University of Southern Queensland
Faculty of Engineering and Surveying

# Investigate the best percentage by weight of glass powder, as fillers in phenolic resins using tensile tests.

A dissertation submitted by

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# Abstract

This project is based upon investigating the best percentage by weight of glass powder in phenolic resins by testing the mechanical properties of the composite material using tensile testing.

In today's society cost is always an issue and for the need to reduce the costs. For this reason theory's are being developed and tested within this report. Glass powder will be used as filler material in the phenolic resin at varying percentages by weight to identify if the mechanical properties increase with the composite as well as being a cheaper alternative than the neat phenolic resin.

Phenolic Formaldehyde thermosetting resin was mixed with and acidic catalyst at ratios from 30:1 up to ratio of 12:1, as well as adding glass powder by weight as filler. Once initial curing has occurred the specimens were subjected to post-curing in a conventional oven where they were baked at 3 different temperatures for a set amount of time. In addition, tensile testing was preformed on the post-cured specimens to test for the yield, tensile and young's modulus of each specimen. This will then allow for an analysis to be conducted, identifying what the effects the glass powder has on the phenol formaldehyde matrix composite.

In addition, stereo microscope was used to identify at higher magnification what the surface of the composite look like as well having a closer look at how much porosity had produced. Furthermore identify if the glass powder was able to blend in with the phenolic resin to enable higher mechanical properties than the neat phenolic resin.

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# Limitations of Use

**Prof F Bullen**
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# Certification

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

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

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Signature

Date

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# 1 Introduction

*This research project is to investigate the best percentage by weight of glass powder, as fillers in phenolic resins using tensile tests.*

## *1.1 Introduction*

This chapter will outline the purpose of this research project. It will seek to review and investigate the use of phenolic resin in engineering and investigate the effectiveness of adding glass powder as filler material to the resin.

## *1.2 Research and Development Work*

Glass powder as filler in the phenolic resin composite is only relative new method therefore there is not much known about the strength it can add to the phenolic resin mixture. Tensile testing will be conducted to analyze the effects that the glass powder has on the mechanical properties of the phenolic resin composite mixture. The tensile testing will be used as a testing method to find the Young's modulus of elasticity of each specimen as well as the yield and tensile strength. From these test the stress strain graph will be produced where conclusions can be obtain on the difference that has occurred in the newly formed composite. This paper will go through a series of experiments using a different ratios and percentages to the glass powder in the preexisting formulas of the phenolic resin and catalyst mixture to indicate whether glass powder is a viable option to consider when making a phenolic resin composite. Once this is established, more tests will be conducted on the make of the specimen.

The phenolic glass composite specimens will be cured and tested. The specimens will consist of three materials, Phenolic Formaldehyde Resin, (Hexion Cellobond J2027L) Phenolic Resin hardener Catalyst (Hexion Phencat 15) and Glass powder (Sphericel Hollow Glass Spheres). This will be mixed at a ratio of 12:1 to 30:1 Resin to Catalyst, depending on the percentage by weight of glass powder. A mixture of 5% intervals of glass powder by weight will be added to the Resin Catalyst mixture. This will be conducted from 0 – 30% glass powder ratio.

Once the specimens are made, cured and tested results will be analyzed, to find out the optimum percentage by weight of glass powder to use in the composite mixture to achieve high stronger material properties.

## *1.3 Composite Materials*

Composite materials are a combination of two or more separate substances. A common example of composite materials within the engineering sector is Fibre-glass, concrete, rubber tyres as well as reinforced plastics. A composite material takes advantage of the different material and mechanical strengths and abilities of different materials. The main characteristic of a composite material is it allows materials to be mixed together, yet still be apparent in the way they still sustain their strong material properties as well as captivating the other materials strengths. A general example of composite that originated hundred of years ago is mud and straw bricks. On its own mud characteristics are, a good binding agent but has poor compression force strength, which will allow to bricks to deform. With the addition of another material such as straw, which has high compression strength allows to mix and bond with the mud and form a strong bond. The straw acts a reinforcing material similar to how concrete and reinforcement bars work in all buildings being made today.

## *1.4 Phenolic resins*

Phenolic was one of the earliest wholly synthetic polymers to be discovered. It came about the years of study of natural polymers. A polymer is a solid material which contains many chemically bonded parts which form a solid. Some of the earliest records, pre 1800, found that natural polymers for example wool, leather, cotton and rubber can be altered to form a plastic like material. An inventor by the name of Leo Hendrik

Bakeland was the first person to form a non-natural polymer (synthetic), which was later called Bakelite in 1909 (Shackelford, 1992). This was the make of phenol and formaldehyde. This later lead scientist across the world to base more experiments using similar non-natural materials to identify other plastic synthetic polymers (Strong, 2000). Phenolic thermoset material is still, among the most highly used material due to its low cost on a cost-per-volume basis (Ku et al, 2007). All synthetic plastics are then divided into two groups thermoplastics and thermosets, depending on the chemical bonding. Thermoplastics are generally used where softness, flexibility, and resilience are exhibited. Some actual examples are footwear, wire insulation, adhesives, polymer blending Thermosets are either a solid or liquid at room temperature but once heated the resin will set and cure and cannot be melted to be reshaped (Strong, 2000). Some general examples of a thermoset composite being used is in the maritime industry on boats, in air crafts for various assorted devices and most regularly use in components in the electrical industry. The process that creates the thermosets is formed by condensation of polymerization (Smith, 2000). During the progression being carried out via two different conditions, the result in two different intermediate materials being produced, novolacs and the other resoles. The one that occurs depend on the mole ratio of the formaldehyde to phenolic and catalyst mixture.

## *1.5 Glass powder*

Microballoons or microspheres have been used as a filler material in many industries. In the construction industry is can be used to fill gaps, which can also dampen sound or vibrations that the building may have as well. Glass microballons are also currently being used in the medical area as a source to be used as a skin replacement for burn victims.

Glass powder is used to enhance the performance and reduce viscosity in paints, coatings and as a lightweight additive in plastic parts. As well as having above average material characteristics, glass powder is high heat resistance along with pressure and impact resistance. ‘Accordingly, it is widely used for weight saving of resin molding components for e.g. Automobiles, portable electronic equipment, buoyancy material for ships, as well as aircraft and in the medical sector for skin replacement (Patent Storm, 2008)'

## 1.6 Contribution to New Knowledge

This dissertation will allow for future references to be available and allow for this to be presented as previous knowledge on glass powder being used within the phenolic resin mixture as well as providing mechanical testing result to reiterate the findings. This dissertation will draw conclusions on the results obtain from tensile testing of the glass powder phenolic resin composite and show the effects that are had on the mechanical properties of the mixture via tensile strength, yield strength and young's modulus of elasticity.

## 1.7 Summary of Chapters

In Chapter 2 numerous journal articles will be reviewed with a more in-depth literature review into composite materials in particular phenolic as well as other components used in the final make-up of the phenolic resin glass mixture.

Chapter 3 will lead into the methodology of how the experiments will be conducted along with the preparation and safety precautions need to commence the experiments.

Chapter 4 begins evaluating and discussing the results that were found by the experiments and then recommendations will be made on the viability of the testing. Each of the three mechanical tests conducted will be analyzed individually, then lead into a discussion on what the results mean to industry.

Chapter 5 is final chapter in this dissertation where the results that have been obtained will be, briefly summarized and recommendations will be drawn so later references can be used for study and experimental purposes.

## *1.8 Publications*

This will later be submitted for publication after this dissertation has been finalized.

Ku, H Trada, M Cecil, T, Tensile strength of glass powder reinforced Phenolic resins, Journal of Composite Materials 2009 (submitted for publication)

# 2 Literature Review

## 2.1 Introduction

In this chapter a more detail literature review will be conducted on composite materials in particular phenol formaldehyde resin as well as other components that will be used in the final composition of the new glass powder reinforced phenolic resin composite.

Plastics once modified by natural polymers can form other form of plastic. A specific example of the modification of the polymers is phenolic resins. It has been used within a wide range of industries for several different applications. Phenolic resins are widely used in manufacturing to form common plastics that make up everyday appliances. Phenolic resins are very versatile and are currently being used in making electronic appliances, floatation devices on ships and as an adhesive agent that is used to join commercially available plywood together. With the ever increasing demand for the phenolic resin, grows the need for a cheaper alternative of phenolic resins to be manufactured. As this demand increases, the need of additional consideration from engineers and technical staff on the possibility of using a filler material increases. The filler could be combined with the phenolic resin to form an innovative glass powder reinforce resin composite that not only is a cheaper alternative but can also have advantages of improved mechanical properties.

## 2.2 Introduction to Composite Materials

Composite materials have become a common part of engineering with the need to have a lighter and stronger alternative compared to the more conventional materials such as steel. The use of fibre composite materials is possibly the most recognized composite available. AN example of a common example of composite material is concrete, as on there own the cement concatenate and sand have individual properties that the other doesn’t but when combined both individually strengths combine to form a strong composite material. Other examples of composites within the engineering sector are rubber tyres, as well as reinforced plastics. Composite materials are defined as a blend or combination of two or more separate materials. The main characteristic of a composite material is it allows materials to be mixed together, yet still be apparent in the way the material will sustain its material properties as well as captivating the other materials strengths. This then leads to a better a composite material than the two materials individually (Smith 2008).

## *2.3 Phenolic Resin*

Phenol-formaldehyde or phenolic resin thermoset is the make-up of thermoset material of at least two main ingredients, of which are: the resin and its hardener. The fillers, that are included in the phenolic resins, can be reinforcing materials which can be organic or inorganic. Such organic polymers can range from wood flour, glass and cellulose (Smith, 2000). Organic polymer fillers are mostly carbon-based whereas inorganic polymers are glass, silicone, magnesium carbonate, calcium silicate (Kawai et al, 1988).

Phenolic was one of the earliest wholly synthetic polymers to be discovered. This came after years of study of natural polymers. A polymer is a solid material that contains many chemically bonded parts. Some of the earliest records, pre 1800, found that natural polymers for example wool, leather, cotton and rubber can be altered to form a plastic like material. From here the research began to improve and in 1868 John Wesley Hyatt discovered the first plastic. Celluloid was called the first ever plastic as Hyatt had substantially modified the natural polymer and then allowed the new mixture to be cured into a mould forming new shapes (Smith, 2000). Once this development was discovered scientist began to add other natural polymers in the hope to discover a new composite material. An inventor by the name of Leo Hendrik Bakeland was the first person to form a non-natural polymer (synthetic), which was later called Bakelite in 1909. This was the make of phenol and formaldehyde. This led scientists across the world to base more experiments using similar non-natural materials to identify other plastic synthetic polymers (Strong, 2000). Phenolic thermoset material is still, among the most highly used material due to its low cost on a cost-per-volume basis (Ku et al, 2007).

Using phenol formaldehyde due to its high adhesive qualities leads to molding problems, as it tends to stick to the moulds. To overcome this problem releasing agents are then sprayed on to the surfaces of the mold. Phenol formaldehyde or phenolic Resin independently has the material characteristics of low tensile and flexural strength with a high thermal expansion.

Whilst the resin is subjected to a flame, it will only char rather then catch fire or melt. Phenolic resin is therefore widely applied in situations where a low flammability is required, for e.g. on appliances. The neat resin has darkened pigments which are ingrained into the resin and limits the use of the resin in certain instances. To overcome this, a dark pigment is then added to homogenize the colour of the resin which also diminishes the UV light sensitivity (Ku, 2009). Once the resin is mixed with another material it is proven that the mechanical properties of the Resin will increase, which properties increase depends on the special properties that the other material contains. For example if graphite fiber is added to the phenolic composite it has proven to increase the tensile strength of the harden material by 10 times of that of the unreinforced phenolic resin (Wang et al, 1997). All synthetic plastics are then divided into two groups thermoplastics and thermosets, depending on the chemical bonding.

### 2.3.1 Thermoplastic

Thermoplastic elastomers were first introduced in the 1960's. Thermoplastics are commonly used plastic which when the polymers are at room temperature it's a solid but once exposed to high temperatures is able to be melted down to be re-solidified. The main difference between thermoplastic and thermosetting polymers is thermoplastic are not involved in chemical reactions that cross-link materials and become "set", i.e., they can no longer flow or be dissolved. At room temperature, thermoplastic elastomers, crosslinks occur by tying the elastomers chains together in to a three dimensional network. Once heated the strength of the material is lost or dissolved in solvents, when the material cools the solvent evaporates and the integrity of the original network begins to reform and becomes hard again. The addition of a solvent allows the polymer solution to flow easily. Some common examples of thermoplastic are in areas where high temperatures are not a major factor in the working conditions of the component, due to the fact that a thermoplastic material can be melted when exposed to high temperatures and then re-solidified. Thermoplastic materials are generally used where softness, flexibility, and resilience are exhibited. Some actual examples are footwear, wire insulation, adhesives, polymer blending (Wiley, 2002).

### 2.3.2 Thermoset

Thermoset plastics can be either solid or liquid at room temperature but once heated the resin will set and cure and cannot be melted to be reshaped (Strong, 2000). The process that creates the thermosets is formed by condensation of polymerization (Smith, 2000). During this process being undertaken under two different conditions, two different intermediate materials are produced, novolacs and the other resoles. Which one that occurs, depends the mole ratio of the formaldehyde to phenolic and catalyst mixture. Resole resin is produced when the mole ratio of formaldehyde to phenol and catalyst is greater than 1. An example of the resole resin used today is Hexion Cellobond J2027 a commercially available resin. The other intermediate material that can form via the condensation of polymerization is novolac. Novolac is the opposite to resole, as a novolac has the composition of excess phenol so the mole ratio of formaldehyde to phenol is less than 1. For example if one mole of phenol was to react with formaldehyde to form a novolac only 0.7 to 0.85 of a mole would be used, where as for a resole the formaldehyde would be increased to above 1 with phenol remaining at 1.

Once the phenolic resin is allowed to be cured a process called chemical crosslinking occurs. Crosslinking is the process of where the polymer molecules react together and join a three dimensional network. This only occurs by a reaction of the novolac with hexamethylenetetramine (hexa), a basic catalyst. When pressure and heat are applied to the hexa-containing novolac resin, it produces ammonia which then provides methylene. This then starts the crosslinking process and once the hexa material is added they call it a two-stage novolac system. During the formation of the intermediate material results in the development of water a by-product. This causes whilst curing an extensive microvoiding in the phenolic matrix. This has little effect on the composite properties, but due to the high water absorption can cause structures to delaminate when exposed to high temperatures. Unlike a thermoplastic material once the crosslink of the polymers have occurred in a thermoset material and exposed to high temperatures the material will only soften, but will remain the general shape until much higher temperatures are applied then decomposition will occur (Wiley, 2002; Strong, 2000; Ku et al, 2009 Smith and Hashemir, 2000 Shackelford, 1992).

## 2.4 Catalyst

Catalyst is any substance that increases the rate of a reaction without itself being consumed. In general, catalytic action is a chemical reaction between the catalyst and a reactant, forming chemical intermediates that are able to react more readily with each other or with another reactant, to form the desired end product. During the reaction between the chemical intermediates and the reactants, the catalyst is regenerated. (Britannica 2008) The rate in which the chemical reaction occurs depends on the speed of which the molecules are traveling in the different materials. There are two methods of reaction of the catalysts adsorption and intermediate compounds. Adsorption is when a molecule sticks onto a surface of a catalyst whereas intermediate compounds is when chemicals react with several catalysts to which they then formed together to form an intermediate compound (Purchon 2006). Catalysts can be potential hazards when being used. They are not very reactive or flammable, but they are rated as moderate for toxicity as well as being classified as a hazardous substance, dangerous goods. This is due to an extreme rating for body contact under the guidelines set out in the criteria of NOHSC and ADG Code.

## 2.5 Glass Powder

Glass microspheres have been used in various kinds of polymeric compounds since the mid-1960. Once the idea of using glass was introduced it was found to be unfavorable as results showed that it did not have great enough mechanical properties needed for the high shear forces and pressures involved with injection molding. It was not to till the late 1980's that glass spheres were commonly used as filler into the polymeric/ phenolic resin compound mixtures where injection molding was used. Injection molding is a common manufacturing process that is used for shaping plastic resins. Most plastic components are formed by this process. The process starts, where the plastic resin is fed into a hopper of a machine then it is forced through an injector barrel where it will be heated. Once it has achieved a certain temperature the heated resin is forced through a nozzle and into a mould, where it later cools and will allowed to cure into desired shape (Chemical Engineering Tools, 2008).

Over the period of 20 years it was discovered that the size and shaping of the glass played a large part in the process. Once this was discovered many companies over a variety of industries swapped over to microspheres as they had a more consistent sizing and shapes then that what was previously available on the market. Having irregularly shaped particles due to non-uniform shrinkage can lead to misalignment. By contrast, spherical particles respond evenly to shrinkage, so the part does not warp (Potters Industries, 2008).

A common method used to produce hollow glass microspheres is by mixing sodium sulfate with sodium borosilicate glass. This mixture is then dropped into a hot flame that melts the powdered glass and sodium sulfate. Once the sodium sulfate is melted the results from the decomposition reaction, is released in a minute amount that will form bubbles within the molten glass droplets. The hollow droplets are then rapidly cooled from the liquid state to form the hollow glass spheres (Patent Storm, 2009).

The glass powder is used in industry to enhance performance and reduce viscosity in paints and coatings and as lightweight additives in plastic parts. They are chemically inert, non-porous, and have very low oil absorption. With the addition of hollow spheres to fiberglass reinforced plastics (FRP), epoxy, compounds, and urethane castings can provide weight reduction cost savings and improved impact resistance. Insulating features of hollow spheres also work to the chemists' advantage in thermal shock and heat transfer areas. (Potters Industries, 2008)

According to William Shaker, Market Development of Polymer Additives at Potter Industries, one conventional additive can match the performance benefits of the glass spheres. The advantage of the spherical hollow glass spheres is its low density of between 0.6-1.1g/cc small particle size and lightweight. With particle sizes considerably finer than previously available, SPHERICEL® hollow microspheres can be used in thin film coatings to improve integrity. "Because glass spheres do not absorb resin, more resin is available to create the film," explains Shaker (Potters Industries, 2008). "The result is a tighter and more uniform film with improved durability, even under adverse conditions" (ThomasNet, 2005). Also Potters Industries offer SPHERIGLASS® solid glass spheres. This is a denser alternative to the hollow glass spheres used in this research. In having a higher density than the hollow spheres allows it to be used where much high strengths are needed. For the scope of this research only hollow glass spheres will be used during experiments.

## 2.6 Materials Selection

In this research the catalyst Hexion Phencat 15 was chosen as it is a fast action acid catalyst. This will allow for the glass powder and the phenolic resin to react much faster than a slow acting catalyst. Once the chemical reaction has begun the composite compound can start to cure. Using fast acting catalysts will cut down on the time taken to fully cure the specimens. Phencat 15, in most cases used to cure surface pastes, which will be ideal for conducting experiments in the thin moulds that will be used. Also a surface paste is used when high temperatures are involved. (Super shine, 2008)

### 2.6.1 Catalysts

The reaction between the Phencat 15 catalysts and the phenolic resins can be strongly exothermic (Munoz et al, 2007). The catalyst is toxic, so skin contact of the plane catalyst can cause burns. Munoz found that Phencat 15 catalyst when mixed; whilst the ratio of catalyst to resin is too high (ratio greater than 10:1) experiments had to be halted as the mixture did become exothermic and become quite hot.

### 2.6.2 Phenolic Resin

A general Cellobond J2027L Phenolic resin was chosen to be used in the composite mixture. This resin has a low viscosity which makes it ideal for use in manufacturing where injection molding is used. Due to the low viscosity it will be a good choice as it will be easy to pour and manage in the molding stage.

### 2.6.3 Glass powder

For the glass filler, Potters Industries SPHERICEL® 60P18 (spherical) hollow glass spheres was chosen. The hollow glass spheres were chosen instead of the alternative solid glass spheres that potters industries also offers. The hollow spheres were a better option as the focus of this research is to investigate into the use of glass as a filler, not only to enhance the mechanical characteristics of the phenolic resin mixture but also allow for a cheaper alternative, than the pre-existing composites currently available. In addition, the hollow spheres, has a lower density than the solid spheres which will allow for a lighter but still strong composite to be created (Potters Industries, 2008).

### 2.6.4 Cost Analysis

When conducting any experiments the expenses for materials and equipment need to be assessed. Firstly the components that will be used to make the composite material, phenolic resin costs approximately $6.50 per kilogram and the catalysts costs $8.00 per kilogram. Previously studies which have been conducted have used an alternative filler material called E-spheres SLG as it is a fly-ash a by-product formed from burning of coal, the cost that is incurred is lower then other filler materials at a costs $3 per kilogram, whereas currently the price of the glass powder which to be used in this study is $5 per kilogram. It is a more expensive filler to use but as research is still in early stages, a full conclusion cannot be made, on the feasibility and the effects that the glass hollow microspheres has on the mechanical properties of the phenolic resin. The above prices what the university paid for each material. Other equipment that is needed will already be provided, due to other studies that have been previously conducted i.e. moulds.

## *2.7 Research work done*

Kawamura and Jenkins were pioneers with the use of fillers as the use of fillers within the phenolic resin was not common industry. They published a paper about the use of glassy carbon fibres mixed with phenolic resin. In this publication by Kawamura and Jenkins, they gave an elementary discussion on the structure and mechanical properties of the fibres by assessing the composite fibres that were formed by static tensile testing, electron microscope and X-ray diffraction. In this paper they discuss results that were found about the change in the measurements of mechanical properties of the fibres once tested. The first major hurdle that Kawamura and Jenkins had to overcome was there limited knowledge about the structure of the glassy carbon. This was due to when analyzing the fibres for poor crystallinity, did not allow for X-ray diffraction to have an acceptable level of accuracy. When observing the structural features with an electron microscope at low resolving power the same problem was in counted. To overcome this difficulty, later testing of the fibres using a high resolution electron microscopy revealed the structure of the glassy carbon fibre.

When, Kawamura and Jenkins began a range of tests which were to test different mechanical properties of the composites. A critical factor that was found was that certain measurements needed to done fires before testing of the specimen. Whilst doing this it was discovered that if the moldings of the specimen was not uniform, the result would be

an inconsistent cross-sectional area of the specimens which would hinder the results obtained from the static tensile test. Kawamura and Jenkins note that the ultimate tensile strength of a fibre is noticeably higher than commonly used glassy carbon. They also comment that in relation to using glass in the phenolic resin mixture to produce a fibre composite has a higher ultimate tensile strength the commercially available glass.
Whilst conducting the tensile tests they carried out Young's modulus for the fibre and found that after heat treatment the modulus increased, due to the possibility of formation of intermolecular cross-links of the phenolformaldeyhde-type chain molecules (Kawamura and Jenkins, 1972).

In a journal article about mechanical and thermo-mechanical failure mechanism analysis of fiber/filler reinforced phenolic matrix composites and how more and more polymer matrix composite materials are finding increasing application. Polymers composite are not only used as structural materials but also as ablative materials due to their high resistance within several industries. Phenolic resins as a plastic material are capable of producing a very strong bond with other materials. The mechanical properties of the plain phenolic resin are low tensile and flexural strength along with a high thermal expansion. With proper bonding, phenolic composites have shown that their mechanical properties can be altered to be equivalent to other composite and metals that are currently available. 'The tensile strength of graphite fiber reinforced phenolic resin composite is 10 times that of the unreinforced phenolic resin. This is comparable to the tensile strength of 6061 aluminum alloy (Wang et al 1997). Wang also discussed how the addition of fillers in to the composite has shown to give a number of desirable effects. In preliminary results Wang et al found that by adding glass powder to phenolic resin a higher value of flexural strength occurred compared to the other tested filler carbon black. From this he concluded that glass filled phenolic resin has a better mechanical integrity than carbon black composite, as well that in general it showed to have higher flexural modulus and flexural strength than unfilled phenolic resin. Once the final results were analyzed it was concluded that on average the flexural strength of the phenolic resin increased 10-15% by introducing 10%wt of glass particles into the phenolic resin mixture (Wang et al, 1997).

Fu et al (2008) in a journal article leads into detail discussion on the effects of the particle size, particle/matrix interface adhesion and particle loading on the stiffness, strength and toughness of particulate-polymer composites. He goes on to describe the experiments that were conducted to show the difference of the mechanical properties of particulate-filled polymer micro and nano-composites are affected by particle size, particle content and the interfacial adhesion between the particle and matrix. Later on in the journal, Fu investigated the effects of particle loading in composite materials and concluded that the modulus (Young's Modulus of Elasticity) increases with increasing particle loading. For example that particulate-polymer composite showed that it as well as hydroxyapatite filled composites had a modulus increase by approximately 50-100% when a 10vol% of filler was added. This was reinforced when tensile testing was conducted as it showed an increase in the values with the fillers present. 'Hence, addition of rigidity particles to a polymer matrix can easily improve the modulus since the rigidity of inorganic fillers is generally much higher that that of organic polymers' (Fu et al, 2008).

Redhel (1995) wrote in a paper article on the importance and patience required when caring out phenolic resin tensile tests. Redhel explains how simple it is to misalign the specimen in the testing apparatus which then will induce bending and a non-uniform stress field in the specimen, which was demonstrated in his testing when a high percentage of the specimens failed around the region of the hydraulic clamps on the apparatus. The results that were obtain showed scatted results which showed the alignment of the specimen is a concern, also Redhel goes on to explain other possibilities for the inconsistent results that were found. Other possibilities were that porosity form either by water evaporating after curing or porosity that formed whilst mixing was being conducted (Redhel, 1995).

Ben and Shoji (2005) states in a recent journal piece about the need to develop a new type of phenolic composite that can overcome drawbacks of current methods which have had different and unfavorable reactions with the Phenolic resin. He explains that they would experiment with the use of a glass fibre as the reinforcement material in the phenolic resin and later test the mechanical and thermal properties of the composite. Ben and Shoji also re-elaborates what Redhel concluded in his journal. For the case of the resole type of phenolic resin, water formed from the condensation reaction still remains in the matrix, and when this water evaporates resulting in the formation of voids during the curing process. To overcome this Ben and Shoji experimented with using glass fibers as a filler to hopefully minimize porosity in the composite (Ben and Shoji, 2005)

Guo et al (2007) explain in his paper that from scanning electron microscopy (SEM) a strong interfacial bonding between glass fibers and the phenolic resin is shown. Throughout the testing of the glass-nonmetals the content of resin and fillers were constantly adjusted. The glass was added to the phenolic mixture at set intervals by weight fraction of 10%, 20%, 30%, and 40%. Due to the outline of Guo paper extra ingredients such as bromide and bisphenol were added to the mixture. These ingredients when added allowed for the composite to be fire retardants and reduce the risk of fire. Once these are mixed in Guo explains that a more detail report would have to be constructed, as both ingredients are toxic and would have to be reviewed on the environmental risks they could have. The results showed that the use of glass-nonmetals as filler in Phenolic Moulded Composites (PMC) shows a probable method for resolving the environmental pollutions and reducing the cost of PMC. Hence, by using renewable resources from a environmental protection viewpoint places more focus on the possibility of substituting wood flour by glass-nonmetals, and allowing for innovative types of PMC that are lower in cost as well as having enhanced properties than traditional PMC (Guo, 2007).

Verma et al (1996) discusses in a paper on the effects that resin modification has on the wear and friction on glass phenolic composite. This paper explains how the resin modification was conducted to show what if any effects transpire from the modifications on glass phenolic composite specimens. Verma showed that the tensile strength and modules, as well as the flexural strength and modulus were improved once the straight phenolic composite was modified. The tensile modulus and strength of the straight phenolic resin were 20.57 (GPa) and 381.44 MPa respectively, then the altered phenolic composite was tested, which resulted in the two values having increased to 36.80 (GPa) and 406.43 (MPa) respectively. This is of significance, as other mechanical tests that were conducted also showed similar increase in the modified composite strengths (Verma et al, 1996).

## 2.8 Concluding Remarks

This chapter has provided background information on composite materials, as well background knowledge on the three ingredients that will be used throughout this project. This will cover an overview of the specific materials phenolic resin, catalyst, glass powder that will be used. It is clear, that the need for more investigation into filler materials to find out what if any improvements the new filler material has on the neat phenolic resins materials characteristic and if there are any mechanical properties improvements. This is indicated by numerous articles above that mentioned that adding filler material to phenolic resin mixture to form a composite has the potential to create a stronger and lighter composite yet still be cost effective. Guo et al (2007) explains that results that were found in his study indicated that the use of glass-nonmetals as filler in Phenolic Moulded Composites (PMC) shows a probable method for resolving the environmental pollutions and reducing the cost of PMC.

# 3 Methodology

## 3.1 Introduction

This chapter will identify what and why a methodology is an important part of a research project. Project methodology allows for planning of project as well setting out the requirements of the study in the limited amount of time allocated. When setting out a timeline, adequate time must be given to each task to be conducted.

Some task for instance, the making of the specimens will take longer than to post-cure the specimens in the oven. This then needs to be taken into consideration. Firstly an analysis should be conducted on the resources that are required to perform the experiments with as well as potential quantities that may be required. As the proportion of the phenolic resin and catalyst varies this will require different amounts of the resin so extra resin may have to be prearranged to keep on track with the set out timeline.

## 3.2 Resource Analysis

To carry out this project there are several resources, needed along with the availability of required laborites and laboratory staff for consultation and direction, on how to use the oven and the tensile testing apparatus.

The following equipment will be required for this experiment:

- Safety equipment (glasses, gloves, footwear, breathing mask)
- Plastic molds (six specimen can be made per mold)
- Metal bolts with wing nuts (to hold the two layers of the mould tightly together to minimize seepage)
- Phenolic Resin
- Catalyst
- Glass Powder

- Sheet of glass (prevent material landing on curing specimens)
- Cooking oil/wax (to line the mould prior to casting of the composite to allow specimen not to stick to the mould, an easy removal once cured.)

As similar studies have been conducted by the University of Southern Queensland and the Centre of Excellence in Engineered Fibre Composites (CEEFC) the phenolic resin and catalyst are already available. The moulds, safety equipment and metal bolts are all reusable items throughout the entirety of the project. These items were provided by the Engineering faculty. The glass powder will have to be ordered as it has not been used in previous studies conducted by the University. The cooking oil/wax and the safety gloves (latex) are items required which are not able to be reused; the quantity of these items will have to be monitored throughout the experiments to ensure they do not run out and delay the already rigid timeframe of the project.

The laborites where the practical side of the project will be conducted are:

- Laboratory Z106.1 (molds are cast)
- Z116.1 (post-curing oven)
- Z104.1 (tensile testing machine)
- Z135.1 (Stereo Microscope)

These three laborites are used often and are regularly available provided the laboratory supervisors are notified when experiments are taken place. The Lab supervisor can also be assistance especially in the oven and testing labs as they are experienced with how the machines operated. Without lab supervisor's the specimens may be damaged and will have to be remade adding extra time on an already tight time schedule. If the oven or the tensile testing apparatus were to break, this would bring the project to a stand still, as time would have to have been reallocated to allow for the repair of the machine. Currently the university only currently has one oven and tensile apparatus, which means if a problem did occur with either machine, time would have to be spent waiting for parts to repair either device. For this reason care will be taken to prevent the machines from being used outside the limits defined in these project guidelines, as well as consultation with the Lab supervisor to ensure the parameters of the machines are not breached. Once all the resources have been established a start can be made on the experiments and safety precautions needed.

## *3.3 Safety Analysis*

Safety plays a major part in any situation or task being undertaken. As the tasks differ, so do the risk and safety precautions that need to be taken to ensure the safety of everyone involved. When entering a workplace for the first time a risk assessment should be carried out to ensure ones safety as well the safety of others. Throughout the duration of the experiments the rules and regulations were followed that are in the Workplace Health and Safety Act 1995 and the recently amended Workplace Health and Safety Regulations 2008. In the Workplace Health and Safety Act 1995 act there is a 5 step risk assessment guidelines to adhere to:

- look for hazards
- evaluate risks,
- asses risks,
- implement plan to minimize risks,
- re-examine to classify if the plan works effectively.

A work permit under Workplace Health and Safety Act 1995 was issued for the laboratories required in the experiments as well as material safety data sheets for the three components to be used in the composite mixture. (Queensland Government, 2008)

The steps will be evaluated and applied to this study.

### 3.3.1 Identification of risk factors

During the execution of this research project, there are many risks to be aware of. There are three processes involved in conducting the experiments for this project. Firstly, the making of the specimens, secondly, post-curing the specimens in an oven and thirdly conducting tensile test on the post-cured specimens. Care needs to be taken when measuring ingredients to make sure it is accurate and while handling the materials in creating composites to make sure safety regulations are adhered too. The post-curing of the specimens in an oven is another risk that needs to be considered. The oven reaches high enough temperatures to cause mild to moderate burns and even possibly severe ones. The third process being conducted is testing the post-cured specimens with the tensile testing apparatus. As with any machine with moving parts it has the chance of being caught. The tensile testing apparatus has moving parts in testing the specimens. Caution needs to be taken so the moving parts of the apparatus do not get caught on it. A preventable measure is a surrounding area to be outside whilst machine is operating.

### 3.3.2 Evaluation

When having to handle and work with chemicals in and around the laboratory the safety rules and guidelines of personal safety equipment are adhered too, as well as to ensure risks are minimized. The three materials that are being mixed together require the correct quantities for the specific batch. If the quantities is changed or miscalculated, it may result in the composite becoming unstable and possibly exothermic, leading the mixture to heat up significantly.

The three components/material used for creating the composite are Phenolic Resin, Catalyst and Glass Powder. The risk associated with each component will be evaluated

<u>Phenolic Resin</u>
“Phenol formaldehyde”
Hexion Cellobond J2027L (Chemwatch, 2005a)

Risks associated with using the Phenolic Resin

- Toxic by inhalation
- Toxic in contact with skin and if swallowed
- Causes Burns to skin
- Limited evidence of a carcinogenic effect

- Serious damage to eyes if it comes in contact
- May cause Sensitisation by skin contact
- Cumulative effects may result following exposure* (limited evidence)

Catalyst

Hexion Phencat 15* (Chemwatch, 2005b) (limited evidence)
"Phenolic resin hardener catalyst"

Risks associated with using the Catalyst

- Harmful by inhalation and if swallowed
- Causes burns
- Cumulative effects may result following exposure *
- Possible respiratory sensitiser*
- Possible cancer-causing agent following exposure

Glass Powder

Spherical Hollow Glass Spheres (Potters Industries INC)
"Glass oxide powder"

Risk associated with using the Glass Powder

- Glass Powder dust in excess of recommended exposure limits may result in irritation of the respiratory tract.
- Local exhaust fan is recommended for operations that generate nuisance dust in excess
- Chronic lung conditions may be aggravated by exposure to high concentrations of dust
- Use NIOSH approved dust mask or respirator where airborne dust is generated to prevent inhaling the dust
- NIOSH approved safety glasses or goggles

All three materials appear to have a certain degree of dangerous risk involved. If care is taken and the personal safety equipment is worn then the risks are minimized. Exposure to the ingredients, is a minimal risk, due to the Exposed period to the materials is about 15-20 minutes whilst the materials are being mixed together, once initial curing in the moulds has commenced the risk of the ingredients begins to decrease.

When the post-curing in the oven commences if the user is not carefully when curing the specimens the possibility of burns to the arms or any other part of the body which comes in contact with the oven whilst preheating is commencing may result in some degree of burns.

After the specimens have gone through post-curing in the oven, each specimen will have tensile testing on them using a tensile testing machine. Mistreatment of the tensile machine any machine can cause, physical harm, due to the powder of it. If a body part was caught within the machine it has safety shields and a kill switch in place in case of emergency. The machine will have to be studied so the position of the safety switch is known before using the machine. Whilst machine is operating the user should have all safety shields in place and be standing away from the apparatus until the action it is undergoing has completed.

### 3.3.3 Control Environment

Firstly, all laboratories have compulsory protective safety equipment that everyone who enters the laboratory must abide by e.g., wear eye protection, covered footwear. When making the moulds latex gloves and breathing masks should be worn. To avoid any harm occurring to the user literatures are provided focusing on the materials which detail, all the hazards and risks that each ingredient/machine have. The literature should be read and understood thoroughly before entering the lab and handling the ingredients. Having the literature also allows the user to read safety procedures in case of an emergency, whether it is a spill on the workbench or on another user. Minimizing and controlling the risks on the oven as well as the tensile testing apparatus warnings signs and marked safe areas for the operator to stand whilst the devices are in use. A laboratory assistant will help the machinist in identifying key safety issues and the warning signs to be aware of whilst operating the devices, to ensure there safety is guaranteed.

## 3.4 Preparation of moulds and ingredients

First task undertaken was to locate the laboratory and equipment needed in the project and to become familiar with safety precautions that each part need. Obtaining literature on the ingredients so good backgrounds on the ingredients that will be used throughout the experiment are obtained. These ingredients are the Catalyst (Hexion Phencat 15) the Phenolic resin (Hexion Cellobond J2027L) and the Glass powder (60P18 Sphericel Hollow Glass Spheres).

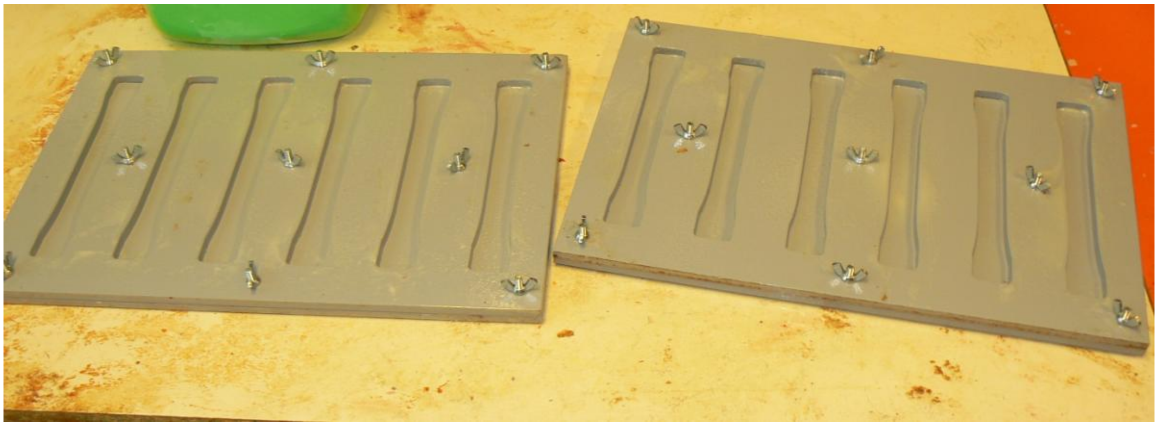

**Figure 3-1 Moulds prepared for use**

Figure 3-1 illustrated the moulds once they have been clear of remaining composite and is lubricated ready to be used again. To prepare the moulds much consideration and preparation is needed to have the moulds ready for use. When cleaning and preparing the moulds any slight left over resin or groves left on the mould needs to be removed otherwise removal of the specimen could be relatively difficult. Once the moulds are cleaned they are then sprayed with Canola oil to prevent the composite sticking to the moulds.

## 3.5 Moulding

Moulding takes place once the moulds have been prepared and cleaned thoroughly. The first round of mould specimens were placed at a ratio of 30:1 resin to catalyst. This was then allowed to cure at room temperature. As this experiment has not been conduct using the glass powder as filler in the phenolic resin mixture, this ratio will be a trail. The ratio may have to be altered at a later stage if the specimens did not cure suitably.

**Figure 3-2 illustrates the glass being added to phenolic resin**

Once the ingredients have been add to the mixture as shown in Figure 3-2. Once ingredients are added the mixture needs to be stirred slowly and consistently to avoid the mixture getting large amounts of air bubbles. If too much air is captured in the mixture when the specimen cures and is removed from the moulds and is able to continue on to be post-cured then tested the porosity, (air bubbles) it will most likely alter the results found in the tensile tests especially testing for porosity.

As soon as the specimens have cured in the moulds it can be removed from the moulds. Whilst removing the specimens it is possible that the specimens may not be fully cured and may warp under its weight. If this is the case and the specimen is removed from the mould in one piece it will cure in a deformed shape. The deformed shape will be tested at a later stage and the results will possibly give a false reading which could result in lower mechanical properties for the specimen. This will be due to preloading of the specimen by the clamps on the tensile testing apparatus as it clamps the material before conducting the tensile tests.

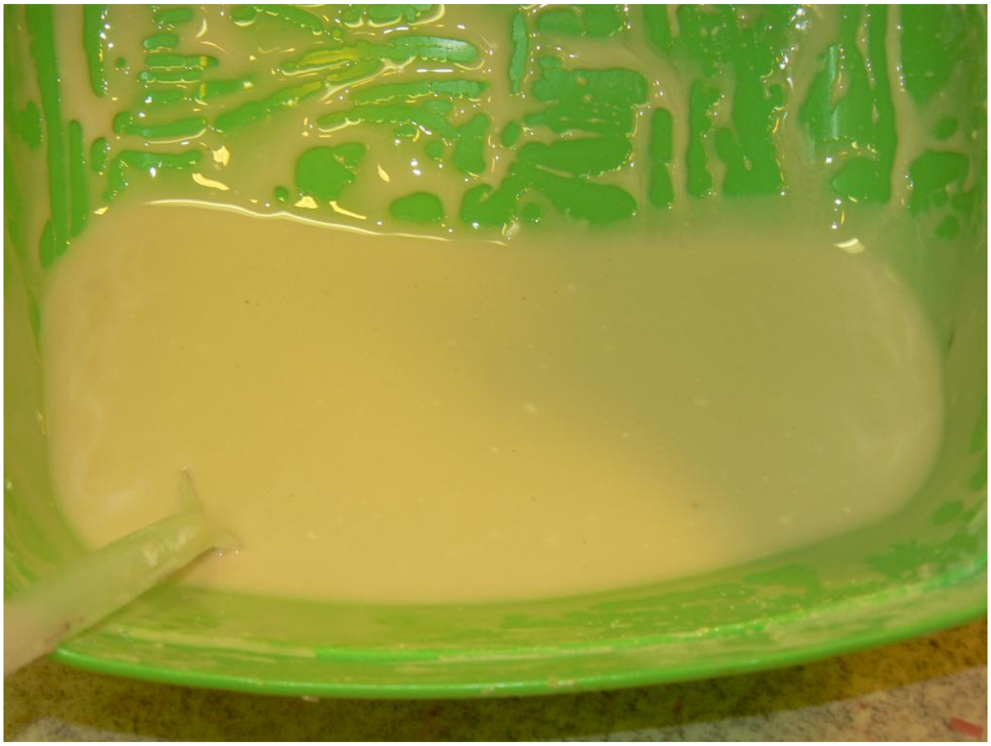

**Figure 3-3 Homogeneous Mixture**

**Figure 3-4 Finished moulds**

Once the glass powder, phenolic resin and catalysts are blended together and the mixture has a homogenous mixture it is placed into the molds. Figure 3-3 indicates what a homogenous mixture looks like. The molds consist of an upper and lower plate. The plates are illustrated in Figure 3-1. They are clamped together by 9 bolts with wing nuts; all bolts are then tightened to ensure they are tight and hopefully minimize seepage of the composite between the plates. Once the composite has been carefully poured into the mould the mold is vibrate slightly to release any air that may have been trapped within the mold. Figure 3-4 shows what the finished moulding looks like once the mould has been prepared and all bolts secured the composite is carefully poured in.

After the composite mixture has had time to cure in the moulds and are able to be removed it will be placed in the oven to be post-cured hopefully without blemishes or porosity. When the specimens are placed in the oven they are placed at a series of temperature and time parameters:

- 4 hours at 50 °C
- 4 hours at 80 °C
- 2 hours at 100 °C

**Figure 3-5 Illustration of Conventional oven**

Figure 3-5 shows the conventional oven that was used to post-cure the phenolic resin, glass powder composite. Once they have been cured in the oven the post-cured specimens will be cooled and then placed through a tensile test to determine the mechanical properties and the strength of each specimen. Issues that may occur during the post-curing process are the possibility of the specimens warp or deform whilst being baked in the oven.

As the mechanical testing that will used to test the specimens is tensile testing, to identify the mechanical characteristics, it is important that the composite while curing remain straight and flat. To ensure that the specimens remain straight once successfully removed from the moulds they will be placed between two pieces of glass. Also to maintain the cured specimens flat and straight when they are post-cured in the oven the specimens will be subjected to approximately 1kg load, this load will be applied during the baking of the specimens.

## 3.6 Tensile Tests

**Figure 3-6 Tensile testing machine**

Before the tensile test can be conducted all specimens need to be measured and recorded into the data logger on the computer that runs the program used by the tensile testing machine. Figure 3-6 illustrates the tensile testing machine that was used to test the glass powder reinforced phenolic resin composites. Once the data is logged the computer can test the specimens and then interrupt the results into the stress-strain graph. From the graph an analysis can be made on which percentage by weight of glass powder had the greatest improved material/mechanical properties. Reading off the stress-strain graph the tensile and yield strength can be determined as well as the Young's Modulus of Elasticity for each of the phenol formaldehyde, glass powder composite specimens. Before the specimen can be tested the cross-sectional area needs to be calculated, as well as taking care in placing the specimen into the machine, setting the distance between the jaws of the apparatus to the same for each specimen (gauge length). This is to eliminate a variable as well as allowing the computer to calculate the yield and tensile strength along with the Young's modulus.

### 3.6.1 Tensile Strength

The tensile strength of a material is the most common and sought after property of a material. Tensile test is easy to resolve as well as being of valuable for the purposes of specifications and quality control for manufactured goods. In tensile tests the force and extension of the specimens are recorded by a data logger. Figure 2 show a typical example of a stress-strain graph which shows the tensile force versus tensile elongation for a specimen undergoing the test.

To calculate the tensile strength, divide the maximum load by the original cross-sectional area of the specimen. (Wang, 2007)

$$\text{Tensile strength} = \frac{Maximum \quad load}{Original \quad cross-\sec tional \quad area} \tag{1}$$

or

$$\sigma = \frac{P_{\max}}{A_o} \tag{2}$$

where $P_{max}$ is the maximum load in Newton and $A_o$ is the original cross-sectional area in $mm^2$.

For example, the tensile strength of a sample of how to apply the above equations are illustrated in Figure 1 in Appendix A

$$= \frac{972}{14.9x5.0} = 13.135(MPa)$$

The tensile strength for this example is 13.135MPa

### 3.6.2 Yield Strength

Yield strength is the point at which a definite amount of plastic strain has occurred. This is usually 0.2% of the proof load. For certain materials including phenolic resins a value of 0.05% of the proof load is used to identify an approximate value of the yield point. This is due to phenolic resin being more brittle than steels and other more ductile materials.

By drawing a line in x, y direction the point where it crosses the theoretical values of the stress-strain curve is the proof stress or offset yield strength.

Yield strength is calculated using the relationship below (Wang, 2007)

$$\text{Yield strength} = \frac{Yield \quad load}{Original \quad cross-\sec tional \quad area}$$

For example, yield strength of the sample illustrated in Figure 1

$$\frac{0.05\% \quad offset \quad load}{Original \quad cross-\sec tional \quad area} = \frac{925}{14.9x5.0} = 12.50(MPa)$$

The yield strength for this example is 12.50MPa

### 3.6.3 Young’s Modulus of Elasticity

Young’s Modulus of Elasticity is a measure of how brittle a material is. It is calculated from the previously found stress-strain graph of the material by finding the gradient of the initial linear portion. As the force-extension exhibit a prefect linear relationship the Young's modulus calculated is the secant modulus at a strain 0.1 percent.

To calculate Young's Modulus the following equations are used.

Stress $(\sigma)$ $$\sigma = \frac{F}{A_o}$$

Strain $(\varepsilon)$ $$\varepsilon = \frac{\Delta L}{L_o}$$

Young's Modulus
of Elasticity (E)

$$\text{E}=\frac{stress}{strain}=\frac{\sigma}{\varepsilon}$$

$$\text{E} = \frac{\frac{F}{A_o}}{\frac{\Delta L}{L_o}}$$

Where ΔL is the change in length of the material, F is the force place on the specimen by the apparatus during testing, subscript '$_o$' denotes original measurement before testing was conducted. To identify how this is conducted please refer to Figure 2 in Appendix A.

$$E = \frac{\frac{400-0}{14.9x5.0}}{\frac{0.24-0}{110}} = 2477.473(MPa) = 2.477(GPa)$$

The young's modulus of elasticity for this example is 2.477 GPa

## 3.7 Composite Sample

The filler that was used was SPHERICEL® 60P18 (spherical) hollow glass spheres through a range of 0% to 35% by weight in the cured phenol formaldehyde composite / glass powder PF/GP (X %) where X is the percentage by weight of the filler. As the materials are unrefined the specimens were cast, into moulds to be later tested via tensile testing. The neat resin is a dark brown coloured liquid and once mixed with glass powder the mixture becomes a cream like colour. The catalyst is then added it’s also a dark coloured liquid, as the percentage of glass increases in the specimens the whiter the cured specimen becomes. Table 3-1 demonstrates the mass of the resin, catalyst and glass powder that are required to make 150 grams of uncured composite for 10% by weight of glass powder. When making the specimens, 6 specimens can be obtained from one mould. The amount of mixture required to adequately fill the moulds is approximately a 150 grams. This is to allow for any spills or inconsistency of the mixture. If the exact amount the mixing pot would have to be completely clean to have the complete ratio that had been carefully measured previously, hopefully by increasing the mixture size to 150 grams instead of the exact amount of 120 grams will minimize or eliminate the possibility of any neat resin, catalyst or glass powder that was not mixed thoroughly being placed in the mixture. This may occur as when dealing with such small amounts it is easy to overlook a small clump of glass powder which would yield an undesirable composite and lead to inconsistent results. The test pieces must conform to standards, to allow consistency in past, present and future studies.

**Table 3-1 Required amounts for 10% Glass powder**

| Parameters | Resin ( R ) | Catalyst ( C ) | R +C | Glass Powder | Composite |
|---|---|---|---|---|---|
| | | | | | |
| Percentage by weight | 30 | 1 | --- | --- | --- |
| Percentage by weight | --- | --- | 10 | 1 | --- |
| Weight of Materials in 150g of PF/Glass Powder (10%) | 130.6 (g) | 4.4 (g) | 135 (g) | 15 (g) | 150(g) |

## 3.8 Concluding Remarks

This chapter has described the methodology that will be used to begin the experimental part of the project to be conducted. The methodology has sets out the procedures and materials required to complete the experiment in a safely manner but also how to carry out the experiment to ensure the results will be of an acceptable nature, and to permit adequate and precise results to be drawn from the results that have been found. From tensile tests preformed on the composite a recommendation can be drawn on which percentage of glass powder as filler in phenolic resins is the best selection

# 4 Results and Discussion

## 4.1 Introduction

This chapter provides the results obtained from the tensile test outlined in the previous chapter as well as explanations of tensile and yield strength and Young's moduli. In addition, a series of microscopic photos will demonstrate the effects on porosity and its formation. This chapter will analyze the positive and negative effects of using glass powder.

Currently the price of the phenolic resin is $6.50 per kilogram and Phencat catalyst costing $8.00 per kilogram, previously a study used E-spheres SLG which is fly-ash a by product of burning coal as filler and only incurred a costs $3 per kilogram, whereas currently the price of the glass powder by weight is $5 per kilogram. It was a more expensive filler to use but as research has indicated thus far, the feasibility and the effects that the hollow glass microspheres has on the mechanical properties of the phenolic resin has been favorable.

## 4.2 Summary of Findings

**Figure 4-1 Test piece loaded in the tensile testing machine**

Figure 4-1illustrates a frontal view of the tensile testing apparatus once a specimen has been load into it.

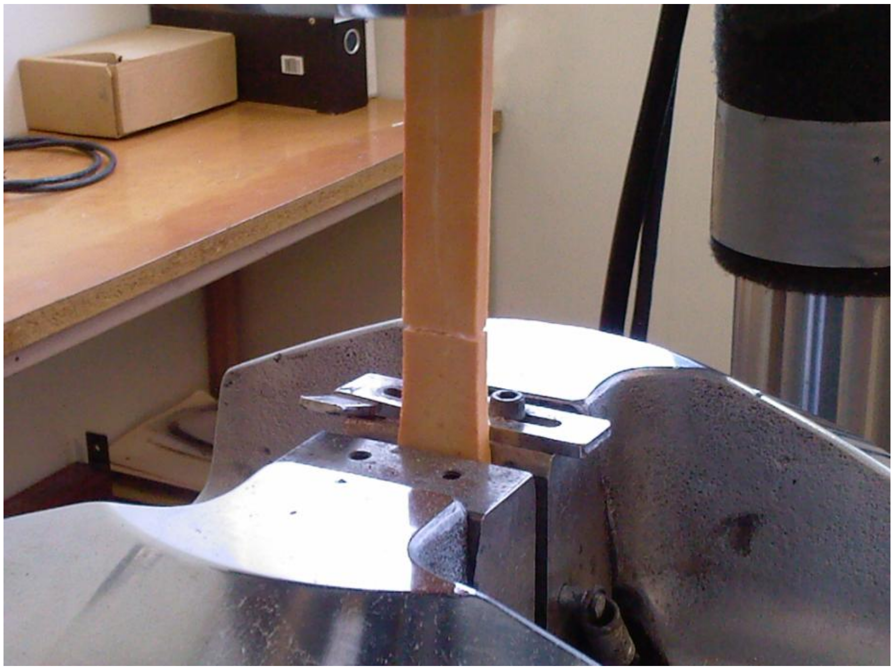

**Figure 4-2 Test piece that has failed in the tensile testing machine**

Figure 4-2 shows a specimen that was tested and failed at a particular section. This is a good result as the point at which it failed was due to the weaker mechanical strengths of the material not due to human error or due to machine damage.

Glass powder reinforced phenol formaldehyde matrix composite were made at varying percentages from 0% to 30% glass powder by weight at 5% intervals. The initial process consisted of mixing the phenolic resin and catalysts together then slowly adding the glass powder slowly until finally a homogenous mixture is created.

**Figure 4-3 Measuring of Ingredients**

This was achieved only after all ingredients had been accurately measured to 0.1 gram of the required quantity. Figure 4-3 illustrates this being done. Once measured the catalyst (Hexion Phencat 15) and Phenolic resin (Hexion Cellobond J2027L) are mixed together to form the basis of the mixture followed by the glass powder (Hollow Glass Spheres) is added slowly as, the mixture is stirred. If there was a delay between adding the glass powder to the phenolic resin and catalyst mixture, a chemical reaction will began and the mixture will begin to form a film across the mixture. Once a film has formed, it needs removal from the mixture, whilst still stirring. Taking out the film that has formed causes more problems as the ratio mixture is now not correct, as you cannot be sure how much of phenolic resin and catalyst has been taking out. When the specimens were being removed from the moulding, it was observed that several specimens had not fully cured and broke whilst be removing.

Another problem that occurred was if any overspill occurred when the uncured mixture was being put in the moulding proved difficult to remove. As this is an increasing problem, a revised method once implicated allowed the specimens to be removed easier. This was done by joining paddle pop sticks together on the base side of the moulding and applying pressure down on the paddle sticks. The underside or base side of the moulding was often the cleaner side with minimal overspill. After trialing, the method it proved to be much more efficient in removing the specimens as if appeared to distribute the pressure being applied more efficiently then could be done so without the paddle pop sticks. Another theory that was considered was that when, the lubricate is applied to the moulds to allow the specimen to slide out. Instead of using the canola oil wax was implemented and proved to be more successful in applying an even coat of the lubricate then the aerosol can of canola oil.

**Figure 4-4 Deformed Specimen**

During initial baking of the Specimens it was observed that a number of test specimens become slightly deformed and developed a bow in the middle. Figure 4-4 shows one of the worse effected specimens that were deformed. Fortunately when this was discovered only a few specimens had been post-cured in the oven, alternative methods were implicated to counteract this occurring in other specimens. To do so, during the baking session, all test pieces were subjected to a heavier load of approximately 1kg, this load was only applied during the baking of the specimens. .

As there is limited literature currently available on the use of glass powder as a filler material in phenolic resin mixture an approximation was made based on similar studies that have been conducted in the past. To commence the experiments a moulding ratio of 30:1 was used, which was phenol formaldehyde resin: catalyst. For the first set of specimens to contain glass powder in the mixture the material once cured was a deep dark colour and appeared to have clumps of glass powder on the surface of the majority of the specimens. Once tested the results yielded reasonable results. An example of this is demonstrated in Figure 4-5

**Figure 4-5 An example of Glass Clumps**

A latter mixture at the same ratio was made and tested with similar results. This ratio was also used with an increase of glass powder by weight to 10%; the results that were obtained showed that all three mechanical tests showed an increase in the strength of the composite material. When the testing was conducted it was observed that the mixture was not as dark as the previously tested 5% mixture, also the material when setting up the specimens the tensile machine had to be altered as crushing began to occur and had to be aborted. This then leads to belief that material is becoming more brittle as the filler by weight increases.

The next percentage of 15% of glass powder by weight was tried at the current phenolic resin catalysts ratio. After it was allowed to cure for 3-5 days the mixture was still soft and was not curing, to enable the mixture to cure the ratio was increased to 20:1 and later trailed at 15:1, as 20:1 after 5 days was not cured fully and whilst being removed from the moulding the composite specimens deformed or critically failed. The mould specimens began to cure much faster due to the ratio so more care was taken to pour the uncured composite mixture into the moulds. Due to this the mixing of the material as it was beginning to cure was becoming difficult at this ratio the process was altered accordingly. When the materials are being added initially the phenolic resin and catalysts were mixed together before the glass powder was added.

This process was altered to allow the phenolic resin to be well mixed with the glass powder and then the catalysts added to the mixture. This proves to make the mixing process easier as the chemical reaction the catalyst produces was delayed. This was evident once the mould had fully cured and was abstracted from the moulding; inspections of the new test specimens appeared to have a better mixture of the phenolic resin and glass mixture than that of the lower ratio’s previously used which yielded glass clumps being easily noticeable in the specimens. Once the 15% glass powder specimens were loaded into the tensile testing apparatus it was seen that clamp pressure needed to be increased as the clamps were slipping along the test piece. This leads to the assumption that the material maybe becoming less brittle and more ductile then the 10% by weight of filler composite mixture. The same mixing process was followed for the rest of the experiments.

The proceeding percentage to be cast was 20% glass powder by weight it was trailed at the current ratio and was left to cure. The specimens were allowed and extra 2 days on top of the 15% specimens. After 5 days the specimens appeared to have a firm top and once beginning to eject the specimens out of the moulds it was discovered that they had in fact not fully cured and were left in the mould for a further 2 days to ensure they were able to be removed without damage.

From here 25% and 30% mixture were made at both 15:1 and later 12:1, at both ratio of phenolic resin to catalyst the composite took up to 2 weeks before the specimens appear to be cured enough to be removed from the moulding. As this was rather difficult several mixtures were made. It was found that in both cases the 12:1 ratio returned better mechanical strengths then the 15:1 ratios. The reasoning behind using two ratios for both cases was due to the difficulty that occurred whilst mixing the mixture as well placing the uncured mixture into the moulds. Due to the high content of glass powder being 25 and 30% glass powder by weight of the total mixture stirring the mixture proved to be difficult. To get the fast curing mixture into the moulds the mixture had to be spooned in instead of previous methods of pouring it in. When placing the mixture into the mould the chance of porosity occurring increase dramatically, later once the specimens were closely examined before tensile testing is conducted to identify if porosity had formed from this method. Fortunately the specimens came out uniformly with minimal porosity occurring. Both of the tested glass percentage began to show sign that the material was becoming more brittle as when being tested the clamping force had to be again reduced.

## *4.3 Results of tensile testing*

Please Refer to Appendix C for actual recorded data from tensile testing machine

### 4.3.1 Tensile Tests

Tensile testing is a most common and sought after a mechanical test, as it easy to resolve as well as being of valuable for the purposes of specifications and quality control for manufactured goods. In tensile tests the force and extension of the specimens are recorded by a data logger. Before the specimen is tested, the cross-sectional area is calculated. When handling the specimens care is required when placing the specimen into the tensile testing machine, setting the distance between the jaws of the apparatus to the same for each specimen (gauge length). This is to eliminate a variable as well as allowing the computer to calculate the yield and tensile strength along with the Young's modulus.

When attempting to remove the specimens from the moulding took time, as the specimen, being small, and not fully cured. Several methods were trialed, due to the difficulty of overspill of the mixture that had cured, incurred problems as by applying force to the ends of the specimens, tended to stick to the edges resulting in cracks at the neck of the specimen. The method that proved to have the best result in removing the specimens was to place two popsicle-sticks on the bottom of the moulded specimen. From here, minimal pressure was applied to evenly distribution the over the specimen allowing for smoothness of the extraction. To ensure higher accuracy of results it was important to extract the six specimens from the same moulding mixture, this is due as the mixture are made slight variation can occur for e.g. Temperature, mixing time.

### 4.3.2 Yield Strength

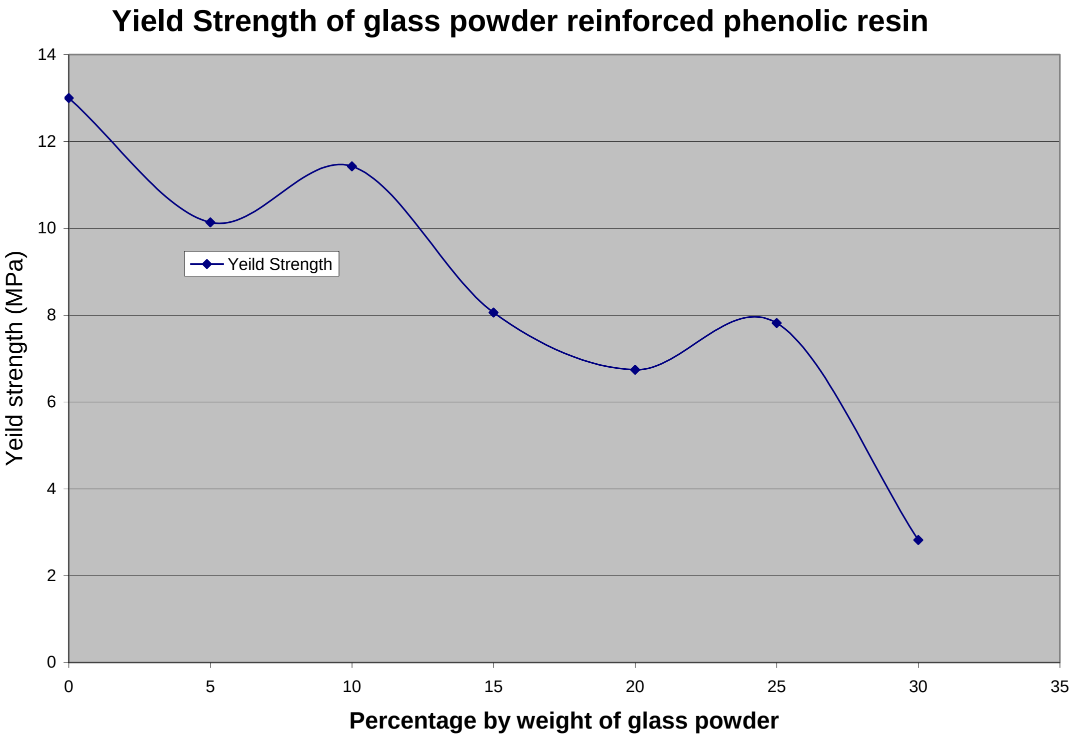

**Figure 4-6 Yield Strength**

Figure 4-6 shows the yield strengths of varying percentages by weight of glass hollow spheres, once merged to form a reinforced phenol formaldehyde matrix composite. The neat yield strength of the phenolic resin was 13.00 MPa; this was higher than that of the test pieces that contained a percentage by weight of glass powder. At 5% by weight of filler the yield strength was 10.14 MPa; it then increased to 11.42 MPa with 10% by weight of glass powder. From this percentage of filler by weight, the composite generally was observed that as the percentage by glass powder content improved, the lesser the yield strength became. At 30% filler the composite sample only gave yield strength of 2.82 MPa. At 25% glass powder it appears that the values found could be inaccurate, this could be that when preliminary measurements where taken the in corrected value may have been logged into the computer. This is also proven via inspection of Table 4-1, which shows the values of yield strength mentioned above with their standard deviation in brackets as well as showing that the values of glass by weight increase the yield strength drops. If cost and yield strength, are criteria for a project, it can be argued that a composite with 10% by weight of glass powder is the optimal.

**Table 4-1 Yield Strength of glass powder reinforced phenolic resin composite**

| Percentage by weight of Glass Powder | 0 | 5 | 10 | 20 | 25 | 25 | 30 |
|---|---|---|---|---|---|---|---|
| Yield strength, (MPa) | 13 | 10.14<br>(1.45.)[#] | 11.42<br>(1.20) | 8.06<br>(1.21) | 6.74<br>(2.15) | 7.82<br>(0.69) | 2.82<br>(0.98) |

[#] Standard deviation

### 4.3.3 Tensile Strength

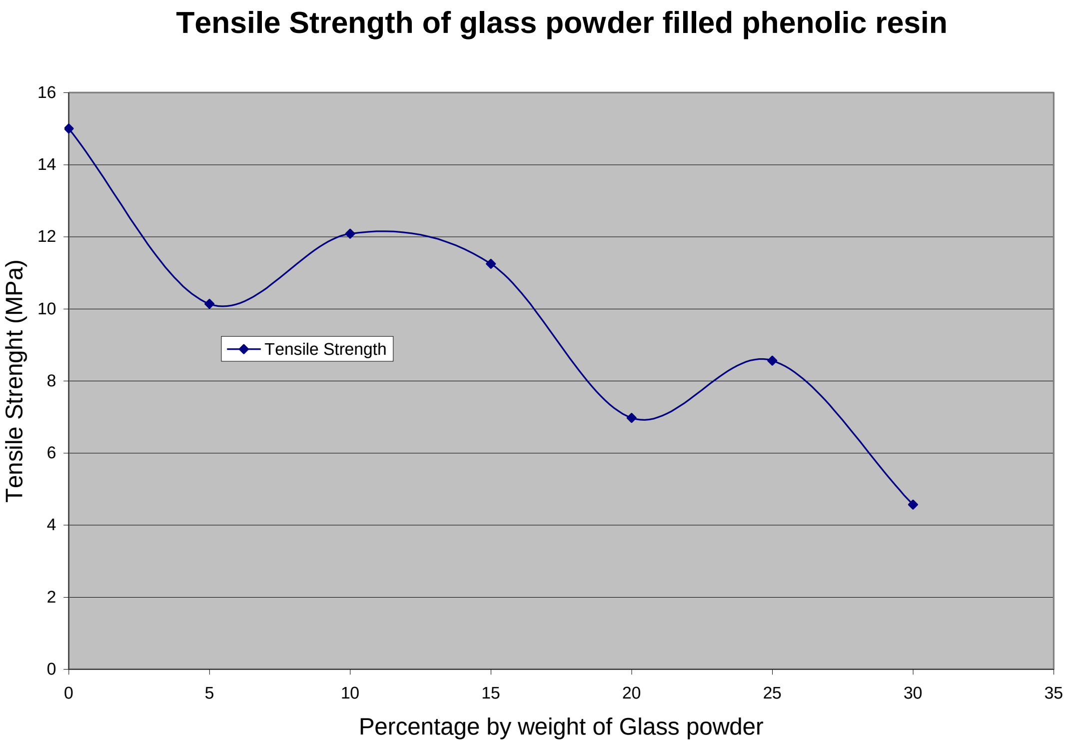

**Figure 4-7 Tensile Strength**

Figure 4-7 illustrates the Tensile Strengths of the varying percentage by weight of glass powder reinforced phenol formaldehyde matrix composite. The tensile strength of the neat resin equated to 15.00 MPa. When glass powder was introduced to the phenolic resin at 5 percent by weight the tensile strength decreased to 10.13 MPa; from this point it was observed that on average the composite mixture increased in value until 10% glass powder by weight, which yielded a figure of 12.08 MPa. The maximum tensile strength that was found from any percentage by weight of the glass powder was at 10% glass powder by weight. After this the glass reinforcement dropped the values of the tensile strength, this is demonstrated in Figure 4-7 Tensile Strength. The tensile strength further lowered to 6.97 MPa having 20% by weight of filler in the test pieces, and then continued to decrease in strength where only 4.56 MPa was found at 30% glass powder by weight. At 25% glass powder their seem to be an irregularity in the results that were found as seen in the graph, this may be caused due to the mixture have more ideal conditions when being produced, i.e. surrounding temperatures. The variation of tensile strength with respect to percentage by weight of glass powder is the same as that of yield strength. If cost and tensile strength were considered at the same time, composite with 14% by weight of filler would be selected. Table 4-2 shows the values of tensile strength mentioned above with their standard deviation in brackets.

**Table 4-2 Tensile of glass powder reinforced phenolic resin composite**

| Percentage by weight of Glass Powder | 0 | 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|
| Tensile Strength, (MPa) | 15# | 10.14 (1.45)# | 12.08 (1.11) | 11.25 (1.98) | 6.98 (2.01) | 8.56 (0.69) | 4.57 (1.67) |

\# Standard deviation

Redjel (1995) found that the tensile strength for neat resin was 27 MPa, which was really very high as compared to the result of this research. The material that was used was a pure phenolic resin 84055 catalyzed by 3 percent of C 1650 and cured at 80°C for 8 days. It was produced and prepared by CDF-Chimie, France. The curing time was excessively long and would not be industrially viable and the energy consumption was enormous.

The trend of the tensile strengths of this research was in line with those of glass bead reinforced polystyrene, i.e. the tensile strengths decreased with increasing particle loading (Dekkers and Heikens, 1983). However, the trend was just the opposite of that of glass beads filled epoxy resin (Amdouni, et al., 1992)

### 4.3.4 Young's Modulus

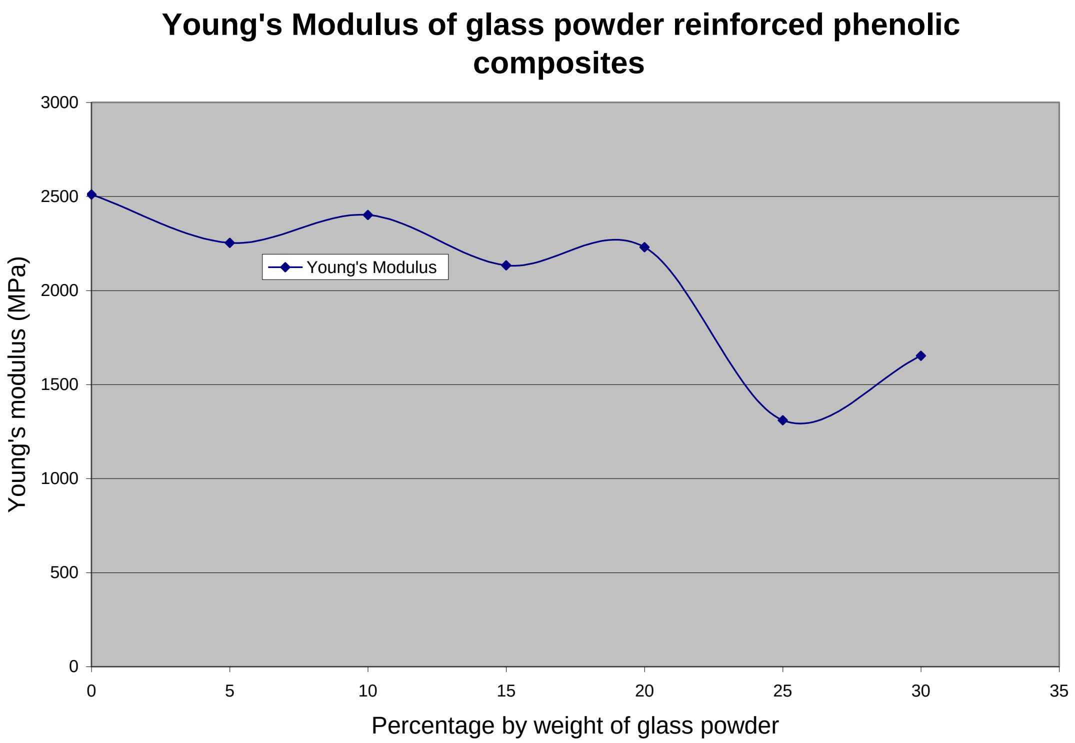

**Figure 4-8 Young's Modulus**

Figure 4-8 illustrates how the Young's moduli changes by weight of glass hollow spheres reinforced into the phenol formaldehyde composite mixture. The young's modulus of the neat phenolic resin had a reading of 2.51 GPa, once the filler material was added the young's modulus decreased to 2.25 GPa when the percentage of glass powder by weight was 5%. Once the 10% filler by weight was tested, it showed slightly higher values than that of the 5% test pieces, which was 2.40 GPa. It dropped to 1.65 MPa when the percentage of filler by weight was 30%. By inspection of the results seen in XXX as well as visual inspection of the graph the reading the was found on 25% glass powder appears to be out of the expected range, this could be due to the pressure being altered on the tensile testing apparatus due to crushing of previous specimens. This also demonstrated in Table 4-3. As previously, concluded tests showed as well as young's modulus indicated that as the glass quantity in the mixture increases the strength of the composite decreases. If cost and Young's modulus were to be considered for a specific task phenolic composite reinforced with glass powder with 10% by weight of filler is optimal.

**Table 4-3 Young's modulus of glass powder reinforced phenolic resin composite**

| Percentage by weight of Glass Powder | 0 | 5 | 10 | 15 | 20 | 25 | 30 |
|---|---|---|---|---|---|---|---|
| Young's Modulus, (GPa) | 2510 | 2253 (133) # | 2401 (138) | 2133 (318) | 2230 (10851) | 1310 (276) | 172 (172) |

# Standard deviation

In comparison to the results of those of phenolic formaldehyde (2.76 – 4.83 GPa) (Callister, 2005). In another study when using pure phenolic resin the Young's modulus was found to be 2.51 GPa, which is 13.5 % lower than that found by a group of researchers for pure phenolic resin (2.9 GPa). The same team used ICI Fiberite resol-type CMXR-6055 phenolic formaldehyde resin; this research used Chemwatch Borden (Hexion) Cellobond J2027L phenolic formaldehyde resin. When obtaining these results the environmental factors such as working temperatures were not discussed as well as the time allowed for the resin and filler material to mix and cure before continuing on to be post-cured (Ku et al., 2006). Table 2 shows the values of Young's modulus mentioned above with their standard deviation in brackets. Redjel (1995) found that the Young's modulus for neat resin was 5.16 GPa, which was considerably higher compared to the result of this research and that found in literature (Callister, 2005).

## 4.4 Microscopic Analysis

**Figure 4-9 Stereo Microscope**

A Stereo microscopic shown in Figure 4-9 was used to conduct an analysis on the broken test pieces to identify if any porosity had formed and the size and number of bubbles that may have from the baking process or from the mixing of the specimen. The formation of these blemishes will impact on the tensile properties of the composites.

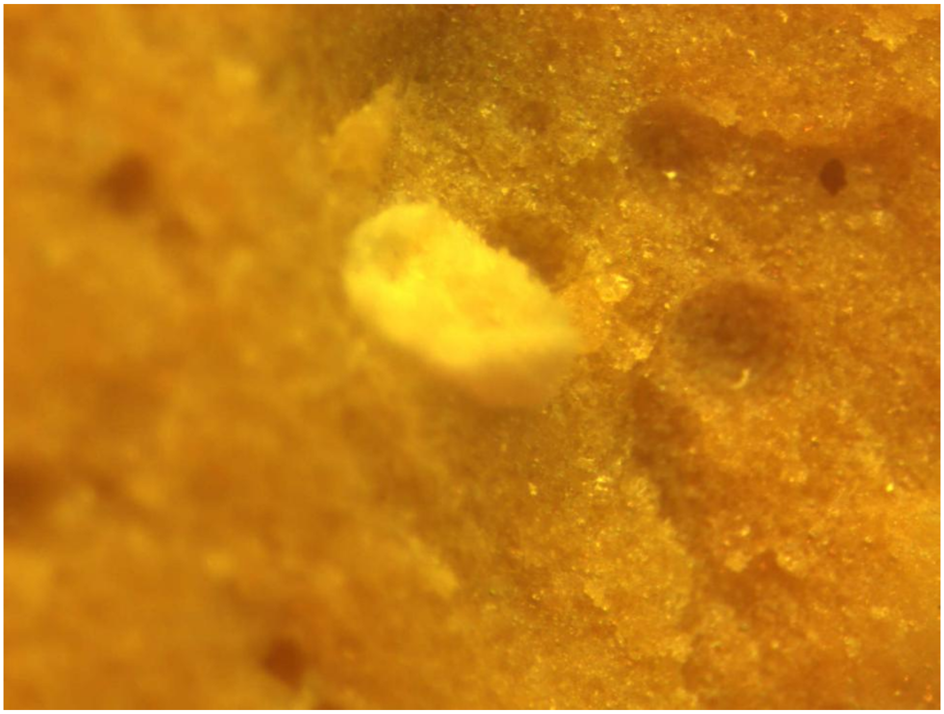

**Figure 4-10 Microscopic view of specimen, with glass powder at 140 times magnification**

Figure 4-10 shows the resulting test specimen that showed a clump of glass powder that was able be seen by the naked eyed. The dimensions of the clump are 4.85 microns by 2.78 wide; measurement was conducted via the camera’s software to identify the real distance. Overall, on only several specimens showed signs of such clumps of glass powder that could be seen by the naked eye.

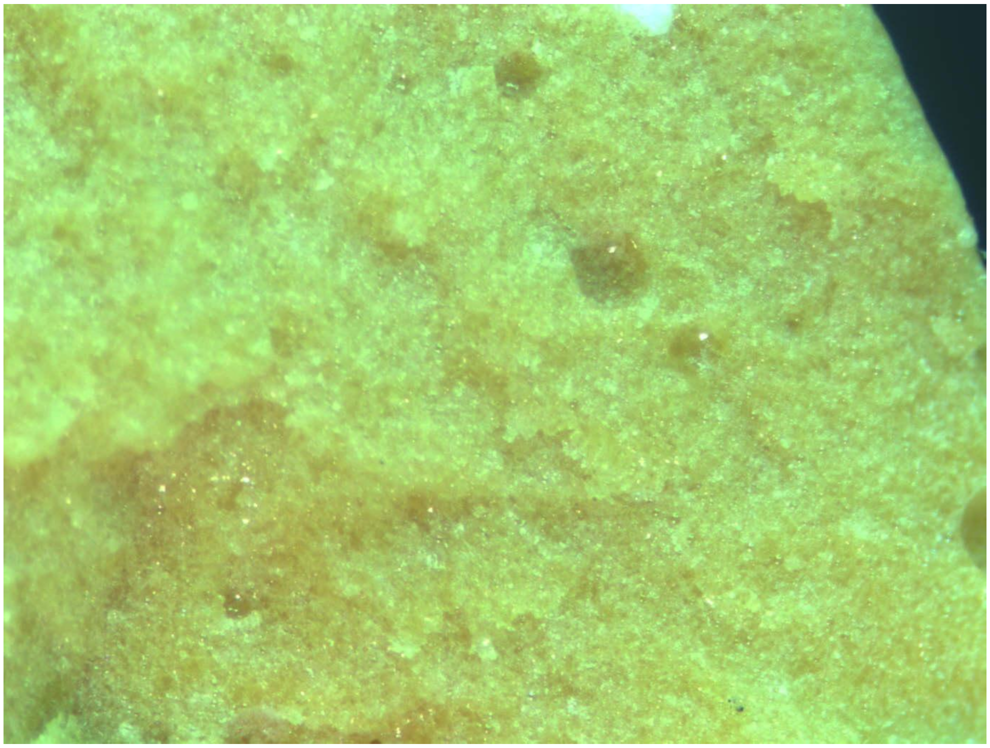

**Figure 4-11 Microscopic view of specimen, with glass powder at 70 times magnification**

Figure 4-11 shows the formation of air bubbles on the surface of this particular specimen. The bubbles once formed can accelerate the rate of failure, also it is noticeable that the surface is uneven, which may alter the results obtained from the tensile testing. This was tested by analyzing two specimens that were from the same batch. The two specimens that were chosen were one that contains only a small amount of porosity with a specimen that had a larger more obvious amount of porosity/ air bubbles.

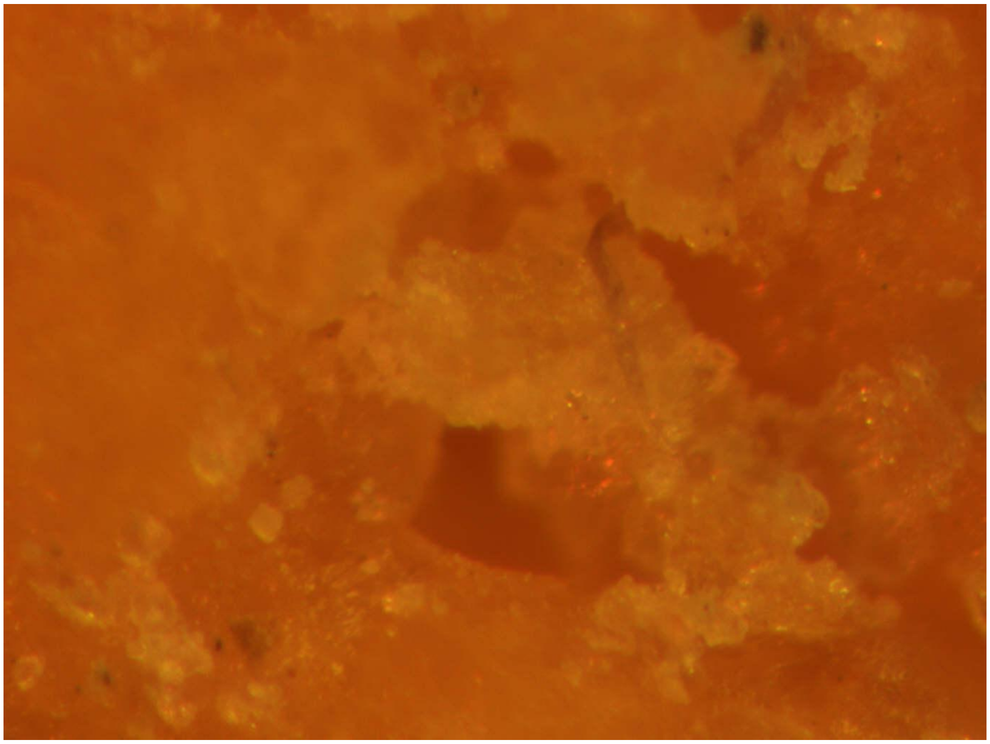

**Figure 4-12 Microscopic view of specimen, with porosity at 140 times magnification**

Figure 4-12 is an example of a higher glass content composite mixture. The difficulty that was found was when mixing the mixture, which had higher glass content the mixture was much harder to stir and place into the moulds, this allowed larger air bubbles to form in the uncured composite.

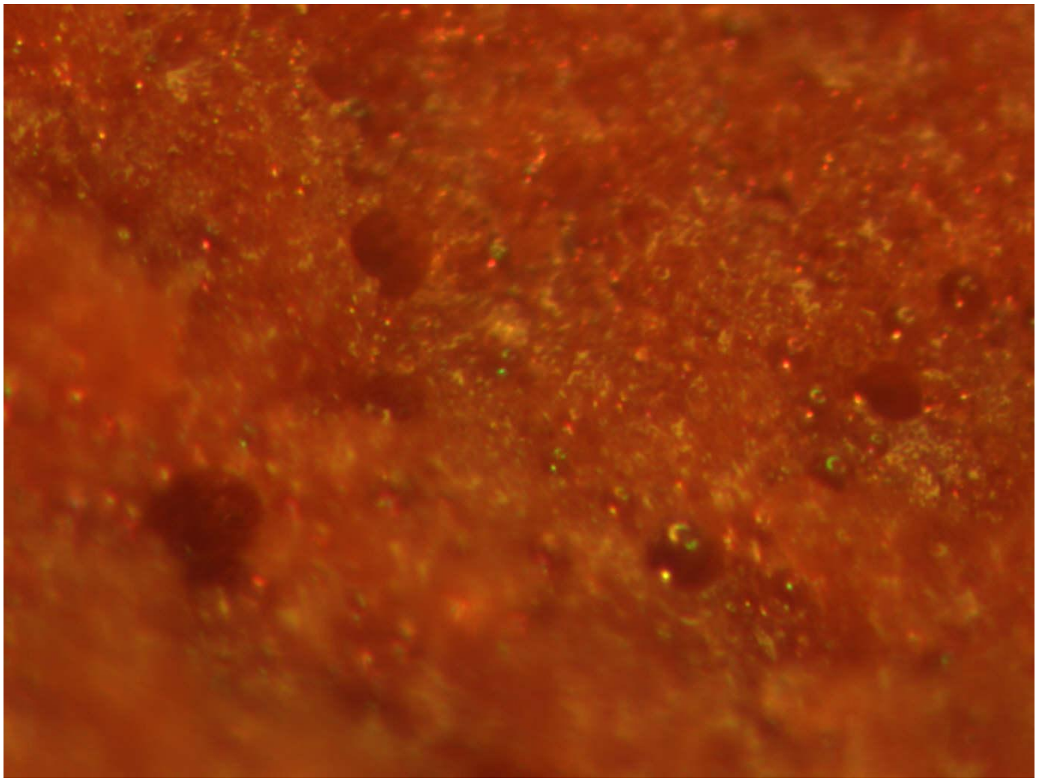

**Figure 4-13 Microscopic view of specimen, with porosity at 560 times magnification**

Figure 4-13 illustrates the blending of the glass powder in the phenolic resin at higher magnification. In addition, several small porosity dimples formed. The most likely would have occurred during post-curing when the condensation evaporated due to the sizing of the porosity.

## 4.5 Concluding Discussion

In the chapter the results that once found by the Yield strength, Tensile strength and Young’s modulus for varying percentages by weight of glass powder reinforced phenolic resin were explained and discussed. In cases where there was less than 25% glass powder by weight present in the mixture, the fluidity of the slurry composite was high and could be cast easily into moulds. The values, which contained no filler material, once reviewed with those found by another study, but they had varying results between the different studies. It is possible that when the fusion between phenolic resin (matrix) and glass powder (reinforcer) increases by adding some other fillers and resins to the composite, may lead to a increase in the tensile strength. The best percentage of glass powder by weight, that when added to the phenolic resin to give an optimum Yield and Tensile strengths, Young modulus and cost is approximately 10 percent. In the above figures this is illustrated, that using glass powder by weight as filler and reinforcing agent within the existing phenol formaldehyde matrix composite is a viable option. To view the raw data from each set of samples that were post-cured by the conventional oven and had tensile testing conducted on them please find the Appendix B attached.

# 5 Conclusion and Recommendations

## 5.1 Introduction

This chapter will summarize the findings found in this study, as well drawing a final conclusion from chapter 4. A recommendation will be recognized on which percentage gives the best percentage of glass powder by weight. After the results have been reviewed and analysis in chapter 4 it was able to been seen how the different glass powder percentages affect the final mechanical properties of the phenolic resin mixture. Most of the data gathered appears to be accurate with only a few results outside the estimated range.

## 5.2 Summary

Throughout chapter 2 a detail literature review was conducted on several journal articles relating to the chosen topic. From this review numerous authors concluded that the need for more research on phenolic resin is required, as industry is ever improving in the sense that their always the need to redesigning equipment for efficiency as well as to be more cost effective. This places more emphasis on the need to conduct similar studies on adding filler material to the existing phenolic resin in the hope that a stronger more specific composite can be created for a specific purpose.

After a methodology setting out the procedures was conducted the experiment commenced, not long after the methods had to be altered to keep the project on the all ready tight timeframe. These consisted of using a different type of lubricate on the preparation of the moulds. Doing this allow for a higher percentage of the specimens came out without any fractures or deformation, Once this was solved there were still several specimens that would become stuck in the mould and would break once more pressure was applied. After the paddle pop concept was implied the amount of specimens breaking or having stress fracture deteriorated down to only a few.

After the results had been found form the tensile testing it was found what effects occurred when glass powder is added to the phenolic resin mixture at varying percentages by weight. In cases where there was less than 25% glass powder by weight present in the mixture, the fluidity of the slurry composite was high and enable to be cast easily. Results showed that when no filler material is used found that it differed to other studies that had been reviewed previously. It also is possible that by additional materials to the mixture as well as another filler or resin that a stronger more specific composite can be discovered.

Results concluded that the best percentage of glass powder by weight to add to the phenolic resin to give the best Yield and Tensile strengths, Young modulus and still be a cheaper alternative was approximately 10 percent. This was evident in chapter 4 where the mean results showed that for yield, tensile and young's modulus was highest at approximately 10% glass powder by weight, for the full tabulated data please refer to Appendix D.

## 5.3 Recommendation for Future Work

Future work for this project includes further analysis focusing on the mixing process of the filler with the phenolic resin, maybe to adjust how the composite is mixed by using mechanical devices to mix the uncured composite. The mixing process consists of placing the glass powder and phenolic resin together and stirring still the two ingredients have blended without a chemical reaction. Once the catalyst is added to the mixture a chemical reaction is triggered and the mixture begins to cure. If a mechanical device was to be used for mixing the materials instead of manual stirring, it could possible allow for a more homogeneous mixture to be formed prior to pouring into the moulds. A comparison can then be obtained whether using the mechanical devices to mix the uncured composite will add strength to the moulds. If a mechanical device was used there is a possibility that the unmixed (clumped) glass powder that was found via microscope would be eliminated. With a mechanical device, a set timeframe to mix the uncured composite mixture could be established where a homogeneous mixture are obtained.

Another recommendation would be to redo this study to compare the results as well as identify and check the validity of the results with the results found in this study. As glass powder has been identified as a viable option to consider for filler in a phenolic resin composite, this option needs to be reinforced with future studies focusing on the strength, feasibility density of glass powder as a filler option. As previously stated solid glass spheres are also available, and a similar study can be conducted to show what characteristics the solid spheres have on the phenolic resin and review the results to this study on the differences of the two materials.

If a further study was to be conducted on the feasibility of using glass powder as filler material in the phenolic resin, investigation could be done on the use of a higher percentage of glass compared to this study. If this was conducted, additional materials would have to be added to the mixture to overcome the issues of occurred when mixing the high percentage of glass powder.

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# Appendix A Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

**ENG 4111/4112 Research Project**
**PROJECT SPECIFICATION**

| | |
|---|---|
| FOR: | **TRAVIS CECIL** |
| TOPIC: | INVESTIGATE THE BEST PERCENTAGE BY WEIGHT OF GLASS POWDER, AS FILERS IN PHENOLIC RESINS USING TENSILE TESTS |
| SUPERVISORS: | Dr H Ku and Dr. F Cardona |
| ENROLMENT: | ENG 4111 - S1, 2008<br>ENG 4112 – S2, 2008 |
| PROJECT AIM: | This project aims to investigate the best percentages of glass powder by weight into the phenolic resin. This will allow for a more cost effective option whilst maintaining a high strength characteristic. |
| SPONSORSHIP: | Faculty of Engineering and Surveying, USQ |

**PROGRAMME:** **Issue A, 20th March 2008**

1. Research the background information relating to phenolic resins, and the need to reduce the cost of composites in today’s society.

2. Investigate a range of percentages by weight of glass powder into phenolic resin mixture.

3. Analyze the specimens and the data collected once the tensile tests have been conducted.

4. Evaluate the data that had been collected and review and draw conclusion on which percentage is a better option.

5. Submit an academic dissertation on the research

*As time permits:*

6. Conduct more defined tests around the best percentage to determine the optimal filler percentage.

7. Cure specimens in a microwave, to allow a comparison between the microwave and the oven as the better option when post-curing.

AGREED:

_______________________________ (Student)                    ___/___/___

_______________________________, _____________________________ (Supervisors)

___/___/___                                                  ___/___/___

Examiner/Co-examiner:______________________________________________

# Appendix B How to calculate tensile tests

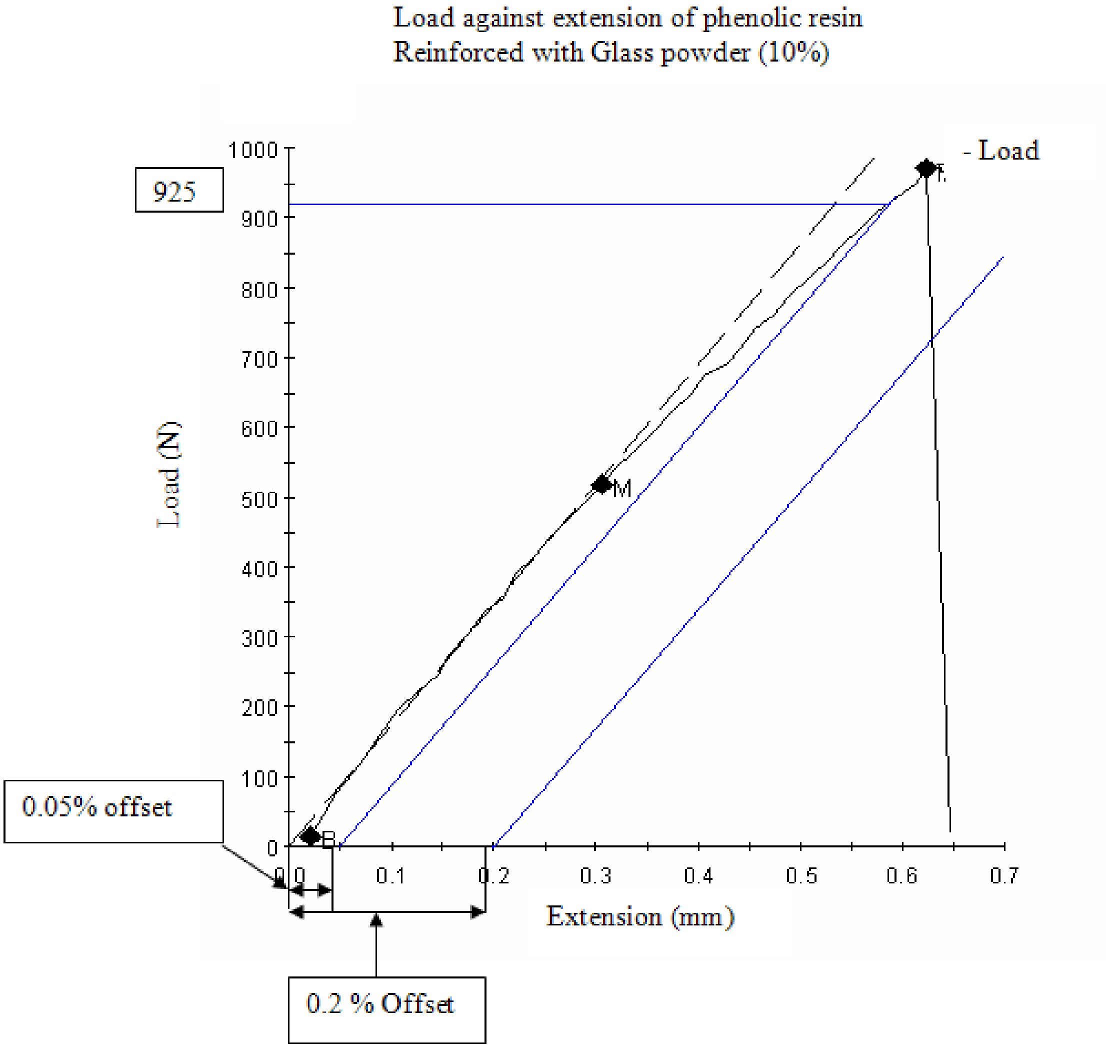


Figure 1: Load against extension of a sample showing the 0.05% proof load

To calculate the tensile strength, divide the maximum load by the original cross-sectional are of the specimen. (Wang, 2007)

$$\text{Tensile strength} = \frac{Maximum \quad load}{Original \quad cross-\sec tional \quad area} \qquad (1)$$

or

$$\sigma = \frac{P_{\max}}{A_o} \qquad (2)$$

where $P_{max}$ is the maximum load in Newton and $A_o$ is the original cross-sectional area in $mm^2$.

For example, the tensile strength of a sample of how to apply the above equations are illustrated in Figure 1 in Appendix A

$$= \frac{972}{14.9x5.0} = 13.135(MPa)$$

Yield strength is calculated using the relationship below (Wang, 2007)

$$\text{Yield strength} = \frac{Yield \quad load}{Original \quad cross-\sec tional \quad area}$$

For example, yield strength of the sample illustrated in Figure 1

$$\frac{0.05\% \quad offset \quad load}{Original \quad cross-\sec tional \quad area} = \frac{925}{14.9x5.0} = 12.50(MPa)$$

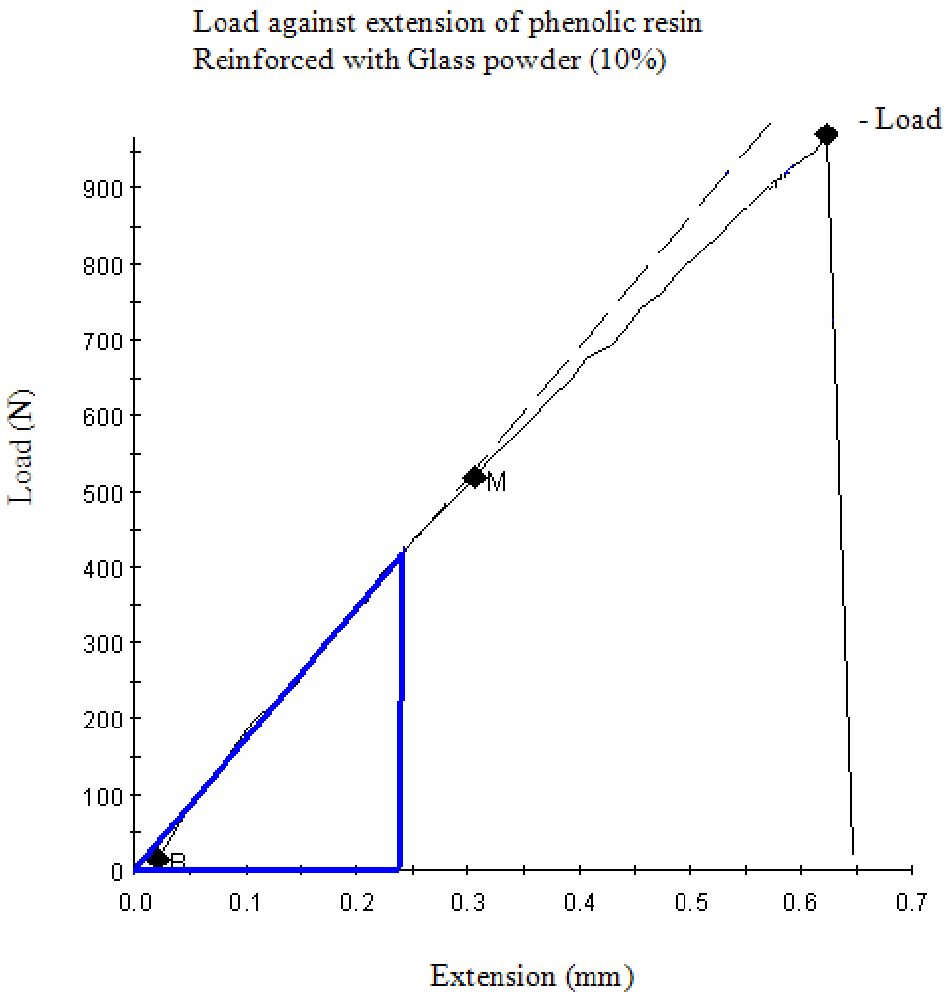


Figure 2: Graph showing how to obtain data to use when calculating the Young's modulus for phenolic composite

To calculate Young's modulus the following equations are used.

Stress $\sigma = \frac{F}{A_o}$

Strain $\varepsilon = \frac{\Delta L}{L_o}$

Young's Modulus $E=\frac{stress}{strain}=\frac{\sigma}{\varepsilon}$

of Elasticity

$$E = \frac{\frac{F}{A_o}}{\frac{\Delta L}{L_o}}$$

Where ΔL is the change in length of the material, F is the force place on the specimen by the apparatus during testing, subscript '$_o$' denotes original measurement before testing was conducted. To identify how this is conducted please refer to Figure 2 in Appendix A.

$$E = \frac{\frac{400-0}{14.9x5.0}}{\frac{0.24-0}{110}} = 2477.473(MPa) = 2.477(GPa)$$

# Appendix C Actual data logged

**travis-5%R30-G RC 30:1**

Report Date: 21/07/2008

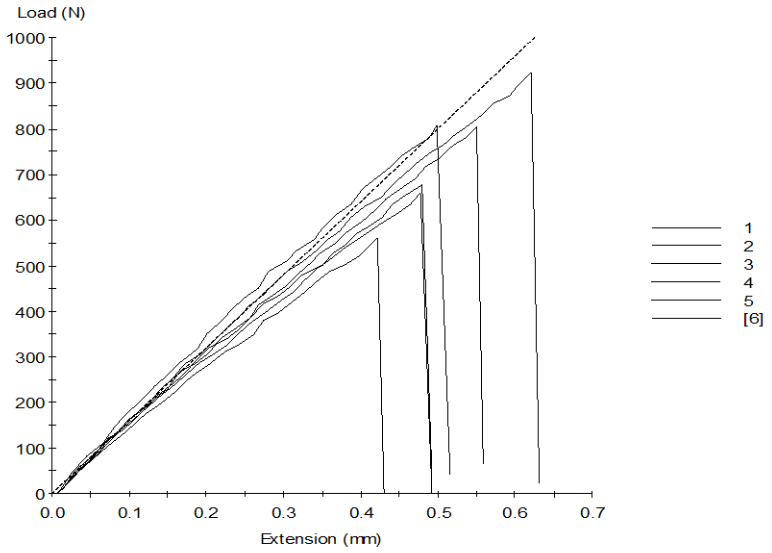
Test Date : 21/07/2008

Method : MMT Tensile Test with return.msm

## Specimen Results:

| Specimen # | Thickness mm | Width mm | Area mm^2 | Peak Load N | Peak Stress MPa | Break Load N | Break Stress MPa |
|---|---|---|---|---|---|---|---|
| 1 | 14.700 | 5.300 | 78 | 678 | 8.70 | 678 | 8.70 |
| 2 | 14.700 | 5.120 | 75 | 659 | 8.75 | 659 | 8.75 |
| 3 | 14.760 | 5.300 | 78 | 807 | 10.31 | 807 | 10.31 |
| 4 | 14.550 | 5.250 | 76 | 561 | 7.34 | 561 | 7.34 |
| 5 | 14.600 | 5.140 | 75 | 803 | 10.70 | 803 | 10.70 |
| 6 | 14.670 | 5.190 | 76 | 924 | 12.14 | 924 | 12.14 |
| **Mean** | **14.663** | **5.217** | **76** | **739** | **9.66** | **739** | **9.66** |
| **Std Dev** | **0.076** | **0.079** | **1** | **130** | **1.72** | **130** | **1.72** |

| Specimen # | Elongation At Break mm | Stress At Offset Yield MPa | Load At Offset Yield N | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0.479 | 7.799 | 607.624 | | | | |
| 2 | 0.476 | 8.129 | 611.820 | | | | |
| 3 | 0.499 | 9.698 | 758.690 | | | | |
| 4 | 0.422 | -0.056 | -4.263 | | | | |
| 5 | 0.550 | 10.378 | 778.832 | | | | |
| 6 | 0.621 | 10.053 | 765.404 | | | | |
| **Mean** | **0.508** | **7.667** | **586.351** | | | | |
| **Std Dev** | **0.069** | **3.925** | **299.579** | | | | |



travis-10%G- **RC 30:1**

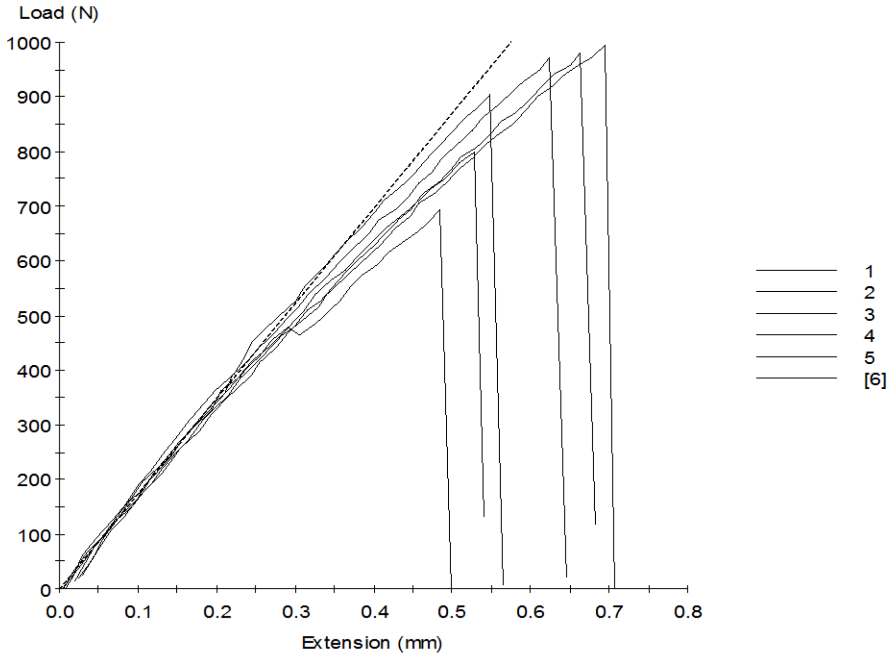
Report Date: 21/07/2008

Test Date : 21/07/2008
Method : MMT Tensile Test with return.msm

# Specimen Results:

| Specimen # | Thickness mm | Width mm | Area mm^2 | Peak Load N | Peak Stress MPa | Break Load N | Break Stress MPa |
|---|---|---|---|---|---|---|---|
| 1 | 14.490 | 5.600 | 81 | 904 | 11.14 | 904 | 11.14 |
| 2 | 14.900 | 5.000 | 74 | 972 | 13.05 | 972 | 13.05 |
| 3 | 14.530 | 5.340 | 78 | 980 | 12.63 | 980 | 12.63 |
| 4 | 14.340 | 5.340 | 77 | 994 | 12.98 | 994 | 12.98 |
| 5 | 14.640 | 5.100 | 75 | 799 | 10.70 | 799 | 10.70 |
| 6 | 14.500 | 5.300 | 77 | 695 | 9.04 | 695 | 9.04 |
| **Mean** | **14.567** | **5.280** | **77** | **891** | **11.59** | **891** | **11.59** |
| **Std Dev** | **0.189** | **0.210** | **2** | **120** | **1.59** | **120** | **1.59** |

| Specimen # | Elongation At Break mm | Stress At Offset Yield MPa | Load At Offset Yield N | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0.547 | 9.050 | 734.352 | | | | |
| 2 | 0.623 | 10.229 | 762.047 | | | | |
| 3 | 0.664 | 10.406 | 807.367 | | | | |
| 4 | 0.694 | 9.732 | 745.262 | | | | |
| 5 | 0.528 | 8.453 | 631.123 | | | | |
| 6 | 0.485 | 6.061 | 465.789 | | | | |
| **Mean** | **0.590** | **8.988** | **690.990** | | | | |
| **Std Dev** | **0.083** | **1.610** | **124.674** | | | | |



**travis-15%G RC 15:1 Specimen 1 deleted due to irregularity**

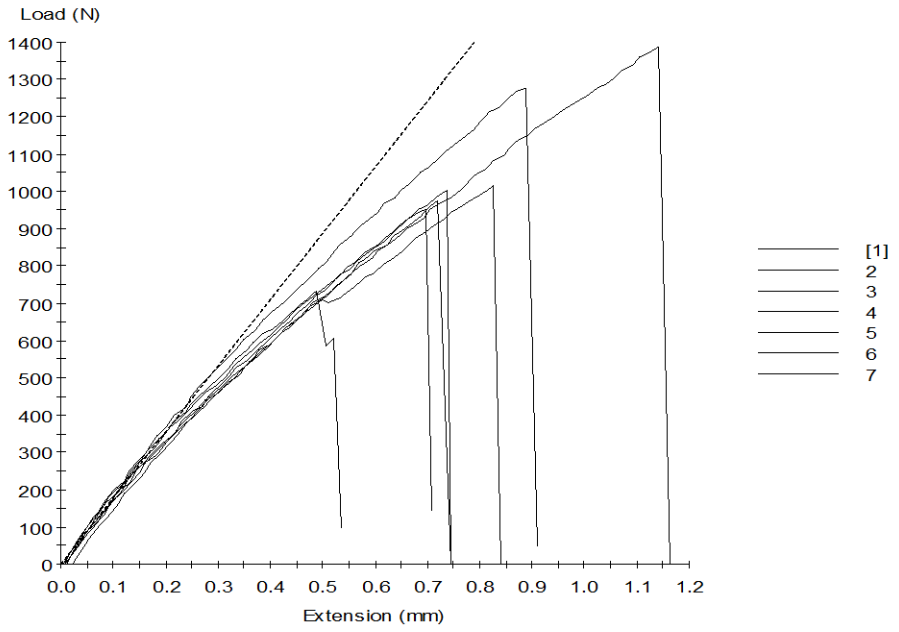
Report Date: 21/07/2008

Test Date : 21/07/2008
Method : MMT Tensile Test with return.msm

# Specimen Results:

| Specimen # | Thickness mm | Width mm | Area mm^2 | Peak Load N | Peak Stress MPa | Break Load N | Break Stress MPa |
|---|---|---|---|---|---|---|---|
| 1 | 14.640 | 6.150 | 90 | 1279 | 14.21 | 1279 | 14.21 |
| 2 | 14.650 | 6.660 | 98 | 974 | 9.99 | 974 | 9.99 |
| 3 | 14.490 | 5.700 | 83 | 1387 | 16.80 | 1387 | 16.80 |
| 4 | 14.550 | 5.530 | 80 | 734 | 9.12 | 734 | 9.12 |
| 5 | 14.500 | 6.100 | 88 | 950 | 10.74 | 950 | 10.74 |
| 6 | 14.530 | 5.750 | 84 | 1017 | 12.17 | 1017 | 12.17 |
| 7 | 14.600 | 5.750 | 84 | 1005 | 11.97 | 1005 | 11.97 |
| **Mean** | **14.566** | **5.949** | **87** | **1049** | **12.14** | **1049** | **12.14** |
| **Std Dev** | **0.065** | **0.384** | **6** | **218** | **2.64** | **218** | **2.64** |

| Specimen # | Elongation At Break mm | Stress At Offset Yield MPa | Load At Offset Yield N | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0.886 | 8.026 | 722.602 | | | | |
| 2 | 0.719 | 6.056 | 590.838 | | | | |
| 3 | 1.141 | 9.267 | 765.404 | | | | |
| 4 | 0.489 | 6.321 | 508.591 | | | | |
| 5 | 0.698 | 5.446 | 481.735 | | | | |
| 6 | 0.827 | 6.539 | 546.358 | | | | |
| 7 | 0.738 | 7.268 | 610.141 | | | | |
| **Mean** | **0.786** | **6.989** | **603.667** | | | | |
| **Std Dev** | **0.200** | **1.307** | **106.225** | | | | |



**travis-20%G RC 15:1**

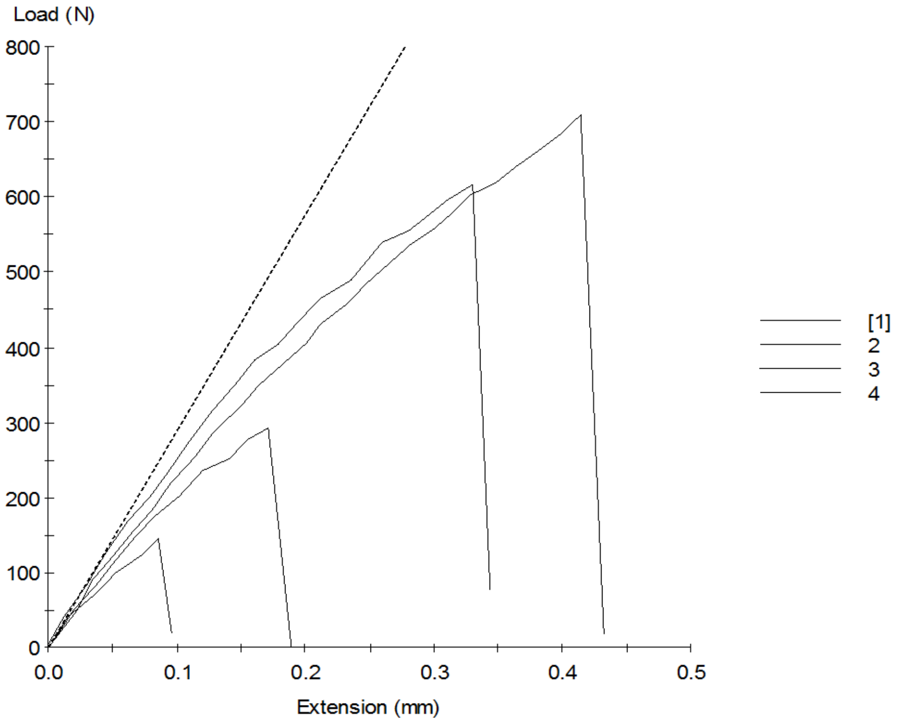
Report Date: 21/07/2008

Test Date : 21/07/2008
Method : MMT Tensile Test with return.msm

# Specimen Results:

| Specimen # | Thickness mm | Width mm | Area mm^2 | Peak Load N | Peak Stress MPa | Break Load N | Break Stress MPa |
|---|---|---|---|---|---|---|---|
| 1 | 14.510 | 6.500 | 94 | 616 | 6.53 | 616 | 6.53 |
| 2 | 14.600 | 6.300 | 92 | 708 | 7.70 | 708 | 7.70 |
| 3 | 14.560 | 6.000 | 87 | 293 | 3.35 | 293 | 3.35 |
| 4 | 14.600 | 5.720 | 84 | 144 | 1.73 | 144 | 1.73 |
| **Mean** | **14.568** | **6.130** | **89** | **440** | **4.83** | **440** | **4.83** |
| **Std Dev** | **0.043** | **0.342** | **5** | **266** | **2.77** | **266** | **2.77** |

| Specimen # | Elongation At Break mm | Stress At Offset Yield MPa | Load At Offset Yield N | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0.330 | 4.271 | 402.844 | | | | |
| 2 | 0.415 | 4.982 | 458.235 | | | | |
| 3 | 0.171 | 2.892 | 252.617 | | | | |
| 4 | 0.086 | 0.209 | 17.423 | | | | |
| **Mean** | **0.251** | **3.088** | **282.780** | | | | |
| **Std Dev** | **0.149** | **2.107** | **197.082** | | | | |



**travis-25%R12-G RC 12:1**

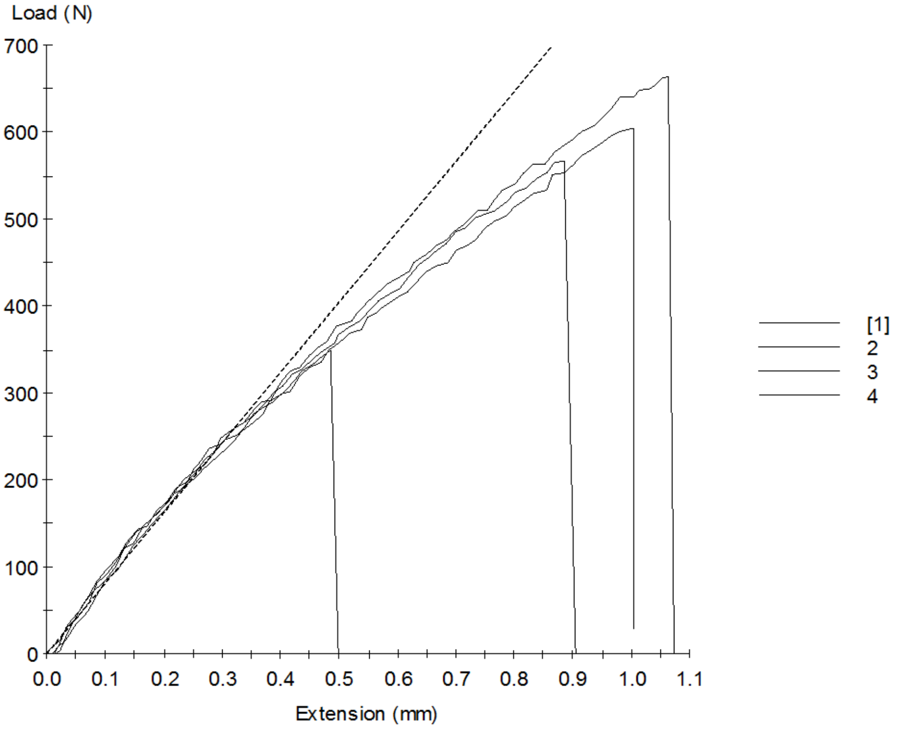
Report Date: 14/08/2008

Test Date : 14/08/2008
Method : MMT Tensile Test with return.msm

# Specimen Results:

| Specimen # | Thickness mm | Width mm | Area mm^2 | Peak Load N | Peak Stress MPa | Break Load N | Break Stress MPa |
|---|---|---|---|---|---|---|---|
| 1 | 14.600 | 5.000 | 73 | 665 | 9.11 | 665 | 9.11 |
| 2 | 14.560 | 5.060 | 74 | 604 | 8.20 | 604 | 8.20 |
| 3 | 14.530 | 5.040 | 73 | 567 | 7.75 | 567 | 7.75 |
| 4 | 14.530 | 5.010 | 73 | 350 | 4.81 | 350 | 4.81 |
| **Mean** | **14.555** | **5.028** | **73** | **547** | **7.47** | **547** | **7.47** |
| **Std Dev** | **0.033** | **0.028** | **0** | **137** | **1.86** | **137** | **1.86** |

| Specimen # | Elongation At Break mm | Stress At Offset Yield MPa | Load At Offset Yield N | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1.064 | 4.829 | 352.489 | | | | |
| 2 | 1.005 | 4.557 | 335.704 | | | | |
| 3 | 0.885 | 4.206 | 308.008 | | | | |
| 4 | 0.486 | 3.194 | 232.475 | | | | |
| **Mean** | **0.860** | **4.196** | **307.169** | | | | |
| **Std Dev** | **0.260** | **0.715** | **53.066** | | | | |



**travis-30%R12-G RC 12:1**

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Report Date: 21/07/2008

Test Date : 21/07/2008
Method : MMT Tensile Test with return.msm

## Specimen Results:

| Specimen # | Thickness mm | Width mm | Area mm^2 | Peak Load N | Peak Stress MPa | Break Load N | Break Stress MPa |
|---|---|---|---|---|---|---|---|
| 1 | 14.810 | 5.040 | 75 | 160 | 2.15 | 160 | 2.15 |
| 2 | 14.850 | 5.050 | 75 | 364 | 4.86 | 364 | 4.86 |
| 3 | 14.920 | 4.880 | 73 | 405 | 5.57 | 399 | 5.48 |
| 4 | 14.770 | 5.050 | 75 | 430 | 5.76 | 430 | 5.76 |
| **Mean** | **14.838** | **5.005** | **74** | **340** | **4.58** | **338** | **4.56** |
| **Std Dev** | **0.064** | **0.083** | **1** | **123** | **1.67** | **122** | **1.65** |

| Specimen # | Elongation At Break mm | Stress At Offset Yield MPa | Load At Offset Yield N | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0.176 | 0.899 | 67.141 | | | | |
| 2 | 0.424 | 1.735 | 130.085 | | | | |
| 3 | 0.507 | 2.432 | 177.084 | | | | |
| 4 | 0.513 | 2.340 | 174.566 | | | | |
| **Mean** | **0.405** | **1.852** | **137.219** | | | | |
| **Std Dev** | **0.158** | **0.706** | **51.465** | | | | |