concrete, with the compressive strength being only slightly higher than that of normal concrete. The equation reflects this relationship by having a higher coefficient and a lower power to allow for the reduced ratio of compressive to tensile strength when compared with that of normal concrete.

The other mix designs that were analysed showed varying results, depending on the shape and manipulation of the graph. However, most had a coefficient between 2 and 4 with the power coefficient dramatically changing between all the samples. This shows that, once the aggregate is added to the mix, it is difficult to find a single formula to relate the compressive and tensile strengths of the mixes.

5.4 Summary

From the strength testing it can be seen that the mix with the least amount of aggregate is the strongest mix. However, there is little difference between the mixes as discussed earlier. This indicates that due to the high cost of epoxy resin, more aggregate could be added to the mix to reduce the cost without losing sacrificing much strength. This is true also for the Young's Modulus of the specimens, with all the mix designs having a low Young's Modulus of 2GPa. From this testing it can be seen that, even though the compressive strength was not greatly improved, both the flexural and tensile strength were increased significantly. Given the low Young's Modulus of the specimens there may be uses for this material where cement based concrete was not previously considered an option.

6 Conclusion

The main project aim was to find the optimum mix design for epoxy resin polymer concrete with coarse aggregate. The first study conducted was to determine the ideal resin to filler ratio to achieve the best distributed aggregate with the least amount of air voids. From this study it was concluded that 60% resin to 40% filler provides the best distribution of aggregate, therefore chosen as the ideal resin to filler ratio.

Study two uses the ideal resin to filler mix from study one and varies the amount of aggregate to create four mix designs. These mix designs were tested for compressive, tensile and flexural strength. It was found that the mix design with no aggregate was the strongest for all three tests. However the strength of the specimens did not suffer greatly with the addition of aggregate, with all of the strengths being relatively similar. Therefore it was concluded that the amount of aggregate in the mix had no effect on the specimen strength. Using these compressive strengths, the Young's Modulus for each sample could be found. For all of the mix designs, the Young's Modulus was found to be approximately 2GPa. This shows that the specimens have excellent elasticity, which was a desired characteristic for this project.

The final study, study three, was finding the empirical prediction formula for the ideal mix design from study two. As all of the mixes were very similar, prediction formulas were formulated for all mix designs. The best fit came from the mix with no aggregate, the other mix designs gave varying formulas depending on the samples chosen.

In conclusion, the amount of aggregate added to the mix does not have any significant effect on the strength of the mix. Also, it can be seen that the specimens have a much higher tensile and flexural strength than that of normal concrete, however compressive strength is similar to that of normal high strength concrete.

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Appendices

Appendix 1 – Project Specification

University of Southern Queensland

FACULTY OF HEALTH, ENGINEERING AND SCIENCE

ENG4111/4112 Research Project

PROJECT SPECIFICATION

For: **Amy Beutel**

Topic: Optimal Mix Design for Epoxy Resin Polymer Concrete

Supervisor: Dr Allan Manalo

Adviser: Md Wahid Ferdous

Project Aim: This project aims to determine the optimum filler to resin ratio that will give a consistent polymer concrete mix, and investigate the physical and mechanical properties of the optimal Epoxy Resin Polymer Concrete.

PROGRAMME: Issue A, 16th March 2015

1. Research background of polymer concrete, focusing on epoxy resin.
2. Determination of the optimum filler to resin ratio for a consistent polymer concrete mix.
3. Investigate the physical properties of the polymer concrete mix with different filler to resin ratio
4. Determine the physical and mechanical properties of the epoxy resin polymer concrete with different amounts of coarse aggregates.
5. Analyse and interpret results.

6. Develop an empirical prediction formulae to describe the properties of epoxy based polymer concrete.
7. Further research into how aggregates effect normal concrete compared to polymer concrete.
8. Writing and submission of project dissertation.

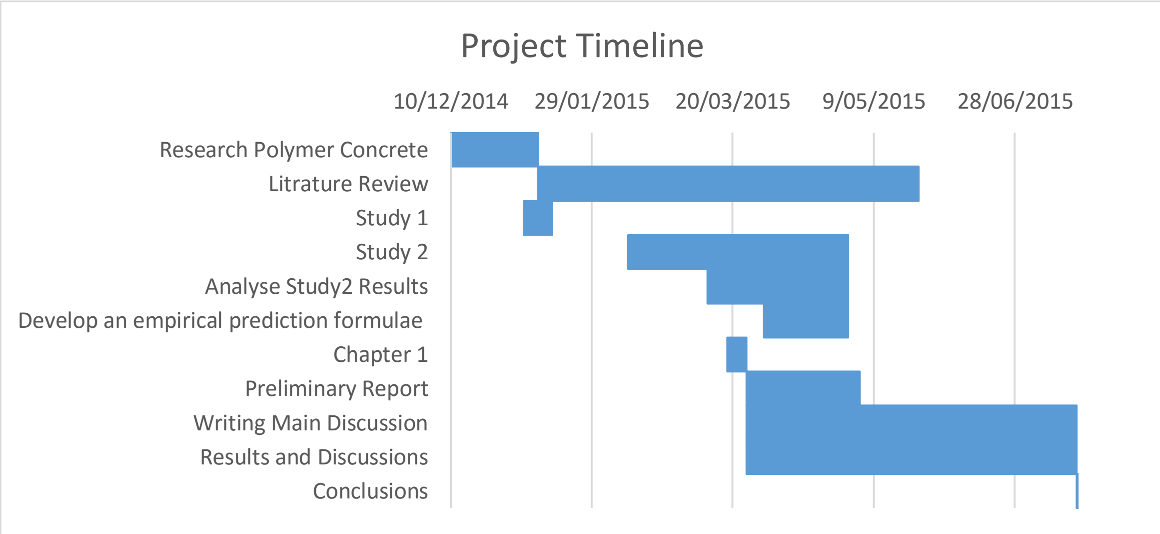
As Time Permits

1. Research into the use of fine aggregates instead of coarse aggregates.
2. Research into the use of a different type of resin.

Appendix 2 – Timeline and Resources

Project Timeline and Resources

Project Timeline



Resources

Materials

Most of the materials required for this project, such as the fine fillers, epoxy based resins and PVE moulds are available at the CEEFC while the aggregate will be requested from the university.

Equipment

All of the testing and measuring equipment is available at CEEFC (either P9 or P11), with the wet saw available in Z1 for the cutting of specimens.

Research

All the papers required for the research aspect of this project will be obtained either online or from the USQ Library.

Appendix 3 - Procedure of Concrete Compression Test

(A Civil Engineer, 2011)

Step1 - Preparation: Check all the things you need are ready. Check concrete compression machine is in working order.

Step2 - Safety: Wear hand gloves and safety goggles.

Step3 - Taking measurement: Take the measurement of concrete specimens (which are sent to laboratory for testing). Calculate the cross sectional area (unit should be on mm2) and put down on paper. Do the same for each specimen.

Step4 - Start machine: Turn on the machine. Place one concrete specimen in the centre of loading area.

Step5 - Lowering piston: Lower the piston against the top of concrete specimen by pushing the lever. Don't apply load just now. Just place the piston on top of concrete specimen so that it's touching that.

Step6 - Applying load: Now the piston is on top of specimen. It is the time to apply load. Pull the lever into holding position. Start the compression test by pressing the zero button on the display board.

Step7 - Increasing pressure: By turning pressure increasing valve counter-clockwise, adjust the pressure on piston so that it matches concrete compression strength value. Apply the load gradually without shock.

Step8 - Test is complete: Observe the concrete specimen. When it begins to break stop applying load.

Step9 - recording: Record the ultimate load on paper displaying on machine's display screen.

Step10 - Clean the machine: When the piston is back into its position, clean the creaked concrete from the machine.

Step11 - Turning off machine: Match your record once again with the result on display screen. The result should still be on display screen. And then turn off the machine.

Step12 - Calculate concrete compressive strength: The result we got from testing machine is the ultimate load to break the concrete specimen. The load unit is generally in lb. We have to convert it in newton (N). Our purpose is, to know the concrete compressive strength.

We know, compressive strength is equal to ultimate load divided by cross sectional area of concrete specimen. We took the concrete specimen's measurement before starting the testing and calculated cross sectional area.

Now we got the ultimate load. So we can now calculate the concrete compressive strength.

Compressive strength = Ultimate load (N) / cross sectional area (mm2).

The unit of compressive strength will be N/mm2.

Normally 3 sample of concrete specimens are tested and average result is taken into consideration. If any of the specimen compressive strength result varies by more than 15% of average result, that result is rejected.