University of Southern Queensland

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Using Tensile tests as benchmark, investigate the best percentage by weight of slg, as fillers, in Phenolic resins post-cured by microwaves.

A dissertation submitted by

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Abstract

This project is based upon finding the best percentage by weight of slg fillers in phenolic resin, and finding the mechanical properties via tensile testing.

Importance is placed on reducing input costs in industry while meeting employer needs. For this reason strategies have been developed and tested within this report. Increasing the amount of slg fillers that are added into phenolic resins will ensure cost savings and a decrease in weight of the specimen without sacrificing the strength of the mechanical properties.

Commercial Phenol Formaldehyde based resole thermosetting resin, was mixed with an acid catalyst at a 50:1 ratio along with a percentage of a ceramic based slg filler. Tensile testing was performed to the produced composites to determine yield and tensile strength. Young's Modulus was also calculated to test the stiffness of the material. These tests were used to determine the optimum addition level of filler to the sample. Once composites were removed from the moulds post-curing was conducted in a microwave. Times recorded varied from 25-30 minutes, depending on the percentage of slg filler. Composite samples ranged from a percentage of filler added to the composite from 0% to 35%, in increments of 5%, hence eight samples in total were produced. To allow for an accurate comparison three more composites were produced at 5%, 15% and 25% and post-cured by conventional oven, this ensured primary results were be used. Conventional oven post-curing showed clear results at 5% that were three times that of post-curing by microwave at 5%, however there was a rapid drop in strength varying from 5% to 25% from post-curing by conventional oven. Post-curing by way of microwave produced more consistent results, however the standout percentage's in strength were 10-20%. In addition to the findings, microscopic photos were taken to provide further information about the effects of the two post-curing methods. A cost analysis of the materials used in the study was calculated to demonstrate the benefits of filler addition to composites.

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Signature

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Date

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Glossary

Phenolics = Common term given to phenol formaldehyde resins

Catalyst = Common term for the acid based catalyst used in study

Slg = Micro-sphere filler used in study

Filler = Material mixed into resin to reduce cost and weight

CEEFC = Centre of Excellence in Engineered Fibre Composites

P_{MAX} = Load at failure (Newtons)

F = Force

A_o = Original cross sectional area

A = Area (cross sectional)

$\underline{\Delta}L$ = change in length

L = Original length

ε = strain

σ = stress

E = Young's modulus

GPa = Giga pascal

MPa = Mega pascal

1 - Introduction

Topic: *"Using tensile tests as benchmark, investigate the best percentage by weight of slg, as fillers, in phenolic resins post-cured by microwaves."*

1.1- Introduction

This chapter will outline the purpose of the research study, demonstrating the need for the solutions that will be obtained. The optimum percentage of filler required will be determined to demonstrate the strength properties of composites post-cured by microwave.

1.2- The Problem

The problem to be investigated is the effects of post-curing by microwaves. This issue is contentious as Phenolic resins are a vastly used product in industry. The expected outcomes of the study are to achieve a set of results which analyze the strengths of the specimens and show similarities to those post-cured by a conventional oven. Once tensile testing has been performed on the specimens; Young's Modulus, tensile strength and yield strength can be found. Post-curing by conventional oven at 5%, 15% and 25% will reflect a comprehensive comparison as all results used will be primary; as everything has been produced and tested by the same methods. Once specimens have been produced and tested, a microscopic view will be taken to show bonding. This will be done on 5%, 15% and 25% for both post-curing methods; conventional oven and microwave.

1.3- Research Objective

Three materials will be used in the study; phenolic resin, an acid catalyst and a slg filler. The phenolic resin (Hexion J2027L; manufactured by Borden Chemicals) is mixed with an acid catalyst on a 50:1 ratio, along with a percentage of filler. The filler used is an Evirosphere slg which is a fly ash by-product. The project requires eight moulds to be

produced that vary from a 0% to 35% filler amount. The total amount of mixture is 300 grams. For example if a 10% mixture was to be made, it would consist of 30 grams of filler. The remaining 270 grams a 50:1 ratio of catalyst and resin is calculated therefore 264.7 grams of resin and 5.29 grams of catalyst would be added. Once the mixture has cured in the mould at room temperature, specimens are then removed and placed into a microwave for post-curing at a temperature of up to 100 degrees Celsius. The objective is to complete post-curing and increase the strength properties of the specimens. Hence the purpose of this project is to investigate the strengths of specimens at the different percentage of fillers, through tensile testing.

Once an outcome is produced and strengths calculated they can then be related to those results that were obtained from previous studies on the effects of post-curing by conventional oven. This will prove that post-curing by microwave will produce similar results and therefore be more beneficial as the time taken will be significantly reduced. To further support this argument, conventional oven testing will be conducted to demonstrate a reliable indication of the benefits.

1.4– Concluding remarks

This chapter demonstrates the necessity of this research study, and how testing and analysis will be conducted to determine the ideal combination of materials and what the optimum strengths can reach. The following chapter will provide an in depth analysis into the background of phenolics, fillers and the testing that will be performed.

2 - Literature review

2.1 - Introduction

The following chapter will give an insight into the history of resins, and explain the material properties and their intent for use in this research project. The testing apparatus will be discussed in depth; showing how to extract meaning from the data. Post-curing methods of microwaving and conventional oven will be analysed in terms of how the specimen is effected.

2.2 - Background of Resin

Phenolics were the first thermoset materials synthesized (under the name of Bakelite by Dr. Leo Bakeland in 1907) [Strong 1996, p.274-276]. Due to their low cost and ease of formation, Phenolics are among the most common thermosets used. They are formed when the combination of phenol and formaldehde react together under heat and pressure. Generally a filler of some type is added to the resin in order to lower the cost and improve mechanical characteristics. Phenolics are formed from the condensation polymerization reaction between phenol, an aromatic molecule, and formaldehyde; a small organic compound often used as a solvent or as a preservative [Strong 1996, p.274-276].

Phenolic resin (Hexion J2027L) is a commercial phenol formaldehyde based resole thermosetting resin. It was one of the first major plastic materials used by industry, and is still one of the most widely used thermosetting resins to date due to its excellent properties. Phenolics are formed by the polymerization reaction between the phenol and formaldehyde; however two types of reactions can occur depending upon the type of catalyst used. This will produce two different intermediate materials, being novolacs and resoles.

The resole process is a condensation polymerization reaction which takes place with excess formaldehyde and is a carefully controlled linear, non-cross linked polymer liquid. Cross linking can be obtained by heating the viscous liquid. Alternatively an acid catalyst can be added to allow curing via room temperature known as stage one resins; this demonstrates the purpose of adding the acid catalyst 'Phencat 15' [Smith & Hashemir 1993, p.523-525].

A Novolac resin is formed by a reaction that is directly opposite to that discussed above; insufficient formaldehyde is formed. The resulting novolac material is a non-cross linked polymer in the form of a powder; novolacs require curing agents as the addition of heat will not suffice [Strong 1996, p.274-276]. Hexamethylene is the most common curing agent; a heat additive, and is commonly applied with pressure to compress the powder. This results in a first stage reaction that produces a thermoplastic resin, which does not contain the desirable properties of a strong cross linked network. For this reason the intermediate material novolac is not used.

2.3 - Resin and Catalyst Used in Study

The commercial resole phenolic resin used in study was J2027L manufactured by Hexion Specialty Chemicals Pty Ltd; officially called Hexion Cellobond J2027L [Chemwatch 4601-85]. Phencat 15, an acid catalyst which allowed cross linking to occur at room temperature, was essential in conducting this study. With reference to phenolic molecule of Appendix B, there are five 5 hydrogen atoms in the benzene ring however, because of limited space, there are only three possible sites for reaction and the phenolic molecule is said to have a functionality of three and this is shown in Appendix C [Ku H et al. 2006]. The resin and catalyst form a strong cross linking 3-D network and with the addition of a filler, mechanical properties will increase while costs decrease. The cross linking reaction is strongly exothermic so caution should be taken in not allowing excessive heat buildup in the mould [Strong 1996, p.274-276].

2.4 - Fillers

Fillers, also known as Envirospheres slg (E-spheres), are a commercial ceramic microsphere product otherwise known as a fly ash by-product.

> Fillers can be divided into two categories: those that reinforce the polymer and improve its mechanical performance, and those that are used to take-up space and so reduce the amount of actual resin to produce a part- sometimes referred to as 'extenders' [Osswald/Menges 1996, p.172].

The purpose of fillers is to reduce shrinkage during curing at room temperature, lower costs and improve strength properties, as well as increase electrical and thermal insulating properties and chemical resistance. 'The resin alone often give rather brittle and weak mouldings so in practice they usually are filled and reinforced' [Whelan, 1995, p.27].

Typical examples of fillers consist of:

- clay
- ground limestone
- glass fibers (increase performance)
- wood fiber (extenders)
- silica (improves insulation)

In this research study, the desired filler will consist of a white powder and have the chemical properties shown in Table 2.1.

Table 2.1 – Typical filler properties

Chemical Properties		Typical (By Weight)	
Silica SiO2		55 - 60%	
Alumina Al2O3		36 - 40%	
Iron Oxide Fe2O3		0.4 - 0.5%	
Titanium Dioxide TiO2		1.4 - 1.6%	
	Nominal Particle Size Range In Microns	Approximate Particle Mean in Microns	Comments On Grade
E-SPHERES SLG	20 - 300	130	General Multipurpose

2.5 – Costs of Materials

The cost of materials was a contributing factor in conducting this study, as the filler is a free product. Slg filler is a by-product from the burning of coal and is found on site. As this wastage takes up valuable room and companies are happy to disperse it at no charge. Fillers are more cost effective than plastic and therefore any combination of the plastic and filler will be less costly in terms of total weight or total volume that the pure plastic material itself [Strong 1996, p.274-276]. The main cost in this project is the phenolic resin and catalyst, which are $3.50 and $8.00 per litre respectively [CEEFC]. Therefore it is important to have the specimen containing as much filler as possible without sacrificing strength. A detailed cost analysis for each sample is given in chapter 4.

To calculate the cost of each sample some initial calculations needed to be conducted. All resin and catalyst was bought in bulk litres, whilst sample production was weighed in grams.

Therefore the density of the two materials was essential to find; listed below.

Resin

1 litre = 1.225 kilograms

Therefore 1/1.225 = 0.81632

$3.50 per litre = $0.0035 per millilitre

Catalyst

1 litre = 1.056 kilograms

Therefore 1/1.056 = 0.947

$8.00 per litre = $0.0080 per millilitre

To calculate the cost of materials of the sample 0% of filler by weight the following would take place:

0% is made up of	0.29411kg of resin	= 0.29411x0.81632 = 0.24 litres
	0.00588kg of catalyst	= 0.00588x0.94700 = 0.0055 litres

Therefore: Resin = 240x0.0035 = $0.84

Catalyst = 5.5x0.008 = $0.044

Total = $0.884

This method was carried out for each sample, the results of all samples can be found in Table 4.4

2.6 - Specimen

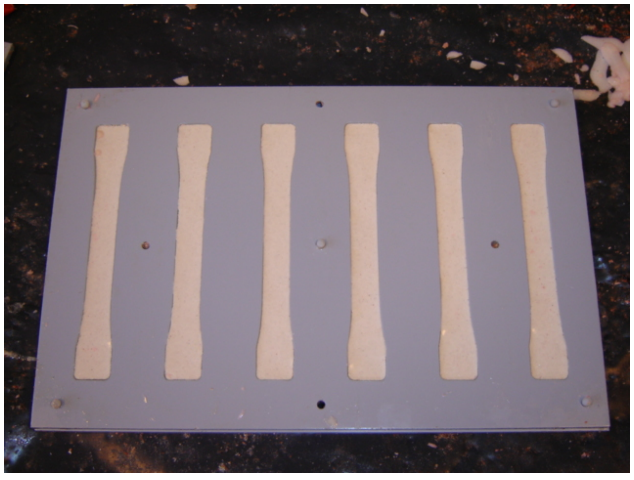

Figure 2.1 – Specimen after initial curing in mould

Six specimens are produced per mould, as seen in figure 2.1. Each specimen was made to the following dimensions, 150mm in length, 20mm in width at the widest point and 15mm in the centre and a thickness of 6mm. Once specimen have been poured into the

mould, a curing time of 72 hours is allowed to ensure specimen have been fully cured. To assist in the removal of the specimens, the mould is pre-greased to allow for easy release. The viscosity of liquid when all three materials are mixed is an important consideration. Included in this research study is the composite made up of 35% of filler by weight. This was the maximum amount of filler used as higher percentages of filler would become too difficult to produce. This is due to the high viscosity that is encountered, making it difficult to pour into the mould. As a result the likelihood of imperfections is increased.

2.7 – Testing

The testing was conducted by the University of Southern Queensland (USQ) tensile testing machine and followed the Australian Standard 1145.2 [*1145.2*]. 'Tensile testing, in which a specimen is clamped between grips which are moved apart at a constant rate, is the most common deformation mode of polymer testing' [Swallowe, 1999, p.242]. The test is relatively inexpensive to perform and the information gained is extremely valuable. By performing a tensile test unknowns such as young's modulus, tensile strength and yield strength are able to be found. During the testing stage, a stress and strain curve is produced, and from this data mechanical strengths can be found. The testing was conducted by the machine shown in figure 2.2. It is important that the specimens are similar in dimensions. If specimen bends during curing, testing will not be 100% correct, as a pre-loaded stress will occur on the specimen during loading resulting in a premature fracture.

Figure 2.2 Tensile testing machine loaded with a specimen, with computer

2.7.1 – Tensile Testing

Tensile testing allows strength properties, such as Young's modulus, yield and tensile strength, to be found. Tensile tests are a force that acts vertically on the specimen. The extension of the test pieces is recorded to establish the elastic and plastic deformation phases [MacDermont & Shenoy, 1997, p.35]. The three strengths that are able to be found from such testing are discussed in more detail in the following sections.

2.7.2 - Yield Strength

Yield strength is the strength at which a definite amount of plastic strain has occurred upon the specimen. The curve of the graph does not have two distinguishing portions to find the Yield strength, therefore an offset line must be put in place. In most cases this is 0.05% of the strain and drawn parallel to the linear growth of the graph. Where

intersection takes place, the yield strength is read across. Appendix D illustrates how the 0.05% proof load was determined. Yield strength is calculated using the relationship 2.1.

$$\textit{Yield strength} = \frac{\textit{Yield load (N)}}{\textit{Original cross-sectional area (mm)}} \qquad (2.1)$$

For example, the yield strength of the sample illustrated in Appendix D

$$= \frac{\textit{0.05\% offset load}}{\textit{Original cross-sectional area}} = \frac{\textit{855}}{\textit{15.010 x 5.310}} = \textit{10.68 (MPa)}$$

2.7.3 - Tensile Strength

Tensile strength can be calculated using equation 2.2

$$\text{Tensile strength} = \frac{\text{Maximum load}}{\text{Original cross-sectional area}} \quad \text{or} \quad \frac{\text{Pmax}}{\text{Ao}} \qquad (2.2)$$

Where Pmax is the maximum load in Newton and A_o is the original cross-sectional area in mm^2. The tensile strength is the significant result to obtain from a tensile test, due to the ease of which it is acquired and is useful for the quality control of a product.

For example, the tensile strength of the sample illustrated in Appendix D is calculated below.

$$\text{Tensile strength} = \frac{1190}{15.010 \times 5.31} = 13.99 \text{ (MPa)}$$

2.7.4 - Young's Modulus

Young's Modulus or the modulus of elasticity is a measure of the stiffness of the material. The information required to find the stiffness is obtained from the linear portion of the graph; the elastic portion of the graph, where the specimen will return to its original state. Essentially the slope of the curve will determine the Young's Modulus. Young's modulus is demonstrated in the relationship 2.3.

$$E = \frac{stress}{strain} = \frac{\sigma}{\varepsilon} \tag{2.3}$$

$$E = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

For example, the Young's Modulus of the sample illustrated in Appendix D was calculated using the data provided. A linear portion of the line was selected.

$$E = \frac{\frac{150 - 0}{80}}{\frac{0.1 - 0}{105}} = 1968.78 \text{ (MPa)} = 1.968 \text{ (GPa)}$$

2.8 – Curing

Once the specimen has been cured in the mould for 72 hours at room temperature, they are then post-cured in a microwave or conventional oven until the specimen reaches 100 degrees Celsius. Post-curing to light-cured resin composite will lead to a decrease in the negative effects of polymerization shrinkage and an increase in the hardness and wear resistance of the material [Marais J. T et al, 1999, 54(3) p. 123-5]. All specimens will be post-cured by way of microwave, however to allow a comparison to be made, three percentage fillers; 5%, 15% and 25% will be heated by conventional oven. Post-curing varies in time, depending on the specimen size and chemical properties. There is likely to be a major difference in time taken to post-cure at 100 degrees Celsius for the two methods.

2.8.1 – Microwave

Post-curing by way of microwave has many advantages; one being a significant reduction in the time it takes to fully cure a specimen to 100 degree Celsius. Microwaves possess many characteristics that conventional methods lack, such as penetrating radiation and rapid heating. As a result of its great success in processing food, people believe that the microwave technology can also be widely employed to process materials, eg cross-link polymers or sinter ceramics [Ku H S, (n.d.)]. Microwave processing of materials is a relatively new technology that provides new approaches to improve the physical properties of materials; alternatives for processing materials that are hard to process; a reduction in the environmental impact of materials processing; economic advantages through energy savings, space, and time; and an opportunity to produce new materials and microstructures that cannot be achieved by other methods [Ku H S, (n.d.)]. Microwaving also shows advantages in the ability to cross-link polymers. However microwaving can have disadvantages as it can penetrate heat into the specimen so fast dis-formation of the specimen may occur if left to long; hence curing time is critical. A possible risk in using microwaves to post-cure is the interaction it will have with phenolic resin. This resin emits a highly flammable styrene vapour that interacts with the probable

arc or heat of the high voltage (HV) transformer in the oven, and can lead to ignition or explosion. Figure 2.3 shows the modified Sanyo microwave 800W, the modification removes excess gases from inside the microwave and hence removes the danger.

Figure 2.3 – Modified microwave used in study

2.8.2 – Conventional Oven

Post-curing by way of conventional oven is an older technology than that of a microwave, and in the past has been found to very effective. An advantage of the conventional oven, is that heating will be constant and even throughout the entire space. As the heat builds up over many hours, less damage is likely to be inflicted upon the specimens. Disadvantages that are found by using conventional ovens, is the much greater time required to achieve the desired effects, and the excessive consumption of electricity. The conventional oven used in the study is depicted in Figure 2.4.

Figure 2.4 – Conventional oven

2.9 - Assessment of consequential effects

Many issues arise from the sustainability, safety and ethical nature that surround this research project. These issues need to be addressed as there is a professional responsibility to up hold the public's trust within the profession.

2.9.1 - Sustainability

The impact of this research project on finite resources will be minimal, as both the phenolic resin and acid based catalyst are naturally produced products. Since the size of the project is small, little materials are used relative to industry. However if the study were to be successful and industry adopt the findings then impacts may occur. The slg filler is a fly ash by-product, which is the finely divided mineral residue after coal combustion; hence this product will have minimal impact upon the environment. Through this study it will be shown that if post-curing by microwave is adopted that it will have energy saving benefits as it will consume a smaller amount of fossil fuel. Although a microwave is a large portion of the post-curing of specimens its impact upon the environment would be minimal. Future environmental impacts as a result of further

experimentation would be minimal, as Australia will be mining and burning fossil fuels for many years into the future, although there may be the need to investigate different ways to produce fillers that are more environmentally friendly.

2.9.2 - Ethical / Safety

Minimal issues are raised due to this research project; one safety issue is the only cause for alarm during the production of samples. As fiber composites are all around us, the importance to increase the strength of them will further increase public safety. No ethical issues arise, as the results produced will benefit the public. However there may need to be future investigation into the materials, which will reduce the impact on the environment.

2.10 - Risk Assessment

All engineering activities involve a risk to people and the environment, and it is the responsibility of the user to recognize and address them.

2.10.1 - Identification

In conducting the production of specimens many risks may be encountered. The three materials used can be very harmful if not handled in the correct manner, as when the three are mixed together an exothermic reaction occurs; hence releasing heat. The post-curing process involves the use of a microwave. Microwaves are knowingly accepted to emit harmful microwaves. Finally the last step of the investigation is testing. The tensile tester is a large machine which is hydraulically driven, and has the capacity to maneuver large loads and if used incorrectly has the potential to be harmful to the operator.

2.10.2 - Evaluation

The extent of the damage upon the user varies from minimal to very extreme.

2.10.2.1 – Resin and Catalyst

The listed risks for both the resin and catalyst are given below:

Phenolic resin: - toxic by inhalation

- Toxic in contact with skin and if swallowed
- Limited evidence of a carcinogenic effect
- Serious damage to eyes
- Sensitization by skin contact
- Serious damage by prolonged exposure through inhalation, in contact with skin and if swallowed
- Possible risks of irreversible effects [Chemwatch 4601-85]

Catalyst: - harmful by inhalation and if swallowed

- causes burns
- risk of serious damage to eyes [Chemwatch 4601-93]

Similar circumstances apply for the catalyst.

Slg filler: - may cause harm if swallowed.

- Harmful if comes in contact with eyes.

Similar circumstances also apply for the filler; however these hazards are extremely slight.

The above hazards have a significant chance of occurring; however prolonged exposure to the materials would not be possible. When making the mixtures for the specimens casting takes minimal time therefore this particular risk would be extremely slight.

Exposure to the resin consists of 15 minutes during mixing and casting. As the study requires 11 samples to be produced, there will be a minimum exposure of 165 minutes, however producing every mould perfectly is highly unlikely.

2.10.2.2 – Microwave

Long periods of exposure to emitting microwaves may cause damage.
Although the specimens have to be post-cured for time periods of up to thirty minutes, there is no need for the user to be watching it, hence incurring damage from emitting microwaves would be minimal. The microwave in the testing laboratory is also fitted with a device to minimize the emitting microwaves to the user, rather it direct them elsewhere.

2.10.2.3 – Tensile Testing Machine

Misuse of the Tensile testing machine can cause bodily harm, due to its powerful nature, and that it is run by hydraulics and electricity. If a hose were to burst hot hydraulic oil under pressure would spray everywhere which could cause severe burns. However this occurrence is unlikely as hoses are concealed in conjute.

2.10.3 - Control

Various controls have been implemented to ensure the user is aware of all hazards. Booklets of Phenolic Resin and Catalyst are provided for the user and consent of understanding is signed to ensure their awareness. Regulations have also been put in place. Whilst handling the material a respirator, safety glasses and surgical gloves must be worn. When casting the moulds, they must stay inside a designated area containing a large exhaust fan to remove harmful fumes and heat. When using the microwave, conventional oven and the tensile testing machine an instructor is present during the first use to explain the working procedures, and warning signs to be aware of.

2.11 - Resource Analysis

Numerous resources are required for this research to take place, being equipment, facilities, staff and materials.

Equipment required: - Plastic molds (six specimen can be made per one)
- Plastic screws (to hold the two layers of the mold together)
- Sheet of glass (to clamp down on top of the mold)
- The three materials (phenolic resin, catalyst & slg filler)
- Safety equipment
- Cooking oil (to line the mold prior to casting)

The molds, screws and glass are critical elements as without them the casts cannot be made, however they are a reusable resource. They have also been used in previous studies hence no cost will be incurred in manufacturing them as they are supplied by the University. The three materials are the most critical resources for the entire project the availability of these materials is very reliable. The materials are supplied in bulk, and if more are required a staff member must be notified and can organize re-stock in a matter of two to three days. As this research project is sponsored by the University of Southern Queensland and the Centre of Excellence in Engineered Fibre Composites (CEEFC), all costs are covered. If supply of materials from the CEEFC were to fail, sourcing the materials would be relatively simple due to the common use of these products. This however would be an unlikely event as the bulk supply is more than enough to produce the eight molds.

Facilities that are required: - Laboratory Z106.1 (molds are cast)
- Z113 (post-curing; microwave)
- Z105.7 (tensile testing machine)

All three of the above facilities are critical to the working of this project; if availability were to be taken away the continuation of the project would be threatened. This is

another unlikely event as the facilities are used by many students at the University. No direct costs are incurred through the use of these facilities as they must be maintained for numerous students. Availability to these facilities is excellent as it is usually free at all times and simply relies on a staff member being available to allow access.

The services of the staff who run the rooms is vital, as they provide important information in the day to day running of the rooms, and can assist in the working of machinery.

Two devices that would influence highly on the progression of the research are the tensile testing machine, and the microwave. The microwave would easily be replaceable due to their popularity. In contrast if the tensile testing machine were to break down extreme cause for concern would be warranted, as they are an expensive machine, and not common. If the availability of this machine were to be compromised failure of the project would occur as the University could not purchase another, and waiting for parts to fix the machine could take time. In saying this, the probability of a problem occurring with the tensile testing machine would be highly unlikely.

3 – Research Design and Methodology

3.1 – Introduction

The methodology in this study was conducted in a precise and accurate manner to ensure conformity among results. This particular chapter discusses the required steps and processes carried out during the production and testing of specimens. In conjunction with the previous chapter and assumed knowledge, a full understanding of mould and specimen design has been achieved. Many previous studies have investigated similar purposes which have proved vital in further developing the argument.

3.2 – Mould Design

The guidelines on mould design that must be followed are detailed below;

- Moulds must be made from PVC to ensure ease of removal
- Moulds should consist of minimal parts, to allow no confusion in construction, and reduce the risk of losing vital parts.
- Moulds should be constructed simply.

Whilst the mould must be assembled simply, it must also ensure that when pulling apart and re-joining numerous times the specimens will all reflect the same dimensions. There are different options to choose in designing a mould; if more removable parts are used it will make it easier to remove the specimen and significantly reduce the risk of damage to the specimen. However if there is only one PVC sheet into which the material is poured, dimension accuracy will be increased, but removal of the specimen once cured will become more difficult. These two options need to be weighed up, by taking into consideration the manufacture of the mould. As pieces reduce in size the intricacy of the mould increases, which will cause difficulty in removal and a compromise in dimensional accuracy. Appendices E and G shows the mould used in the research study.

3.3 – Mould Fastening

The mould was fastened with nine 4mm plastic screw. This layout can be seen in Appendix F. The position of fasteners is crucial to the formation of the specimens, if the PVC sheets aren't held tightly together air bubbles may form and other defects may become apparent. All nine screws are readily available from all hardware stores as is the standard screwdriver required to fasten the screws.

3.4 – Test Pieces and Porosity

Porosity occurs when pouring and drying resin pieces, and can be eliminated during heat treatment [Callister, 1994,]. During firing the formed piece shrinks, and experiences a reduction of porosity and an improvement in mechanical integrity [Callister, 1994, p.435]. As the hardener combines with the resin, the chemical reaction that takes place produces gas, which is usually forced to the surface of the piece and appears as bubbles and gas just under the surface and as indentation on the top of the surface. This is due to voids created between the small particles. 'Any residual porosity, left after curing, will have a deleterious influence on both the elastic properties and strength' [Callister, 1994. p.409].

> Porosity is deleterious to the fracture strength (or modulus of rupture) for two reasons: (1) pores reduce the cross-sectional area across which a load is applied, and (2) they also act as stress concentrations for an isolated spherical pore, an applied tensile stress is amplified by a factor of 2 [William D. Callister, Jr,].

Porosity in ceramic materials may have a dramatic influence on thermal conductivity; increasing the pore volume will, under most circumstances, result in a reduction of the thermal conductivity [Callister, 1994 p. 435].

The amount of porosity generally depends upon the type of resin and the amount of hardener used, though it can also depend upon the temperature at drying.

The design of the mould was required to take into account the possible creation of porosity. Therefore a 6mm sheet plastic added 2mm to the top of the required 4mm test

piece. This allowed for the removal of material containing porosity on the upper surface of the test piece. A majority of porosity rose to the top of the test piece, and by having the extra 2mm the removal was simplified and testing consolidated.

3.5 – Manufacture of Mould

The mould used in this research study was the same as used previously in other studies conducted by the University of Southern Queensland. Through liaising with staff it was found the current manufactured mould would meet the demands of the study, as they also meet the requirements of mould design; which was discussed previously.

3.6 – Mould Preparation

Before the resin could be poured, the mould was cleaned with running water and dried using a paper towel. It was then checked for traces of previous resin mixtures or dirt particles; if any materials were found from previous specimen productions they would contaminate the surface. Old particles that become lodged into the new specimen will disrupt the strength characteristics if dried into the test pieces as it will introduce sections into the pieces that have different tensile strengths, leading to either less space for the material to fail and/or areas of stronger or weaker material.

Once all excess materials were removed, cooking oil was sprayed over the mould (aerosol can) to ensure accurate removal of the specimen. After the oil was sprayed into the mould, the tip of the finger was used to quickly spread the oil around ensuring all surfaces that came in contact with the specimen were coated in a thin layer of oil. Oil was used to reduce friction between the surfaces, as the specimen can become quite tight in the mould. The inclusion of oil assisted in reducing the risk of breakage. The extent that oil impacts on the specimen in consideration to their mechanical properties is unknown and may warrant further research.

3.7 – Manufacturing of Test Pieces

The core of the project revolves around finding the optimum mixture of materials. The following section must be followed exactly for each production of specimen to rule out unknown variables.

3.7.1 – Mixing of Resin

Costs play a major part in the decision making of producing the product, for this reason it is essential to research all areas of the materials involved to enhance certain mechanical properties. The Phenolic Resin and Acid Catalyst are considerably more expensive than the filler. This creates the need to study and research the maximum amount of filler which can be used, whilst still maintaining high mechanical properties.

Six specimen need to be produced per mould, with consideration of specimen dimensions 300 grams of mixture was necessary per production; to ensure minimal wastage. The mixtures of each percentage specimen can be seen in Table 3.1.

Table 3.1 – Mass of materials per sample

Mixture 50:1

% of filler	Resin(g)	Catalyst(g)	Total(g)	SLG Filler(g)
0	294.11	5.88	300	-
5	279.41	5.588	285	15
10	264.7	5.29	270	30
15	250	5	255	45
20	235.29	4.7	240	60
25	220.58	4.41	225	75
30	205.88	4.11	210	90
35	191.17	3.82	195	105

The total weight of 300 grams provided a sufficient amount of mixture to fill the 6 spaces in the mould with minimal wastage. The resin was first measured into a container then the filler was measured out separately and added to the resin. The two materials were then mixed thoroughly making sure that all the filler was added. Next, the hardener was

measured by weight and added to the mixture; being stirred quickly to ensure all filler came in contact with the resin and hardener. The advantage of stirring quickly is that it allowed plenty of time for pouring before the mixture began to harden/cure. Figures 3.1, 3.2 depict how the mixture was measured and mixed

Figure 3.1 – Digital scales used to weigh materials

Figure 3.2 – The three materials used in study; Resin, catalyst and Filler

3.7.2 – Pouring

Once the mixture had reached an even consistency, it was poured into the mould through the use of a plastic spoon, seen in figure 3.3. Excessive mixture is poured in to eliminate the likelihood and affects of porosity and air bubbles. Most defects are in the top 1mm of the specimen and can be removed afterwards if required. The materials needed to be spooned in gently so that air bubbles would not be trapped between the material and mould.

Figure 3.3 – Pouring of mixed materials into mould

3.7.3 – Tightening of Fasteners

Due to the possibility of air becoming trapped between the middle and bottom layer of the mould, the mould must be fastened correctly. By tightening the plastic screws in the correct sequence the air is expelled from the two sheets of the plastic mould.

The top sheet was placed face down with the bottom sheet then placed on top. The screws were secured, but not forcefully enough to apply significant pressure. This is seen Figure 3.4. Once screws were in place, screws were tightened in the correct order which can be seen in the below figure.

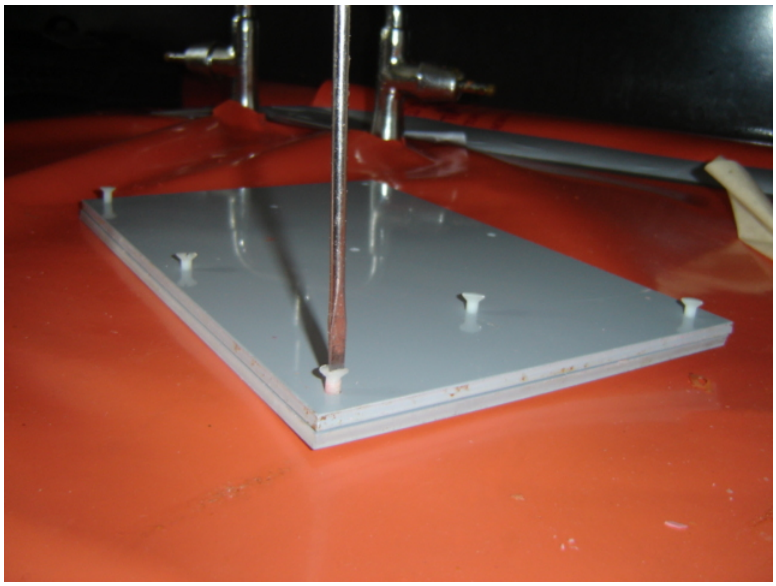

Figure 3.4 – Fastening of plastic screws into mould

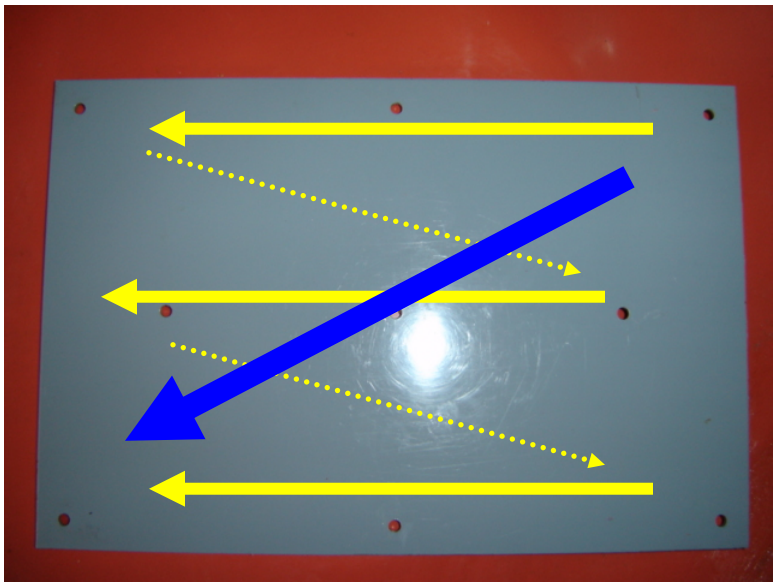

Figure 3.5 – Method in which screws had to be tighten to remove air

Figure 3.5 depicts the method of tightening screws. The yellow arrows demonstrate the correct procedure, which results in the air flow direction demonstrated by the blue arrow. Tightening also allows for consistent pressure across the mould and hence ensures the material cures consistently, producing higher dimensionally correct specimens.

3.7.4 – Removal of Specimen

Allowing a minimum time of 72 hours for preliminary curing at room temperature, the six specimens are then removed and prepared for post curing. After initial cure the specimens become quite tight and set in the mould; therefore the specimen must be separated slowly with caution. Once screws are removed, the two plastic sheets remain stuck together, and with the aid of a screw driver the sheets are carefully pried apart. Excessive material forms a thin layer on the plastic of the top sheet whilst remaining intact with the specimen. The excess is carefully removed with a scraper, as damage to the actual specimen will lead to incorrect results and specimen dimensions may be compromised.

Removing the six specimens from the mould takes patience, as the specimen, being small, have a low breakage point. Many methods were trialed, due to the difficulty incurred by pushing the ends out as they are wider, and tended to stick to the edges resulting in cracks at the neck of the specimen. The successful method was to use two popsicle-sticks which, when stuck together, were the same thickness of the specimen. Minimal pressure was applied evenly over the specimen allowing for ease of extraction. To ensure higher accuracy of results it was important to extract the six specimens from the same batch of mixture. From batch to batch minor differences would be present due to human error.

3.8 – Curing

Initial curing took a total time of 72 hours at room temperature in the moulds. This allowed the specimen to harden and be removed with no deformation of the specimen. Once specimens were removed all samples were post-cured using a microwave, with an additional three samples being post-cured using a conventional oven.

3.8.1 – Microwave

Once the specimens were removed from the mould post-curing is required to meet the objectives of the project. Post-curing was solely conducted using a microwave. Specimens were placed on the microwave turning plate inside the machine, along with a mug of water. Water is used inside the machine as microwaves work through the use of moisture, the water is required to activate radiation waves inside of the machine, to ensure heating takes place. Specimens are placed in the same order for every sample, thus showing the effects of microwaving if any.

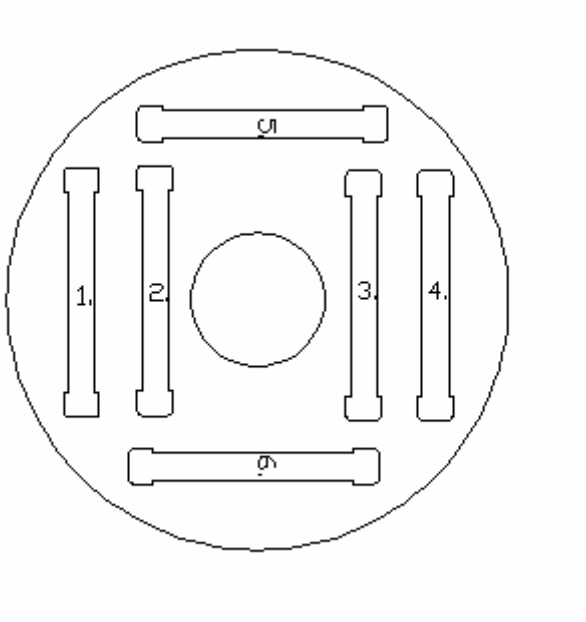

Figure 3.6 – Placement of Specimen inside Microwave cavity

The above arrangement in Figure 3.6 was used for the post-curing of every sample, to ensure if any errors occur in the results they could be traced back to the post-curing stage. Limited research was found in respect to the impact microwaves have upon the specimen. This research study will aid in understanding the effects of penetrating radiation wave within the microwave compartment.

After preliminary curing, the samples were taken to a modified Sanyo microwave cavity. The microwave oven had a total of 800 Watts; with the option of varying the power input at increments of 10%. The power level used was 160 Watts; as the higher power levels were not recommended because it would cause the samples to cure rapidly, resulting in the formation of blow holes. It was also found that post curing at the higher temperatures caused bowing of the test pieces ranging from 1mm – 4mm from the middle. This variation was unwanted as this placed a residual force in the test piece during testing. The microwave heated up the six test pieces to 100°C in 30 minutes, the temperature was measured by an infrared thermometer. One hundred degrees Celsius was the chosen maximum temperature as this was the maximum capacity of the conventional oven. The specimens were then allowed to cool for 24 hours inside the microwave, to ensure the specimen came down to room temperature slowly, and thus removing the chance of changing the atomic structure within.

3.8.2 – Conventional Oven

The extra samples that were produced were post-cured using a conventional oven, this method was more time consuming, as it took a duration of 10 hours at various temperatures;

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

Similarly to the post-curing method of microwaving the specimen did tend to show slight bending once temperatures increased. To combat this, samples were bound together in groups of six (sample batches), as it was not as important for the pieces to be sitting separately as was the case with microwave testing. Figure 3.7 shows the positioning of samples and the way they were bound together inside the conventional oven.

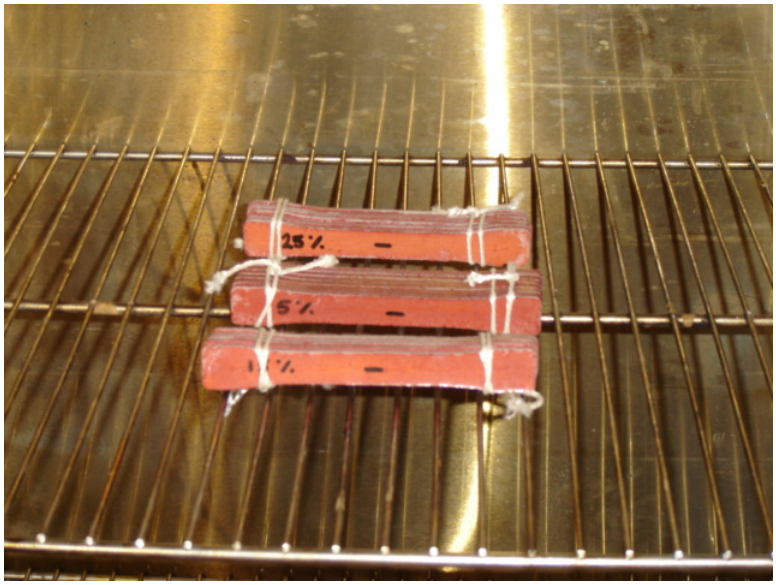

Figure 3.7 – Each sample bound together inside of conventional oven

Between each time period of baking the samples were examined for bending, and the string was adjusted if needed. The 5% sample exhibited small amounts of bending after the four hours at 80°C. All other samples were left in the oven over night between baking. The 5% sample was removed and placed between two glass plates with a small weight in place to counteract the bending.

3.8.3 – Deformation of Specimen

Deformation of specimens was a major concern initially and became quite troublesome, as it was very important to obtain 4 specimens from each sample. The reasoning for the bowing of test pieces is not exactly known, and would warrant future study. The bowing of specimens could be attributed to the settling of resin to the bottom of the specimen. Bowing occurred when temperatures increased rapidly. This was most likely due to resin settling to the bottom and would expand when heat was applied. Thermal expansion was present, causing the atoms to vibrate and move [Askeland & Phule, 2003, p. 925]. This resulted in shrinkage on the top causing the bowing of specimen ranging from 1 to 4mm. If the specimen bowed it would most likely prematurely fail testing due to existing residual forces in the specimen. Residual force resulted when the tensile testing machine tightly clamped the specimen vertically. Although the specimen straightened perfectly, resisting forces were present causing a compromised result to occur. As a stress concentration would then be created and lead to local stresses many time higher than that of the net stress calculated [Collins, 1993, p. 414].

3.9 – Test pieces

The test pieces must conform to standards, to allow consistency in past, present and future studies.

3.9.1 – Size and Dimensions

All specimens produced were constrained to the dimensions in Figure 3.8. Once specimens were post-cured, they were prepared for testing by ensuring all specimens followed the dimensions defined by ISO 527-1 or ASTM D638 [Swallowe, 1999, p.243]. By following the standard it allowed the results to be compared and used with future studies into slg fillers and their effects on strength in phenolic resins.

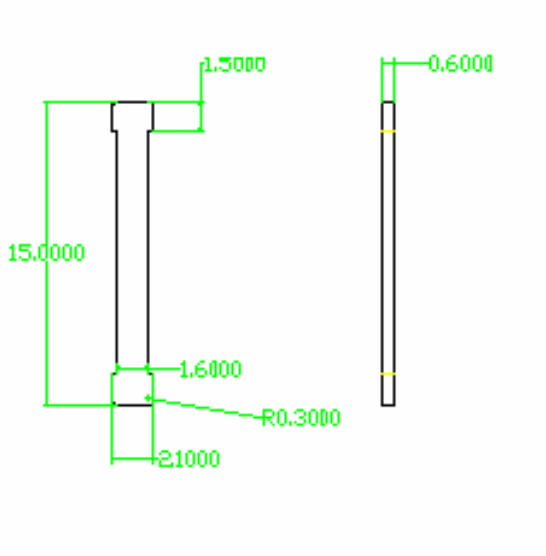

Figure 3.8 – Dimensions of each specimen

3.9.2 Removal of Porosity

When the test pieces were removed from the mould, they were 6mm in height. There was an allowance of 2mm to be removed if required, to ensure the finished product was 4mm in height. This extra height was allowed to account for shrinkage and the formation of porosity, which usually occurred at the top of the specimen during the initial curing process.

To ensure all test pieces were of the same dimensions, the top 2mm were removed via sanding. Little porosity was found on the specimen hence minimum removal was required, as shrinkage reduced the majority of specimen to the 4mm thickness. All measurements were carried out using Kincrome Digital Vernier Calipers. These calipers had an accuracy of 2 decimal places, sufficient for this research.

3.10 – Tensile Testing

The tensile test must be accurate and the same procedure must be followed with each specimen to control variables.

3.10.1 – Testing machine

The tensile testing machine used in the study measured mechanical properties of a material or component. Once specimens were loaded securely into the machine, the test was initiated. As the applied vertical force was acting on the specimen the computer simultaneously produced graphical results.

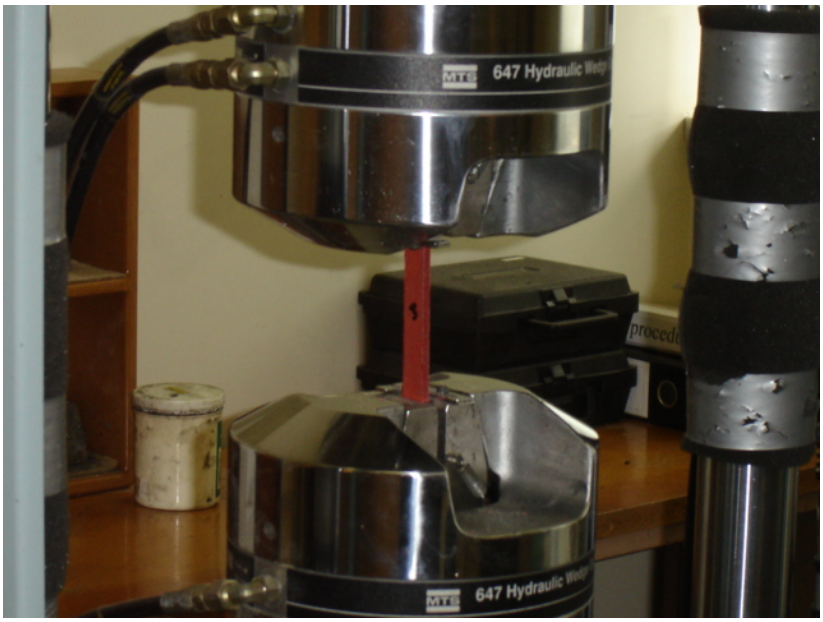

Figure 3.9 – Loaded specimen in Tensile testing Machine

Figure 3.9 depicts a magnified image of the tensile testing machine. The hydraulic clamps (MTS 647 Hydraulic Wedge Grip) restrict the specimen from side ways movement and has the ability to adapt the grip cylinders to different specimen sizes. With the ability to control the hydraulic pressure of the clamps there is no risk of the specimen becoming deformed. Figure 3.10 shows the full system setup and the computer used to control the machine. Results produced are provided in appendix H.

Figure 3.10 – Tensile Machine, with out puts read by the computer

The use of this machine allowed for the measurement of certain parameters during the testing. For this research, the load and deflection were measured throughout the full extent of the test, allowing the values of tensile properties to be calculated.

3.10.2 – Conducting the Tensile Testing

The procedure for conducting this test is defined in Australian Standard 1145.2, for determining the tensile properties of plastic materials. Firstly, test specimens were measured to ensure they compiled within the dimensional accuracy.

The specimens were loaded into the hydraulic clamps and, via the computer, all forces and deflection that were present were set to zero ensuring there were no variances of the results. Once the test was completed all details were noted and documented. The computer recorded real time data concerning load, deflection and time; data collection finished once failure had occurred [Turner, 2000, p.5].

3.10.3 – Data Collection

After testing was completed, all the data was gathered together and reviewed. In this review process, any test pieces that did not produce reasonable results (for example, did not hold any load of failed under very low loads) were discarded. This left each sample having a batch of three to six specimens.

Mean failure loads and deflections at failure were calculated from this data allowing for values of tensile properties to be obtained for each percentage of filler. Chapters 4 and 5 contain tables and graphs of the results and discussion.

3.11 – Microscopic Analysis

The ability to view the specimen up close provided more information to the post-curing methods.

3.11.1 – Microscope

The microscope had the ability to zoom in 20,000 times, allowing porosity and the formation of the specimen to be viewed in detail. Once specimens had been tested to failure by the tensile machine, the broken specimens were examined vertically; by zooming in on the broken face of the specimen. Figure 3.11 demonstrates the method carried out. When the specimen is held vertically by a vice, a lamp is used to provide sufficient light to enable the capture of high quality images.

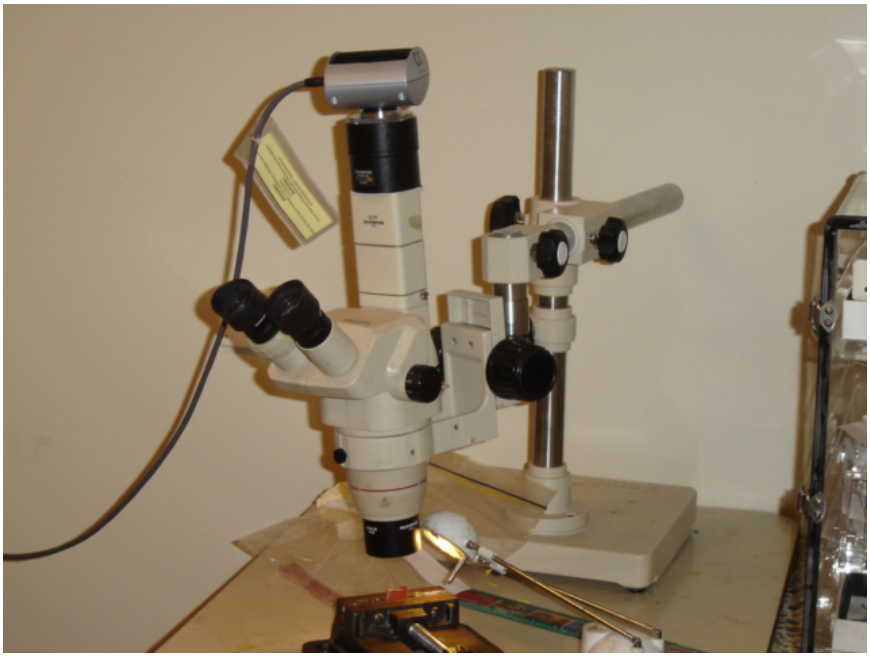

Figure 3.11 - Microscope

3.11.2 – Conducting the Analysis

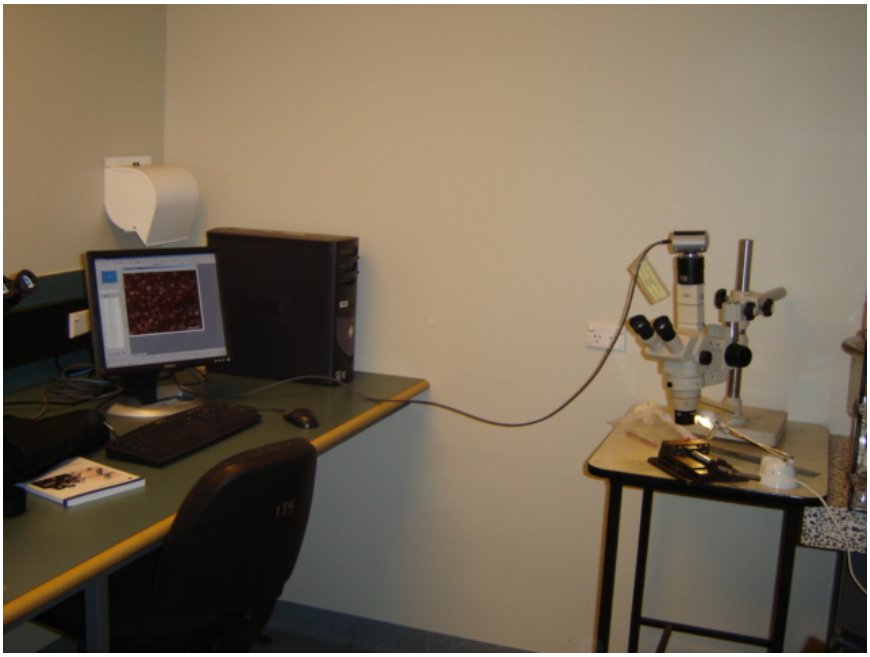

Figure 3.12 – Photo's gathered via mounted camera linked to computer.

Conducting the analysis required some knowledge of the program. It can be seen in Figure 3.12 the microscope and computer are linked together via cable. The microscope had a camera mounted on top of the viewing chamber, which was then transferred to the computer to be viewed on the desktop. The advantage of the camera is that once the microscope focus is set the user has the ability to maneuver the specimen whilst viewing the image on a computer screen. Once the desired image had been found, a snap shot was taken and saved as a j-peg file. The purpose of analysis by the microscope allowed the comparison of the two different post-curing methods at 5%, 15% and 25%.

3.12 – Concluding Remarks

This chapter has provided the methodology used in this study in accordance with the requirements of Australian Standard 1145.2. It has outlined the manufacture of moulds, test specimens, testing and data acquisition. The next chapter will outline the results recorded from the tensile tests.

4 – Test Results

4.1 – Introduction

This chapter provides the results obtained from the tensile test outlined in the previous chapter. Full explanations of tensile and yield strength as well as Young's modulus are given, with the comparison of the two post-curing methods, for the samples 0% to 35% by microwave and 5%, 15 % and 25% by conventional oven. The microscopic photos will demonstrate the effects on porosity and its formation. This chapter will analyse the positive and negative effects of the two post-curing methods. Costing of materials will also be shown to provide further assist in finding the optimum amount of filler.

4.2 – Tensile Strength

The following graphs provided in this section, are the mean of tensile strength for each percentage by weight of filler. Tensile strength was calculated for each specimen as discussed previously. Averages of the six were taken along with the standard deviation. Curves were generated to be used in comparison and assist in finding the optimum range of filler where mechanical properties are strongest.

4.2.1 – Results of Curing by Microwave

Table 4.1 – Tensile strength's for each specimen, showing distribution

Specimen	0	5	10	15	20	25	30	35
1	6.1	5.69	8.68	6.7	9.23	-	6.59	6.74
2	-	8.36	11.65	8.54	11.6	8.09	6.79	6.08
3	6.19	5.99	8.25	10.78	7.48	5.62	5.73	4.56
4	6.4	-	11.19	8.15	11.03	5.34	7.12	9.72
5	-	4.92	-	8.55	5.88	-	5.82	5.75
6	-	4.43	5.31	-	-	-	-	-
Mean (Mpa)	6.23	5.878	9.016	8.54	9.04	6.35	6.41	6.57
St Deviation	0.15395	1.518443	2.554326	1.46	2.39	1.51337	0.610614	1.930285

Table 4.1 demonstrates that there was no impact on the placement of specimens inside the microwave. As there are no distinct characteristics of specimens (for example the weakest specimen was not always in the same place), there is nothing further to analyse. Some could speculate that the specimen placed on the outside had a greater likelihood of weakening, yet in order to make this conclusive further study would be required. The dashes (-) in the table represent specimen that had unusually low results, caused from premature failure, hence they are untrue results for this study.

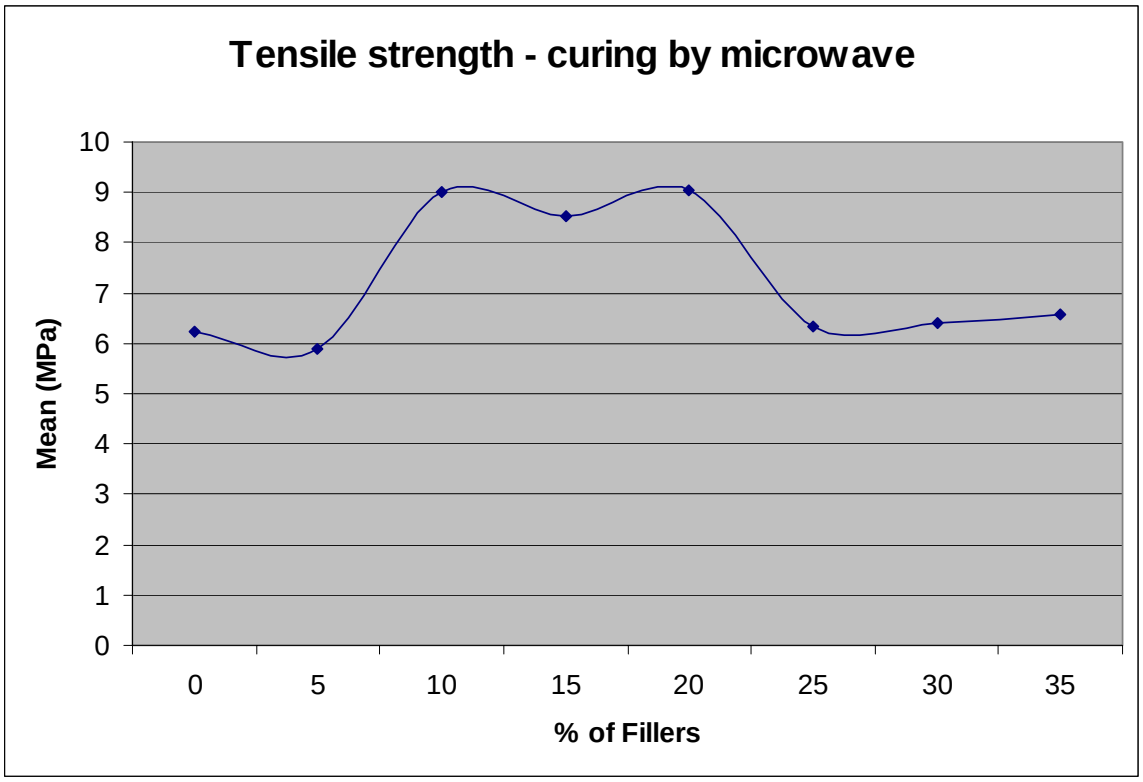

Figure 4.1 – Tensile strength; post-curing by microwave

Figure 4.1 represent mean tensile strength per sample against the percentage of fillers per weight. From this graph an optimum filler rate can be chosen. The filler percentages ranging from 10%-20% show a clear increase from the other percentages of filler of roughly 25-30%. A general trend line can be formed from this figure, which will still

show the 10-20% range as a peak. The mean of 5% seems abnormally low and may need further investigation to ascertain the reason behind the abnormal result.

4.2.2 – Results of Curing by Conventional Oven

The purpose of post-curing the chosen samples by conventional oven was to depict the base trend line produced, and to provide figures for comparison of results.

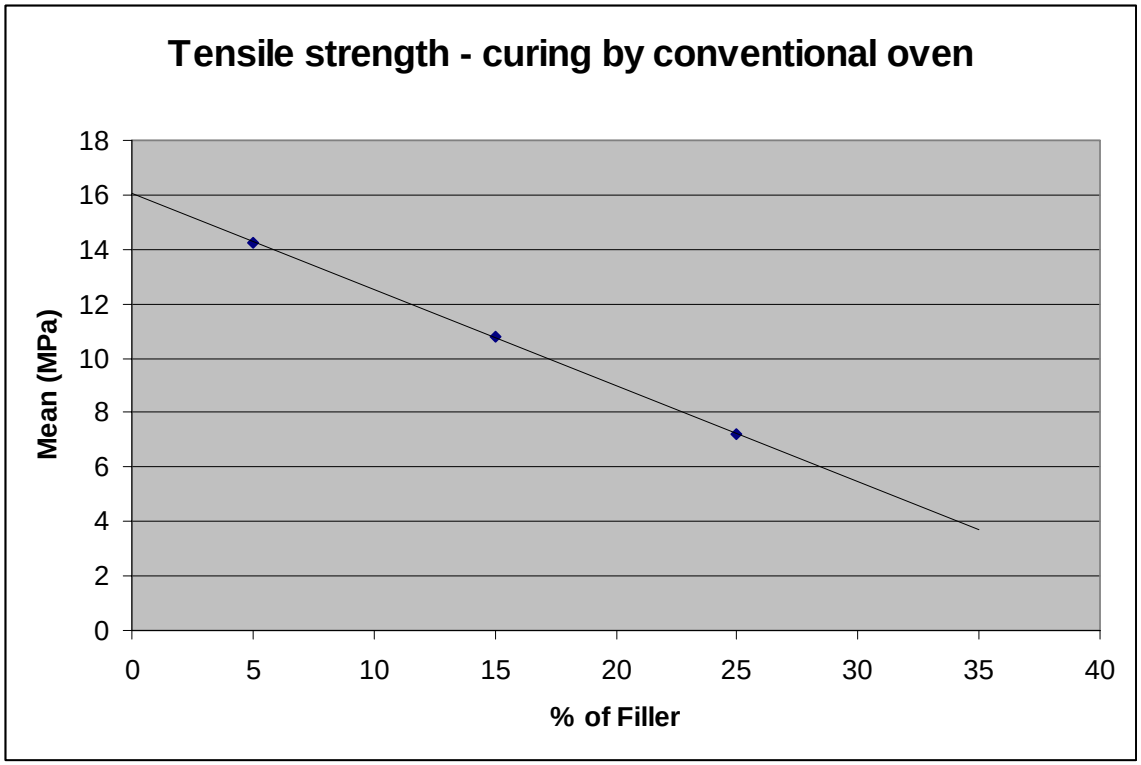

Figure 4.2 – Tensile strength – post-curing by conventional oven

Figure 4.2 shows a very different result to that of the microwave, rather it showed similar characteristics of linear decay. The strongest percentage being 5% at 14.26 MPa. The results rapidly decline representing decay in the mean tensile strength.

4.2.3 – Comparison

Figure 4.3 allows for a comparison of the two trend lines. At five percent the conventional oven had an increase of 234% of tensile strength. As the trend line continues the gap between the two decreases dramatically to a point that at 25% the conventional oven has an increase of only 112%. Of the two post-curing methods the microwave produced more consistent results, whilst the conventional oven was more erratic.

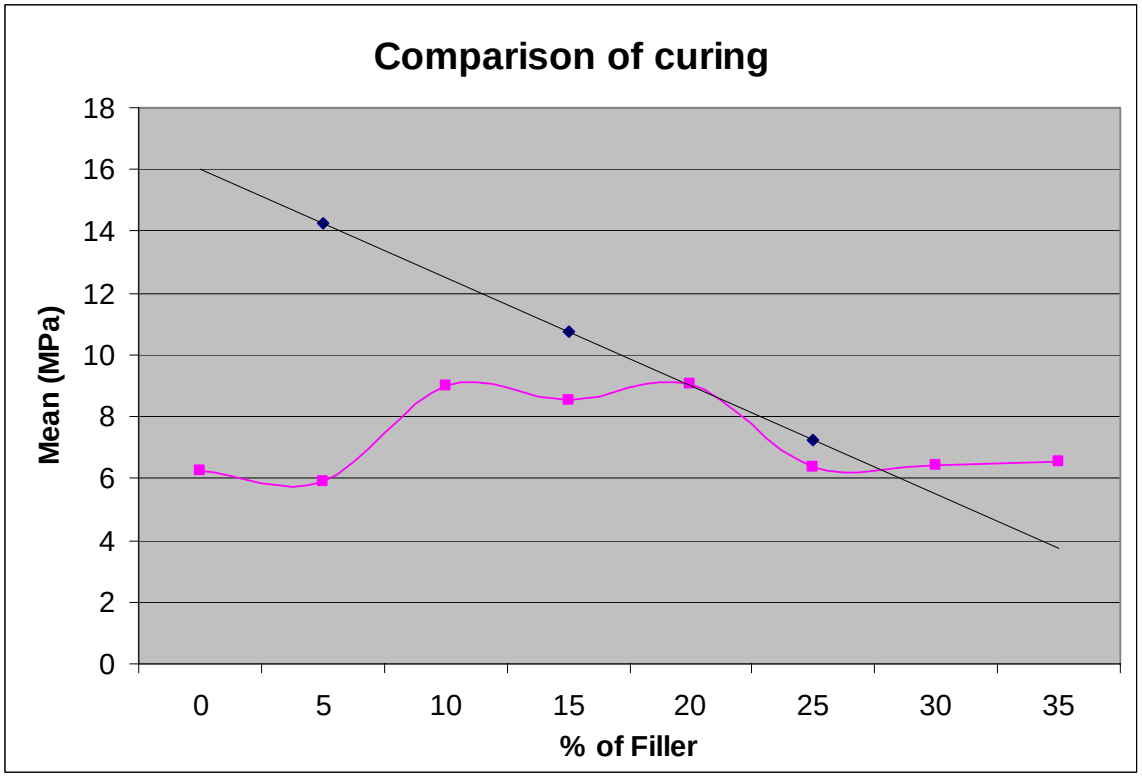

Figure 4.3 – Comparison of post-curing methods for the mean tensile strength

4.3 – Yield Strength

Yield strength had been calculated similarly to that of tensile strength. The following two sections will discuss the results found from post-curing by microwave and conventional oven, demonstrating advantages and disadvantages between the two.

4.3.1 - Results of Curing by Microwave

Table 4.2 – Yield strength's for each specimen, showing distribution

Specimen	0	5	10	15	20	25	30	35
1	n/a	n/a	8.68	4.43	7.89	-	4.78	4.17
2	-	8.31	11.34	6.03	8.95	3.07	4.83	3.58
3	n/a	n/a	7.44	6.95	6.52	5.12	4.2	3.54
4	n/a	-	n/a	6.91	8.82	4.44	4.33	5.38
5	**-**	4.82	-	5.13	5.88	3.4	4.09	3.4
6	**-**	4.01	n/a	**-**	**-**	**-**	-	-
Mean	-	5.713333	9.153333	5.89	7.612	4.0075	4.446	4.014

Table 4.2 again shows the effects of positioning inside of the microwave, and it is evident that there are no obvious effects. Problems arose whilst calculating the yield strength, as roughly 18% of the specimens did not produce sufficient graphs enabling this calculation. These specimen are marked by 'n/a'.

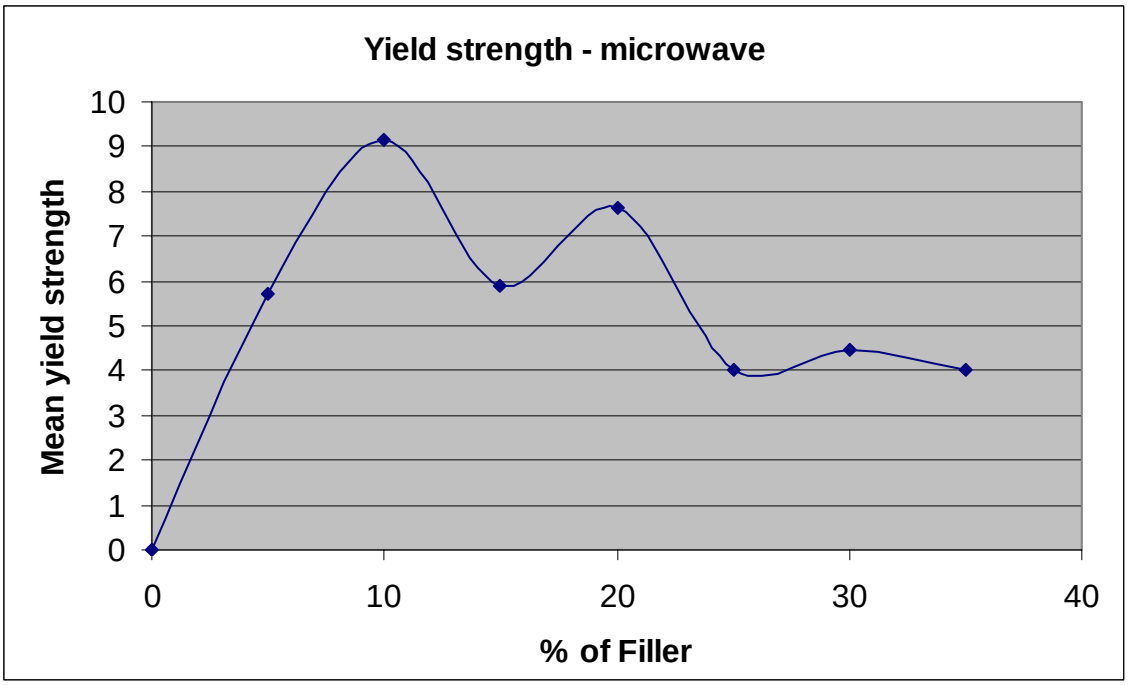

Figure 4.4 – Yield strength; post-curing by microwave

Figure 4.4, represents the mean yield strength result for each percentage of filler. Again the strong section ranges from 10-20%, with 10% being the strongest at 11.34MPa. There was a distinct reduction in strength at 25%, reflecting results found for the tensile strength. The result at 0% is not actually zero as a mean result was unable to found (refer to Table 4.2). This graph may need to be adjusted to allow an estimate of 0%, this will be further developed in the following chapter.

4.3.2 - Results of Curing by Conventional Oven

Figure 4.5 represents the mean result for the selected samples, showing a similar trend line to that of tensile strength, thus demonstrating the linear decay.

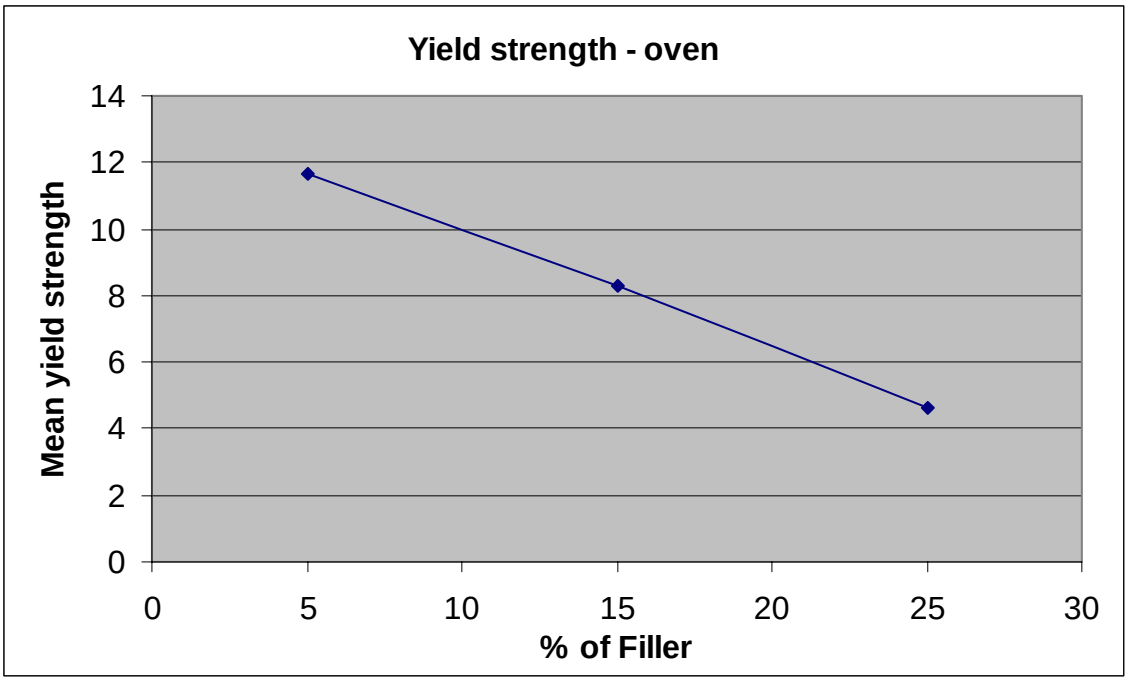

Figure 4.5 – Yield strength; post-curing by conventional oven

4.3.3 - Comparison

When comparing the two results; seen in Figure 4.6, it is evident that they are similar to that of tensile strength. Five percent again has a vast difference between the two methods, this time only being about 200%. However the results at 15% and 25% remain the same. Again, the microwave shows more consistency than the conventional oven.

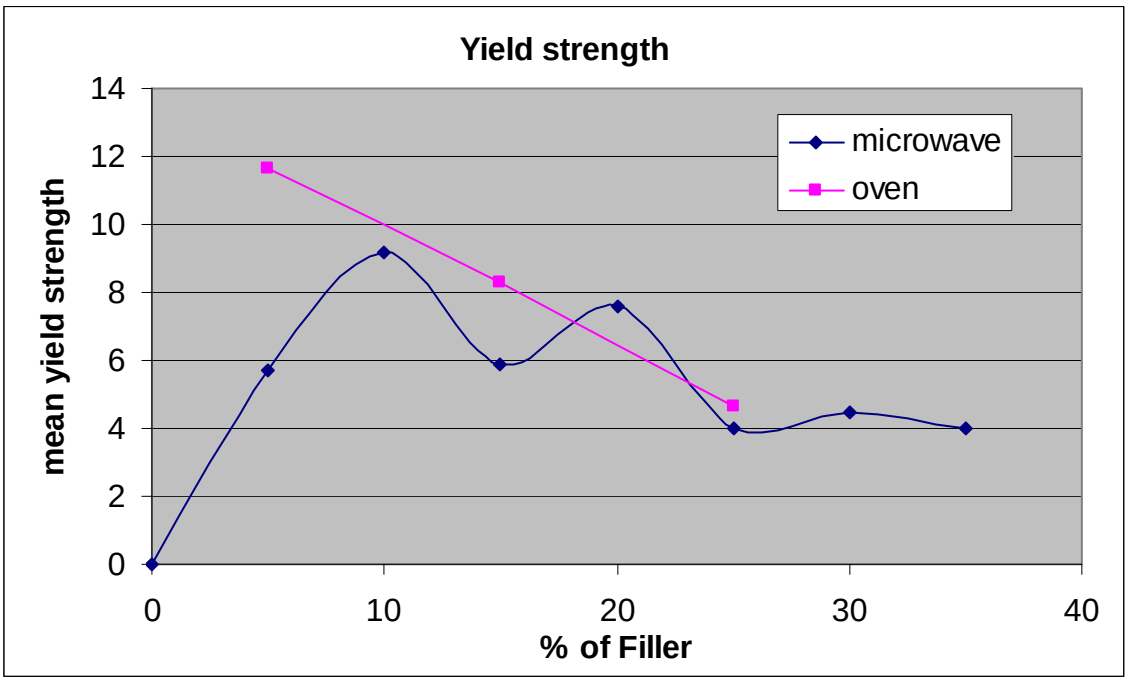

Figure 4.6 – Comparison of post-curing methods for mean yield strength

4.4 – Young's Modulus

The following section discusses the results found by calculating Young's Modulus at each percentage of filler by weight. Again it will discuss the findings from post-curing by microwave and conventional oven.

4.4.1 - Results of Curing by Microwave

Table 4.3 – Young's modulus for each specimen, showing distribution

Specimen	0	5	10	15	20	25	30	35
1	1.75	1.89	1.94	2.21	1.81	-	1.73	1.85
2	-	1.89	1.92	2.04	1.83	1.94	1.75	1.71
3	1.87	1.89	1.87	2.12	1.85	1.94	1.78	2.12
4	1.83	-	1.78	2.157	1.85	1.96	1.92	1.73
5	-	1.85	-	2.157	1.85	-	1.89	2.01
6	-	1.94	1.89	-	-	-	-	-
Mean	1.816667	1.892	1.88	2.1368	1.838	1.94667	1.814	1.884

Table 4.3 shows the effects of microwave positioning; all results per sample are relatively consistent. Therefore again the positioning in a microwave will have little effect on the outcome of Young's modulus.

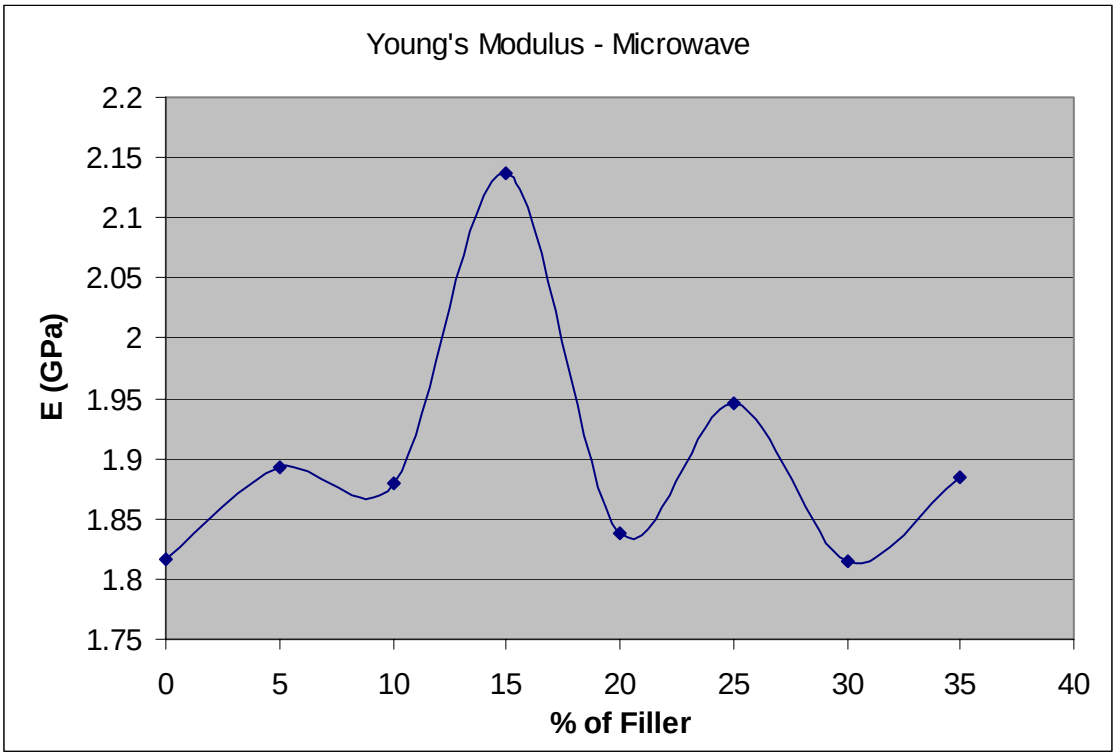

Figure 4.7 – Young's modulus post-curing by microwave

Figure 4.7 depicts a steady trend between all percentages of filler, as seven of the eight samples range from 1.841 GPa to 1.946 GPa. The stand out sample was 15% beating the next best of 25% by roughly 110%.

4.4.2 - Results of Curing by Conventional Oven

Figure 4.8 depicts the results of the mean for Young's Modulus for the three chosen samples. The curve shown is very different to tensile and yield strength as they were linear decay graphs. The 15% of filler is the clear dominate percentage with the next best

being 5% (102% difference). Similarly to the previous graphs produced for conventional oven, 25% was the weakest.

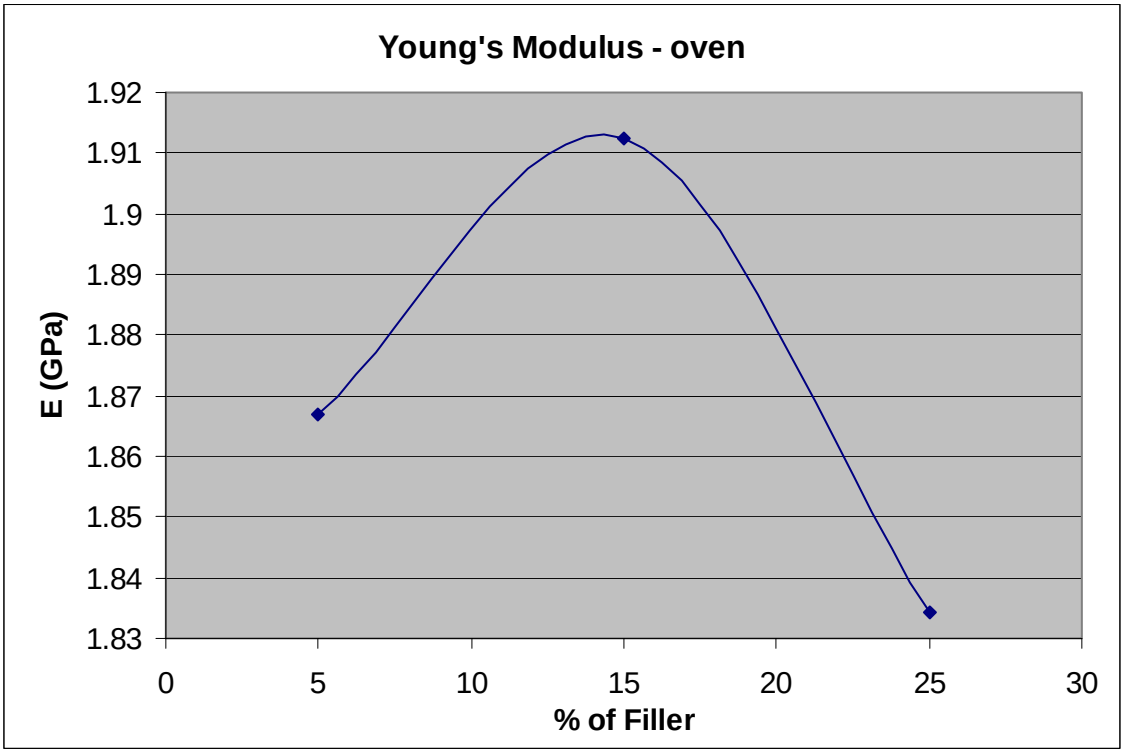

Figure 4.8 – Young's modulus post-curing by conventional oven

4.4.3 – Comparison

Figure 4.9 depicts both results calculated for Young's modulus.

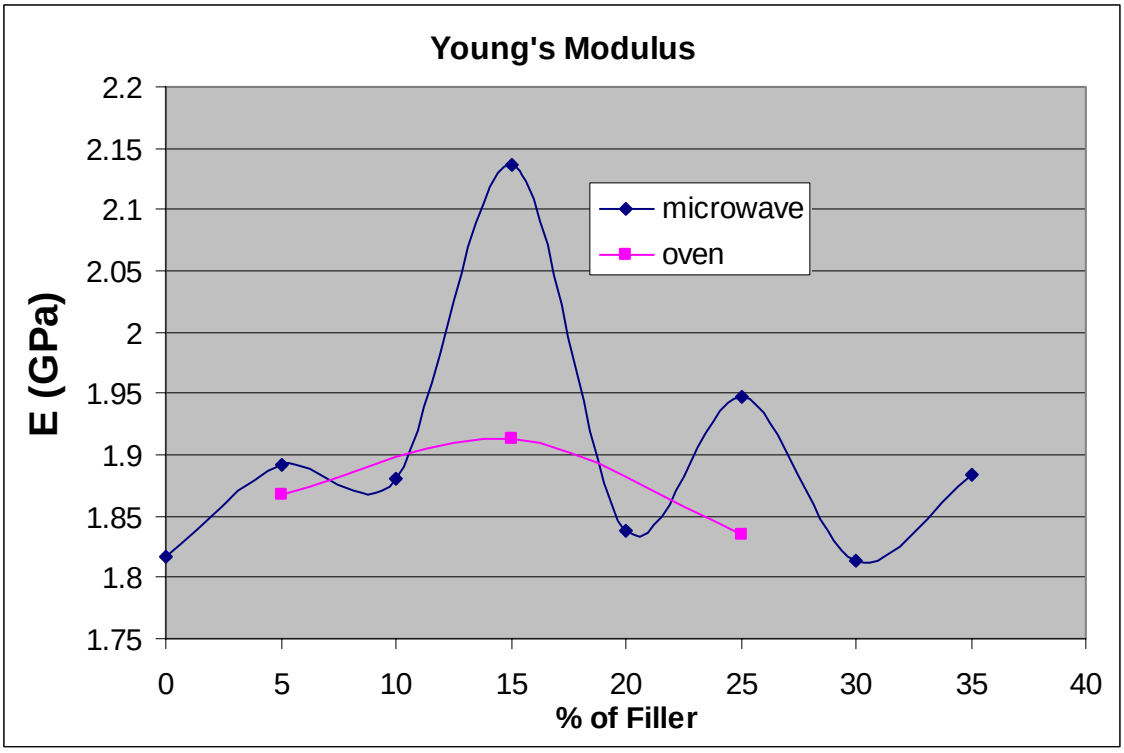

Figure 4.9 – Comparison of post-curing methods for Young's modulus

This graph shows a very different result to Figures 4.3, 4.6 as the microwave produced more dominate results. The clear dominating percentage was at 15% of filler by 117% to that of 25% filler. Also unlike the previous two figures the oven shows consistent results, therefore showing there is not a huge advantage post-curing by microwave, besides the time taken.

4.5 – Microscopic Analysis

The microscopic analysis demonstrated two key characteristics; porosity formation the size and number of air bubbles and where the specimen will form a ceramic like texture. These are key characteristics which have impact on tensile properties.

4.5.1 – 5%

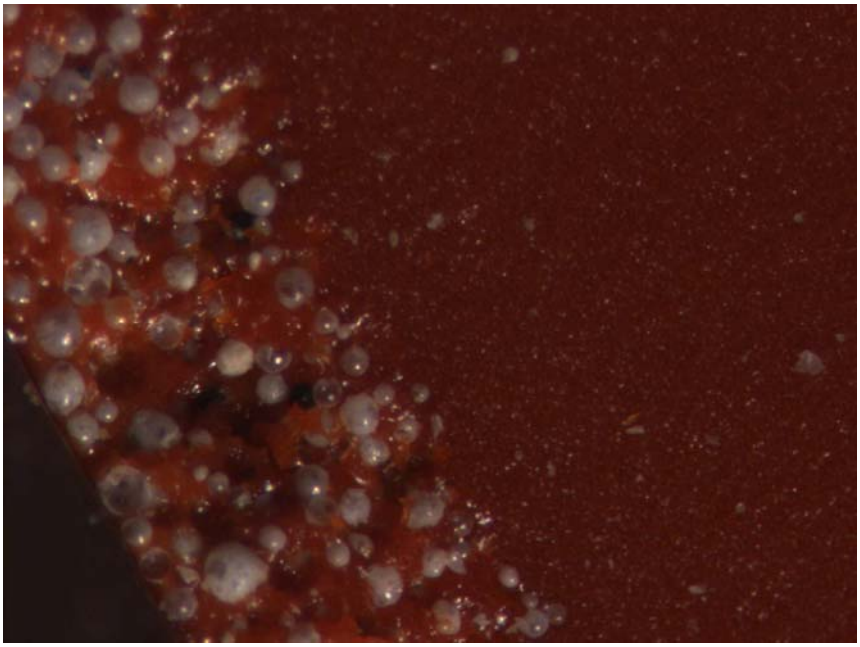

Figure 4.10 – Microscopic view of specimen 5% post-cured by microwave

Figure 4.10 shows the resulting test specimen once failure has occurred. The key points to bring to attention are the air bubbles (porosity), and the ceramic like texture. The air bubbles have formed about 1-1.5mm from the surface, which would accelerate failure. However the remaining two thirds of the specimen had formed a strong ceramic like structure.

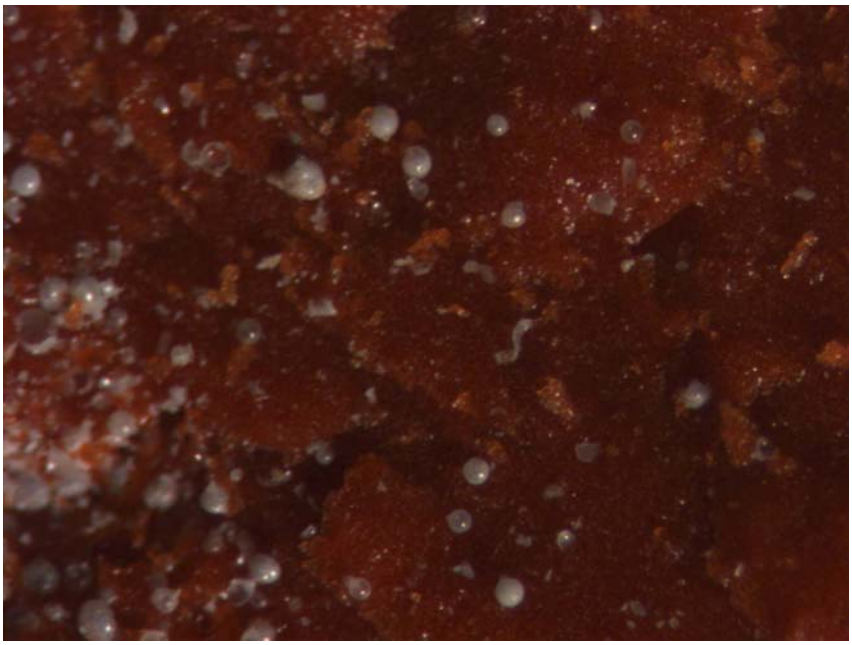

Figure 4.11 – Microscopic view of specimen 5% post-cured by conventional oven

The results from the conventional oven; seen in Figure 4.11, are quite different to that of the microwave at 5%. The porosity which was only seen in the top third of the specimen in the microwave seems to be more dispersed over the entire specimen. Also the fracture seen in the microwave specimen was a clean break where as the conventional oven test showed a rougher break which would demonstrate that a stronger bond was formed.

4.5.2 – 15%

The 15% microwave specimen in Figure 4.12 shows porosity is still present however it is not a thick band seen in the 5% specimen. The porosity seems to have spread to at least half of the specimen but is less dense, and the ceramic texture has a jagged edge. This shows that a resistance was present during testing. The results were shown in Table 4.1, 4.2 and 4.3.

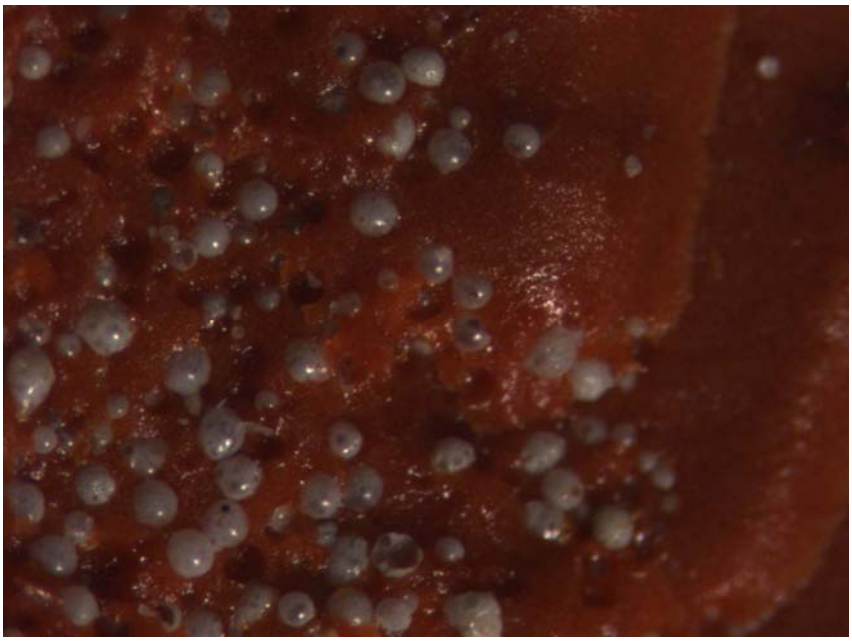

Figure 4.12 – Microscopic view of specimen 15% post-cured by microwave

The conventional oven post-curing method again in Figure 4.13 shows similar results to that of the 5% specimen. The air bubbles are finer and more spread out and the ceramic texture is smoother than that of the microwave specimen.

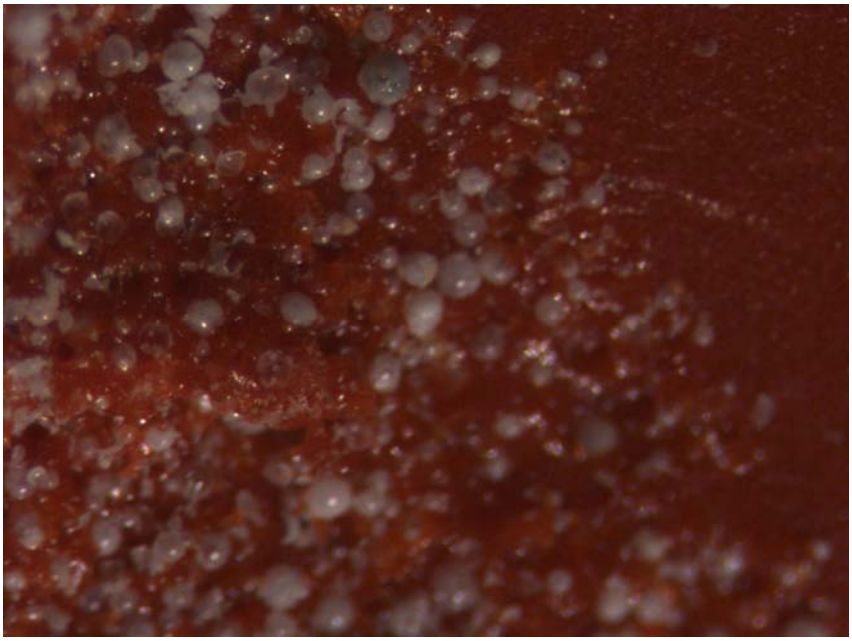

Figure 4.13 – Microscopic view of specimen 15% post-cured by conventional oven

4.5.3 – 25%

The results from the 25% post-curing by way of microwave; Figure 4.14, showed quite different results to the previous two percentages. Air bubbles are present throughout the entire specimen, which demonstrates why the tensile properties at 25% were lower. There is no evidence of a ceramic like texture; however the surface does seem to be quite coarse.

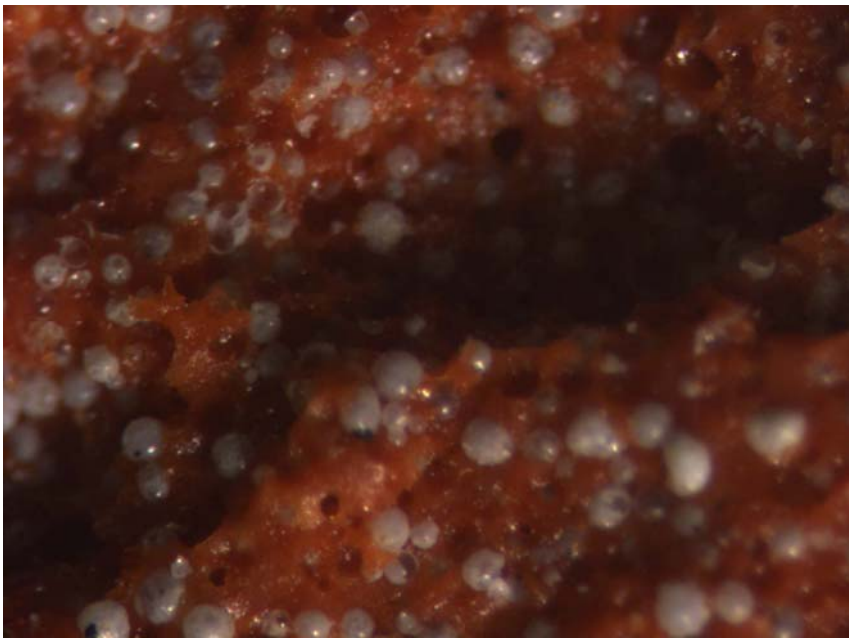

Figure 4.14 – Microscopic view of specimen 25% post-cured by microwave

The texture of the conventional oven post-cured specimen has a smoother texture with, once again, finer air bubbles throughout the specimen. There is also more distance between each air bubble which would assist in improving tensile properties (Figure 4.15.)

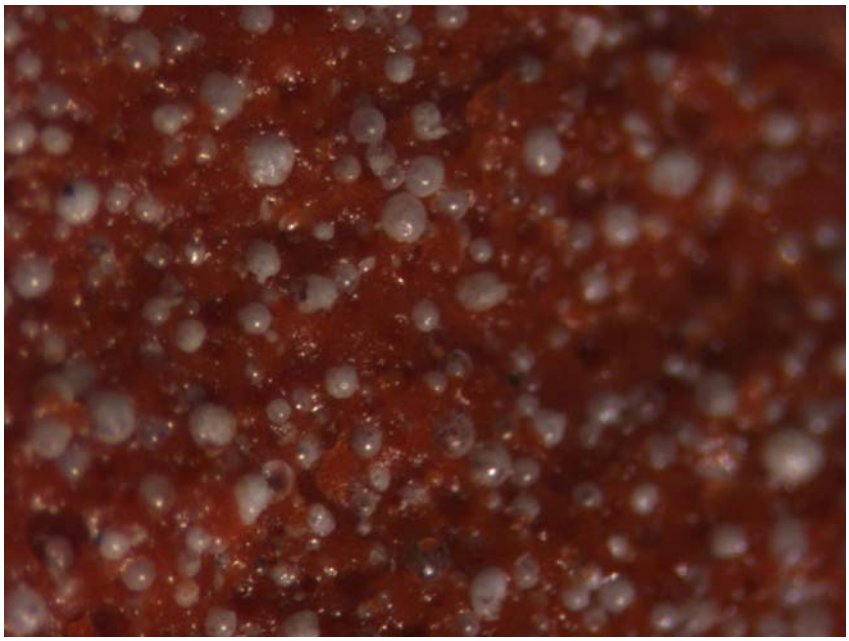

Figure 4.15 – Microscopic view of specimen 25% post-cured by conventional oven

4.6 – Cost Analysis

Table 4.4 – Material costs per sample, showing the percentage differences

	Price ($)	Total ($)	% difference of cost
0%	0.84		
	0.044	0.884	(0-5) 5%
5%	0.798		
	0.04232	0.84032	(5-10) 5.3%
10%	0.756		
	0.04	0.796	(10-15) 7.4%
15%	0.7		
	0.03788	0.73788	(15-20) 4%
20%	0.672		
	0.0356	0.7076	(20-25) 6.3%
25%	0.63		
	0.03336	0.66336	(25-30) 6.7%
30%	0.588		
	0.03112	0.61912	(30-35) 7.8%
35%	0.546		
	0.028936	0.5749	

cost of resin
cost of catalyst

Table 4.4 shows the cost of materials to produce each sample; the calculations can be seen in either Appendix J or section 2.5. The information gathered from the table is important in showing the advantages of using as much filler as possible. Although in this study the costs for each sample are small, when applying it to industry a 5%-10% saving could be thousands of dollars. The two dominate percentages of filler by way of weight are 10% and 15%. The decision is important between the two, as there is a price difference of 7.4%. Further analysis of costs will be discussed in chapter 5.

4.7 – Concluding Remarks

This chapter has shown the results found for the mechanical properties; tensile and yield strength and Young's modulus. The results have been discussed and analysed with comparisons being drawn from the two post-curing methods. The following chapter will conclude the findings of this chapter, and state clear advantages and the optimum percentage of filler by weight. To view the raw data from each sample post-cured by both microwave and conventional oven that was extracted from testing please find the Appendix H attached.

5 – Conclusions

5.1 – Introduction

This chapter will summarize the findings of the study, and draw conclusions from chapter 4. The optimum percentage of filler by weight will be recognized, and analysis conducted into the advantages of post-curing using a microwave. A cost analysis will be conducted on the material for each sample, and will conclude the optimum percentage of filler by weight.

5.2 – Analysis

The analysis involved assessing the data presented through the graphs and tables. The desired result of graphs is to show a general trend line, allowing a distinct peak to be found. Yield strength and tensile strength were extrapolated slightly to allow an accurate curve to be produced. Many results for the yield strength were unable to be calculated due to the results not being available. A minimal amount of estimation was used, however results have remained in sync. Once an optimum sample was selected, comparisons were made between the post-curing by conventional oven and providing valuable data to ascertain benefits.

5.2.1 – Tensile Strength

Referring back to chapter 4, Figure 4.1 showed a varying mean strength for the specimens corresponding to their percentage mixture of slg filler by weight in relation to tensile strength. From the graph it is clearly shown that the percentages 10% to 20% are significant ranging from 8.54 to 9.04 MPa. The samples either side of this range did not exceed 6.57MPa, therefore representing a 20% decrease in tensile strength.

The best percentages of filler were the 10% and 20% samples. The results from the six specimens in each sample were very similar. However the 10% did have a specimen which was on the border line of being an outlier, which would impact on the average. This would be an important decision between the 10% and 20% as there is a 11.4% increase material costs to produce the 10% sample.

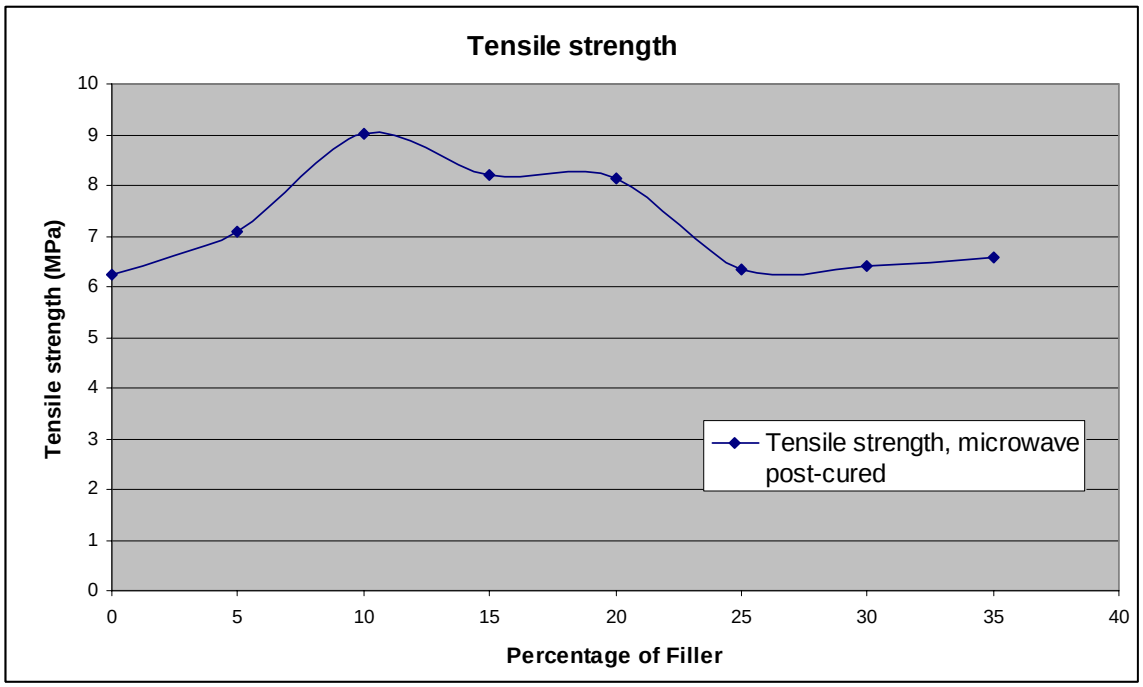

Figure 5.1 – Extrapolated graph of tensile strength

Figure 5.1 depicts an extrapolated form of the Figure 4.1 where the 5% sample increases to 7.1 MPa, along with a decrease in 15% and 25% to 8.22MPa and 8.15MPa respectively. The purpose of extrapolation is to create a general trend line, and to show a more accurate result as many of the specimen were accounted as outliers, therefore a more truthful estimation had to be calculated.

It was then found that the optimum percentage of filler per weight for tensile strength is at 10%, with 15% and 20% in close proximity. It is also important to note that if the strength requirements fit into the category of using 25%, then it would be more cost

efficient to use 35% as the results found between these two is minimal. However when comparing the results of the two post curing methods, the conventional oven would give a lower strength at this rate.

5.2.2 – Yield Strength

Figure 4.4 from the previous chapter shows a defined peak in the mean strength at 10% of 9.1533MPa. The next best being 20%, at a yield strength that is 20% lower than that of the 10%. The results for 5% and 0% seem inaccurate, as not all specimens were available to calculate yield strength. With reference to the post-curing by conventional oven the mean yield strength showed a sharp increase as the percentage of fillers decreased. A decrease was also seen in the mean yield strength as the percentage of filler increased, therefore it has been proven that a lower percentage of filler will produce a higher yield strength.

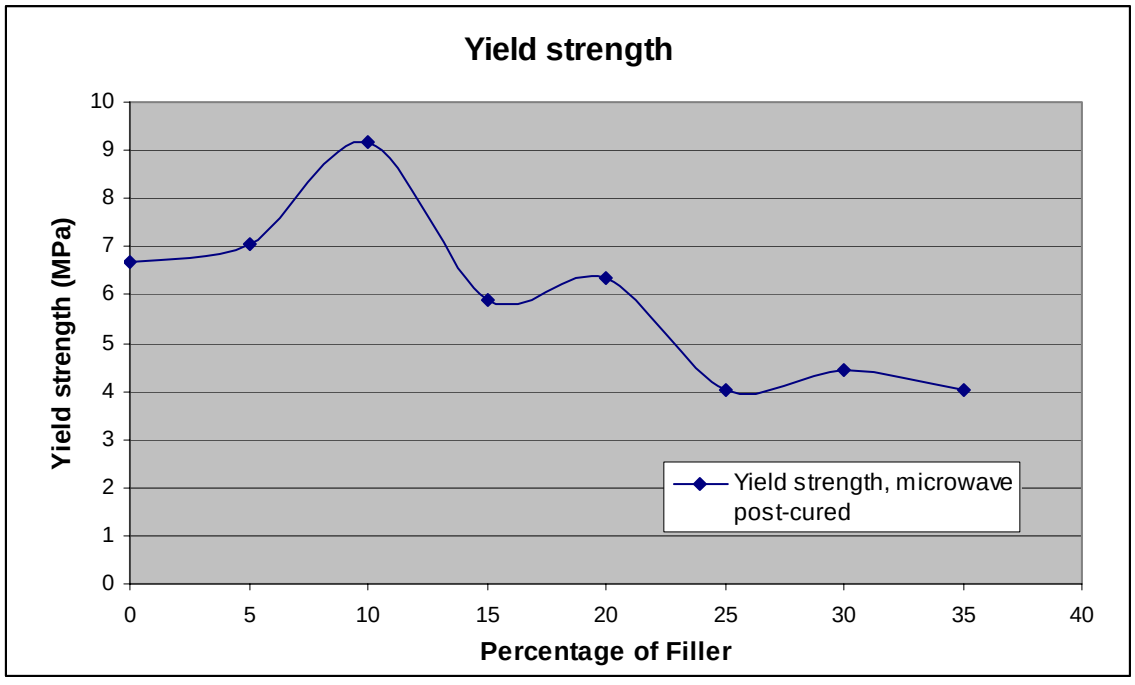

Figure 5.2 – Extrapolated graph of Yield strength

Figure 5.2 is an extrapolated graph of yield strength. It was necessary to estimate the value of 0%, as limited results were available. The 5% sample also required further attention, as the comparison of post-curing by conventional oven showed the lower percentages of filler would produce higher results. The updated graph shows a curved trend line which reaches a peak at 10% of filler by weight. Therefore the optimum percentage of filler by weight is at 10%. However 15% isn't too far behind, if there is a need to reduce expenses.

5.2.3 – Young's Modulus

From Figure 4.7 in the previous chapter it is instantly seen that the graph peaks at 15%. It is important to note that all samples were relatively similar in their results apart from that of 15%.

The stiffest specimen was 15% at 2.13GPa, which was followed by 25% at 1.95GPa, for a closer view of the results please find the table of results attached in Appendix I. As the 25% of filler by weight is the strongest sample after 5%, this result of Young's Modulus of elasticity is a significant result, showing that the 25% of filler has a useful strength whilst importantly has a reduction of 10.3% in material costs.

5.3 – Findings from Microscope

The microscopic views showed some very interesting findings. Although not as expected, the figures 4.10-4.15 have still provided useful insight. As photos were taken from various percentages for both post-curing methods, it can be concluded that the air bubble formation is closely linked with the amount of filler. It seemed that in both post-curing methods as the filler was increased there was less ceramic like structure, thus decreasing strength and increasing the presence of air bubbles (porosity). It was interesting to note that the two post-curing methods had different affects on the porosity. In all cases the conventional oven caused the porosity to be finer, which would increase strength, whilst

the microwave produced larger bubbles. This explains the difference in all strengths as the finer bubbles would allow for more strength as a propagating crack would encounter more obstacles hence a larger force would be required to result in failure.

5.4 – Final Material Recommendations

In microwave testing the strongest value of tensile strength was at 10% of filler per weight with a peak load mean of 756.2N and mean tensile strength of 9.016MPa. This percentage of filler also had the highest yield strength at 9.153MPa however this sample did not produce the highest stiffness (Young's modulus). The sample that produced the greatest stiffness of 2.13GPa was 15%. This would then show that the optimum percentage of filler would be between 10% and 20%. Although the post-curing method by conventional oven did show that the strength increases as the percentage of filler decreases, it is not worthwhile as only small cost reductions will be seen.

The results gathered from the two methods of post-curing provided primary information on the advantages and disadvantages of each method. As there are distinctive differences between the two methods, approximately 9.5 hours can be saved in time. Therefore, if these findings were used in industry, the microwave would have significant savings in power usage.

For the purpose of the study to find the optimum percentage of filler to give the strongest tensile properties by way of post-curing by microwave, a percentage filler by weight of 10% or 15% is appropriate. These two samples produced high tensile properties, and both provide a savings in materials as discussed in previous chapters, as there is a saving of 7.4% in material costs between the two.

5.5 – Limitations of Results

Limitations encountered when reviewing the previous research are:

- All measurements (weights, lengths and volumes) were conducted by hand and although steps were taken to remain consistent with the limits of the equipment, inaccuracies may still result.
- The tensile testing machine did have the capabilities to measure up to 100kN of force, however for this study the maximum force that was exerted did not exceed 1kN. Hence the machine sensitivity may not have picked up all movements in force.
- Due to minor deformation of specimens during the post-curing by way of microwave, a small percentage did bow. This had an implication when loading into the tensile machine. Therefore a force was already present on the specimen, hence the graphs did not always start on zero, and the final results could have been slightly obscured.

5.6 – Fulfillment of Objectives and Further Research

All objectives were fulfilled in the study, which were outlined in the project specification (Appendix A). The objective outlining a comparison of post-curing methods if time permitted. This was important in furthering the discussion of the advantages of using the microwave. Another objective was also added which was not initially intended to be fulfilled but proved vital; this being the microscopic views of fractured specimen. These photos enabled analysis of the effects of porosity and the two post-curing methods, providing extra knowledge for comparison.

Further analysis may be required into the bowing of specimens during the post-curing stage, as it is not exactly known what caused this deformation. Also the post-curing method by way of microwave would benefit from further testing, as it was difficult to

ensure that all specimens reached 100°C. Therefore some specimens may have developed slightly different mechanical properties.

5.7 - Conclusions

This chapter has provided a discussion of the results and their relevant meanings for tensile and yield strength and Young's Modulus. The discussion focused on material mechanics and the objectives of this dissertation of ascertaining the best percentage weight of fillers in phenolic (phenol formaldehyde) resins using a tensile testing machine.

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CEEFC – *Francisco Cardona* – knowledge of material costs

E-spheres, www.envirospheres.com.au, Envirospheres Pty Ltd., P O Box 497, NSW 2070, Australia, undated.

Appendix A - Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111/4112 Research Project
PROJECT SPECIFICATION

Project title:	Using tensile tests as benchmark, investigate the best percentage by weight of slg, as fillers, in phenolic resins post-cured by microwaves.
Student:	Thomas Davidson – 0050009104
Supervisor:	Dr. Harry Ku and a staff from CEEFC
Sponsorship:	USQ, CEEFC
Project Aim:	This project aims to investigate the effect of post-curing in a microwave oven, upon specimens made from phenolic resin, phencat 15 and different percentage by weight of fillers. Tests will be done to evaluate the tensile strength, Young's modulus and Poisson's ratio.
Programme:	**Issue A, 23rd March 2007**

1. Familiarize with equipment and set guidelines for producing the specimens (Complete by 30th March)

2. Produce specimens, cure in microwave and prepare for tensile testing (Complete by 30th April)

3. Begin literature review, researching history and previous study's involving composite strengths and weaknesses.

4. Analysis of results, evaluating the effectiveness of post-curing by microwave.

5. Draw up conclusions.

Time permits

6. Comparison of post-curing methods, and selecting a method which is most beneficial.

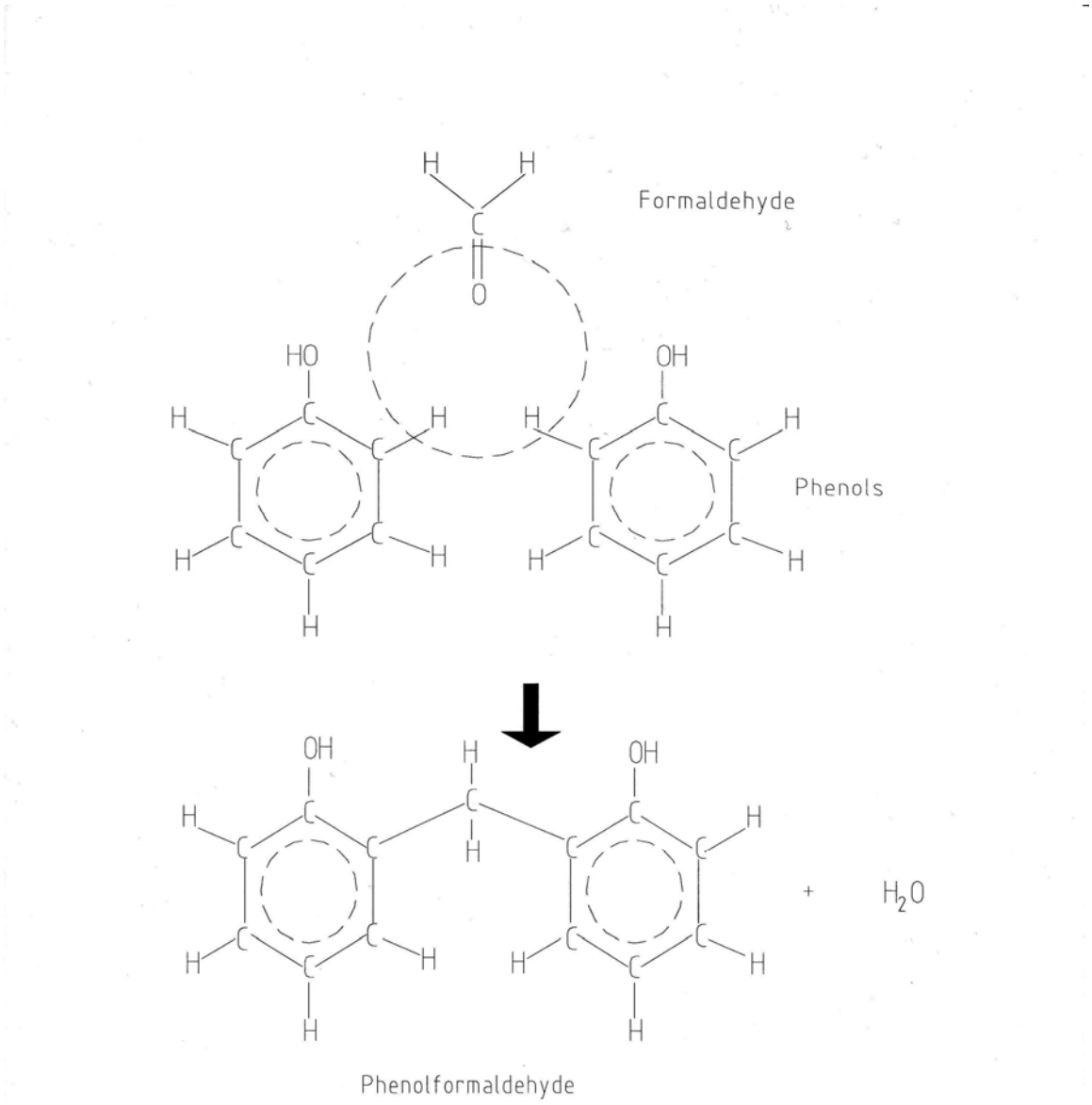
AGREED

(student) _____ (supervisor) _____

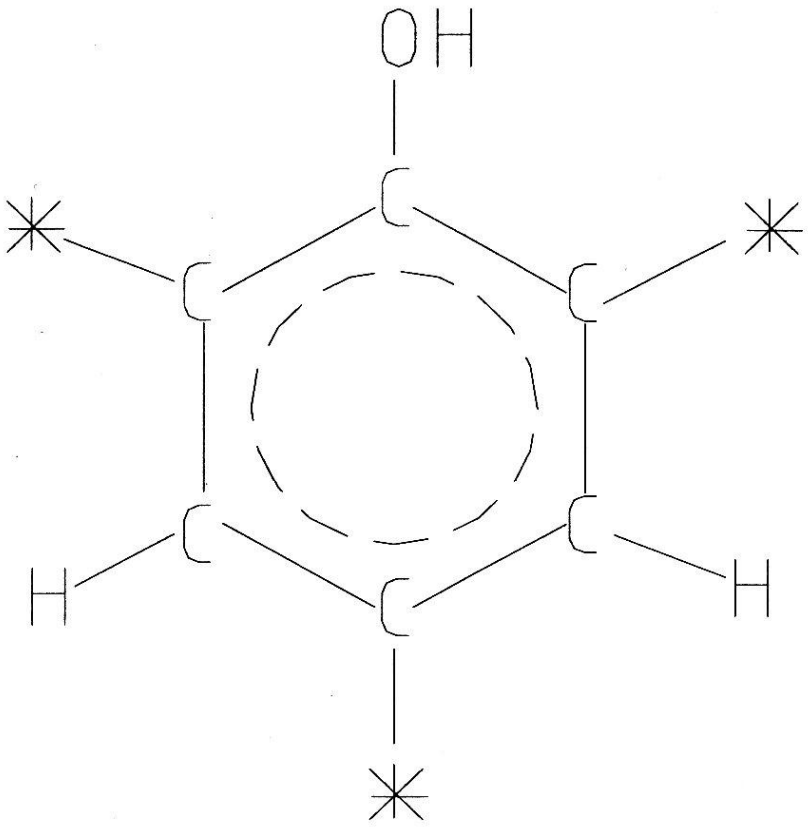
Date: / / 2007 Date: / / 2007

Co-examiner:_____

Appendix B – Formation of Phenol formaldehyde



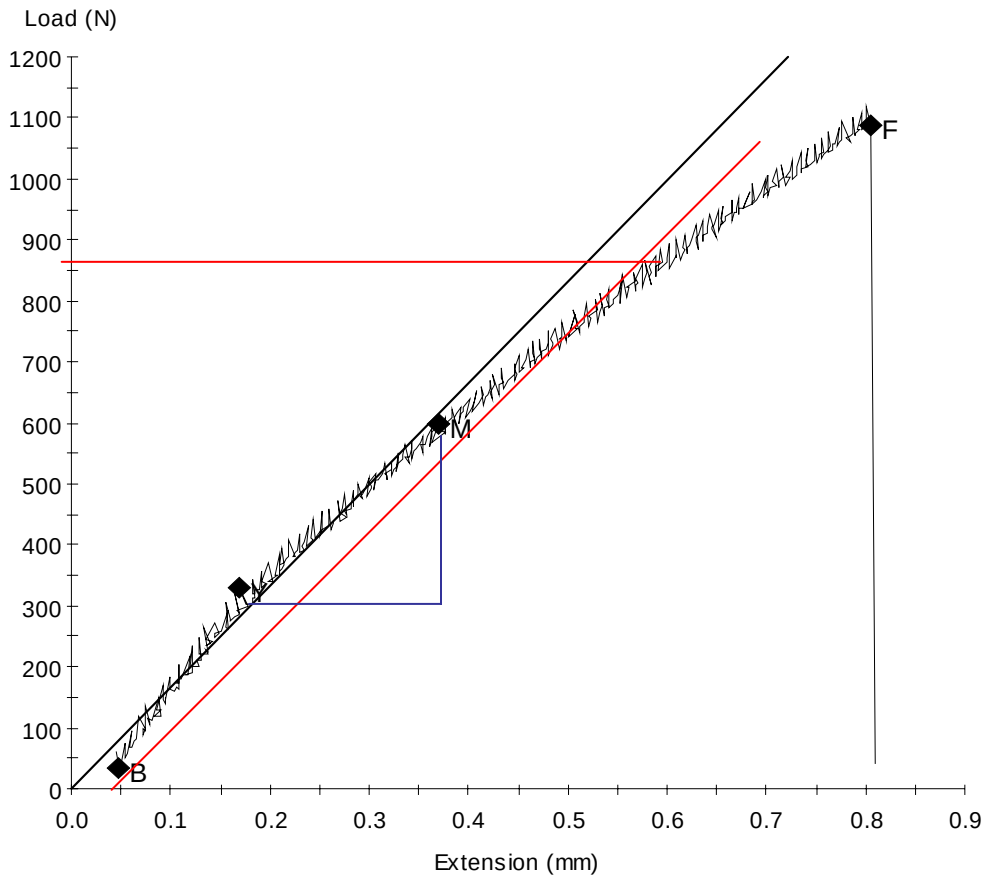
Appendix C – Phenol with Active Sites



Active sites marked with ✳

Appendix D – How strengths were obtained from raw data

Sample ID: tomov-15%-5.mss
Specimen Number: 5
Tagged: False



Specimen Results:

Name	Value	Units
Thickness	5.310	mm
Width	15.010	mm
Area	80	mm^2
Peak Load	1119	N
Peak Stress	14.04	MPa
Break Load	1086	N
Break Stress	13.63	MPa
Elongation At Break	0.806	mm
Stress At Offset Yield	7.118	MPa
Load At Offset Yield	567.339	N

Calculation of Strengths

Tensile strength (highlighted in green text)

Tensile strength is found by Peak stress

Therefore: Peak stress = Tensile strength

= 14.04 MPa

Yield Strength (highlighted in red)

As the graph does not have two distinct portions of the line; meaning the elastic and plastic deformation borderline can be found. To ensure that yield strength can be found from the majority of specimen were calculated using a parallel line at 0.05%.

$$Yield\ strength = \frac{Yield\ load\ (N)}{Original\ cross\text{-}sectional\ area\ (mm)} \qquad (2.1)$$

$$= \frac{0.05\%\ \ offset\ load}{Original\ cross\text{-}sectional\ area}$$

$$= \frac{855}{15.010 \times 5.310} = 10.68\ (MPa)$$

Young's Modulus (highlighted in blue)

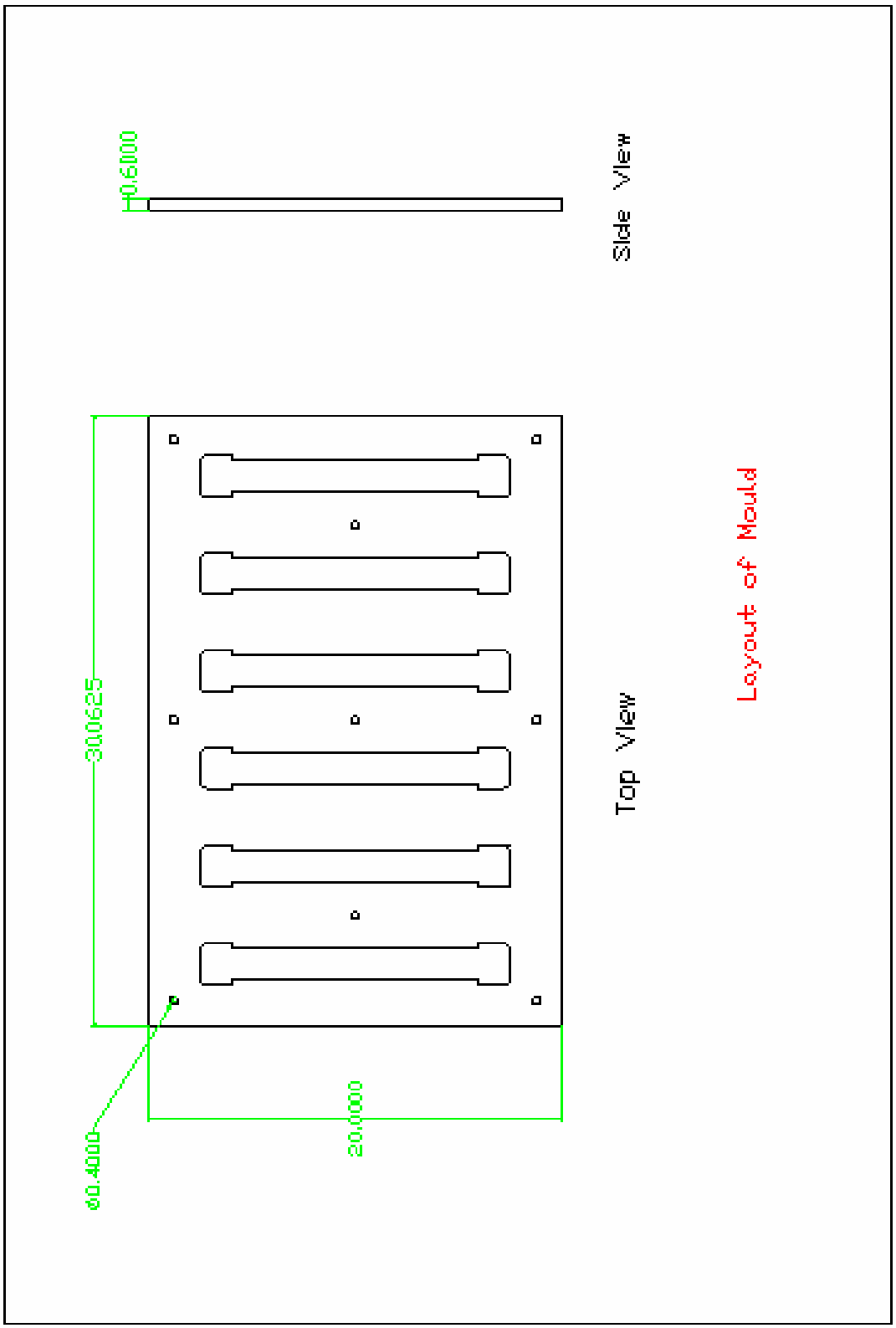
Young's modulus is calculated from the linear part of the curve and is essentially finding the slope of the curve.

$$E = \frac{stress}{strain} = \frac{\sigma}{\varepsilon} \qquad (2.3)$$

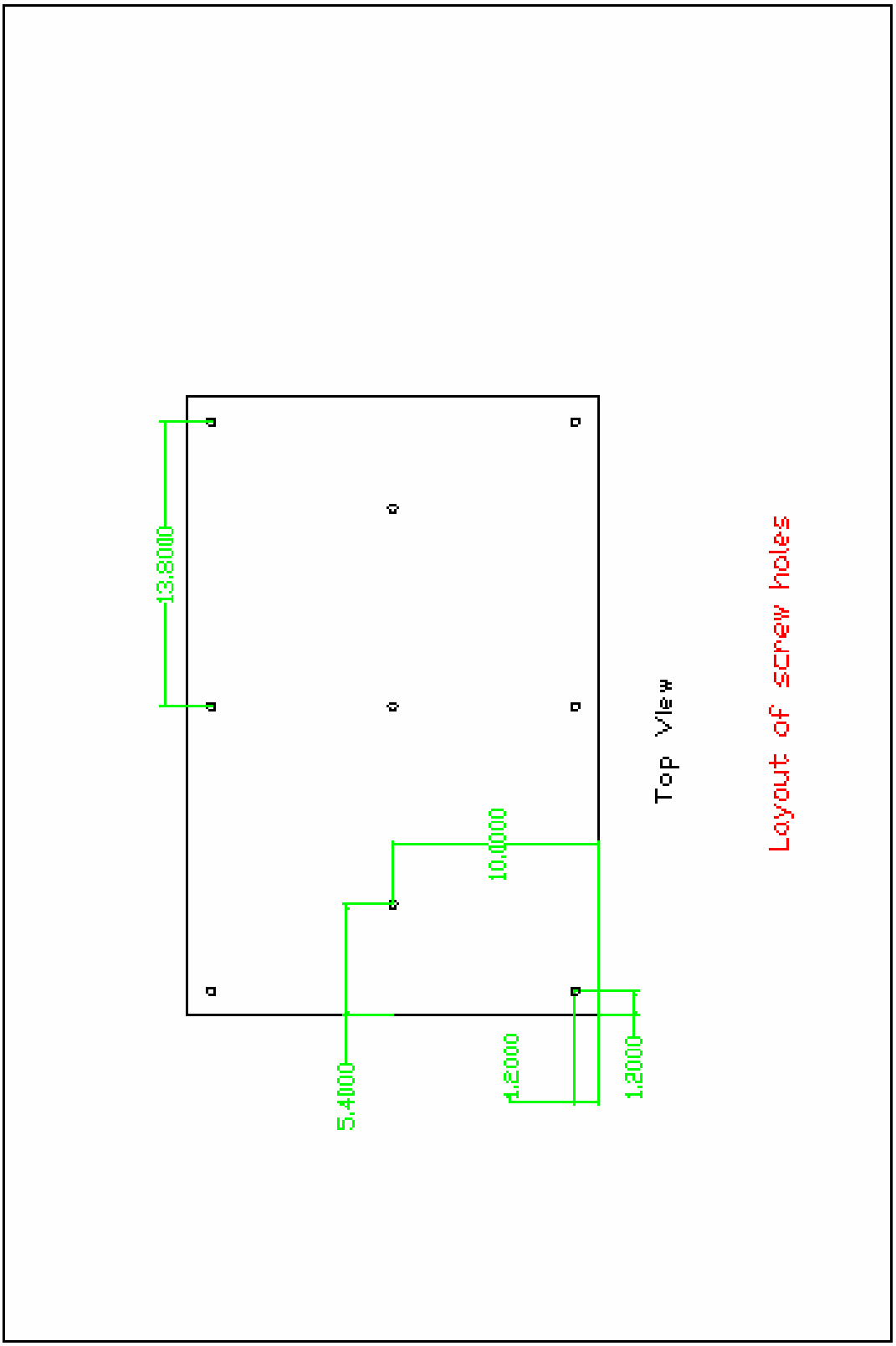
$$E = \frac{\frac{F}{A}}{\frac{\Delta L}{L}}$$

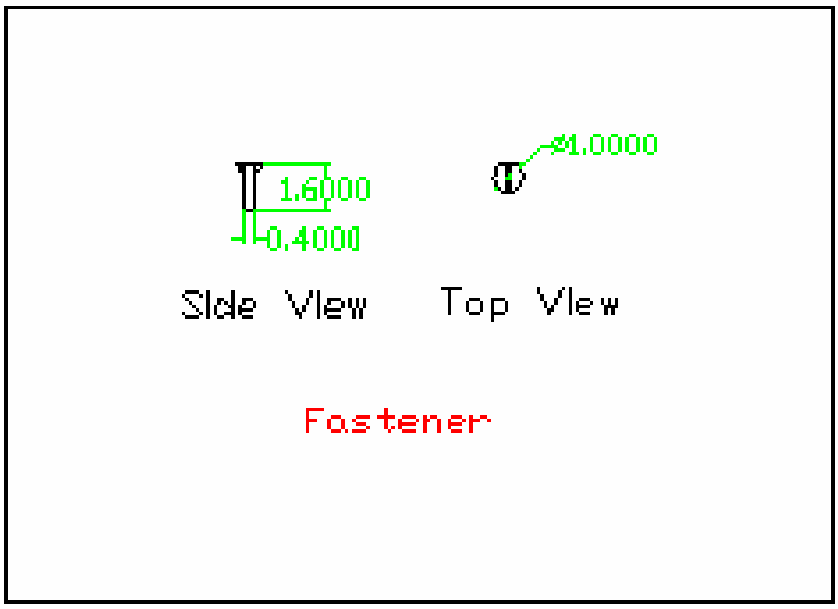
$$E = \frac{\frac{150 - 0}{80}}{\frac{0.1 - 0}{105}} = 1968.78 \text{ (MPa)} = 1.968 \text{ (GPa)}$$

Appendix E – Final Mould Design

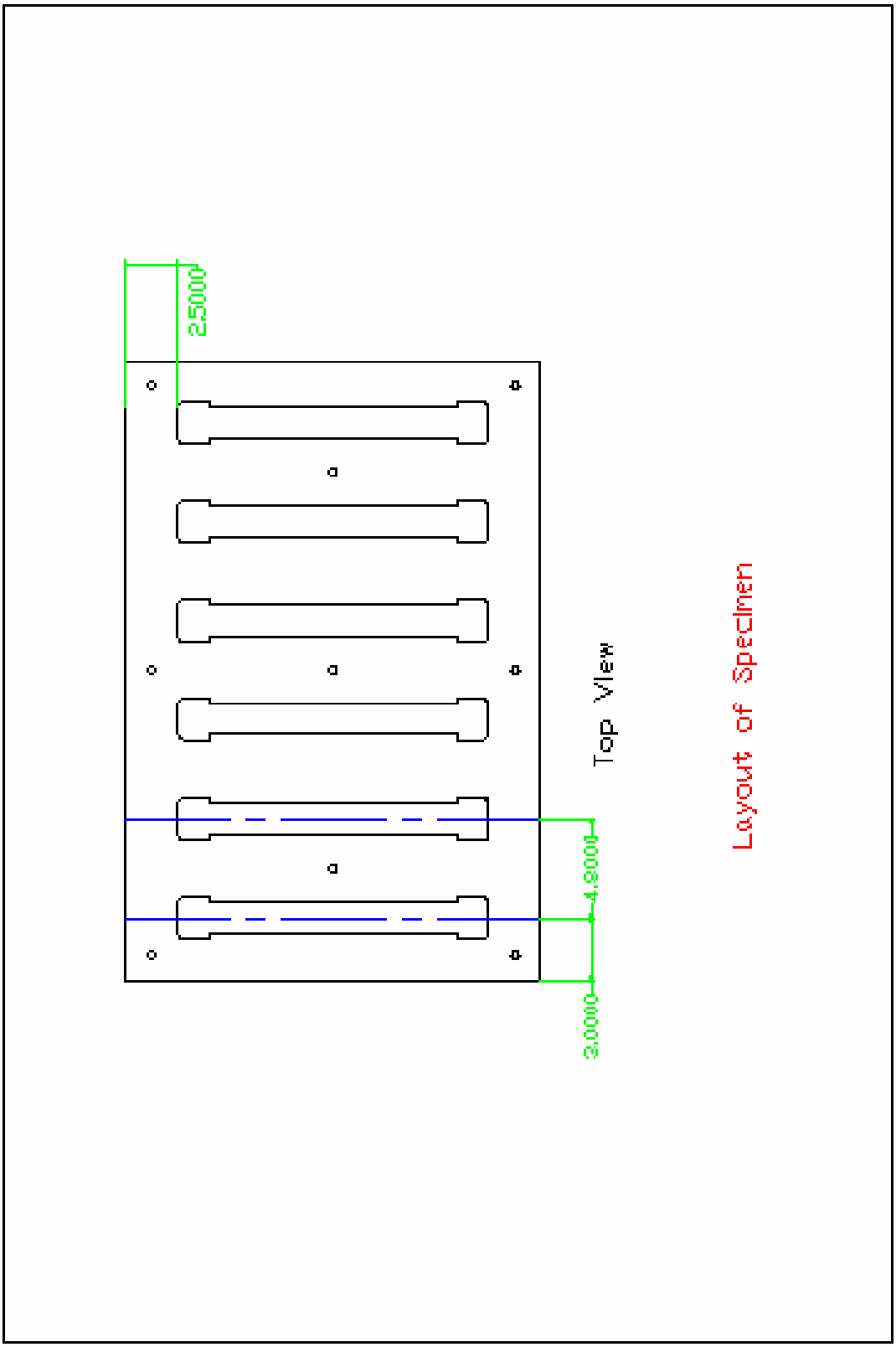


Appendix F – Fastener Layout and Fastener




1.6000
0.4000
Ø1.0000
Side View
Top View
Fastener

Appendix G – Specimen Layout in Mould



Appendix H – Raw Results gathered from Tensile Testing

Tom 0%

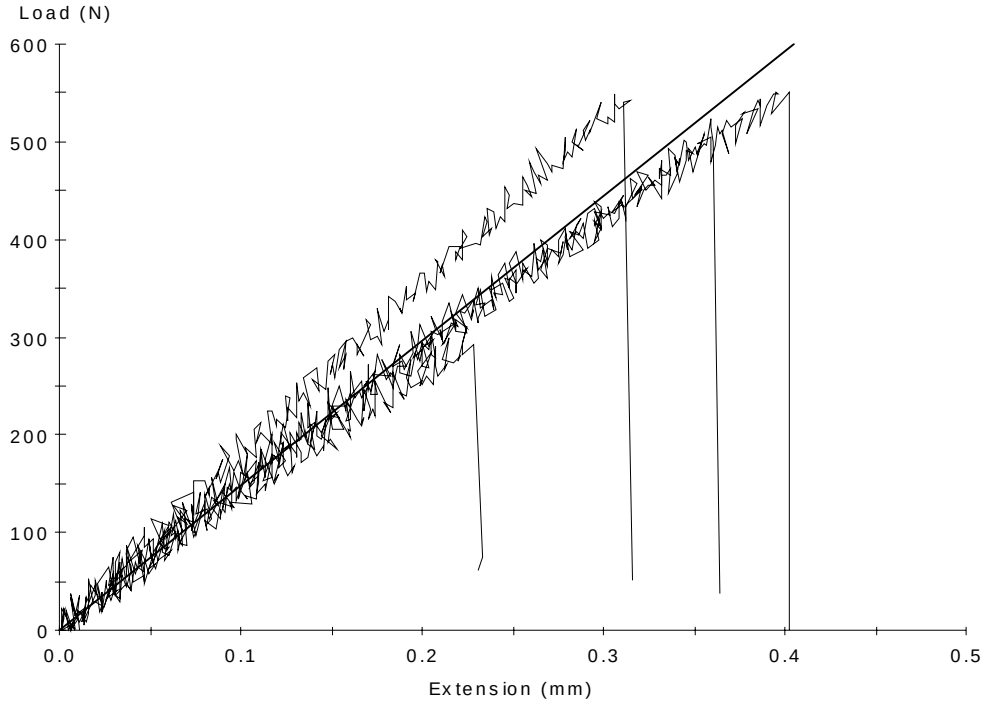
Report Date: 14-Jun-07

Test Date : 14-Jun-07
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	5.980	15.070	90	550	6.10	541	6.01
2	5.600	15.210	85	311	3.65	292	3.43
3	5.590	15.110	84	523	6.19	523	6.19
4	5.720	15.050	86	551	6.40	551	6.40
Mean	**5.722**	**15.110**	**86**	**483**	**5.58**	**477**	**5.51**
Std Dev	**0.182**	**0.071**	**2**	**116**	**1.30**	**124**	**1.39**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.314	3.118	281.017				
2	0.228	1.511	128.742				
3	0.359	2.277	192.324				
4	0.402	2.395	206.206				
Mean	**0.326**	**2.326**	**202.072**				
Std Dev	**0.074**	**0.658**	**62.508**				



Tom2 5%

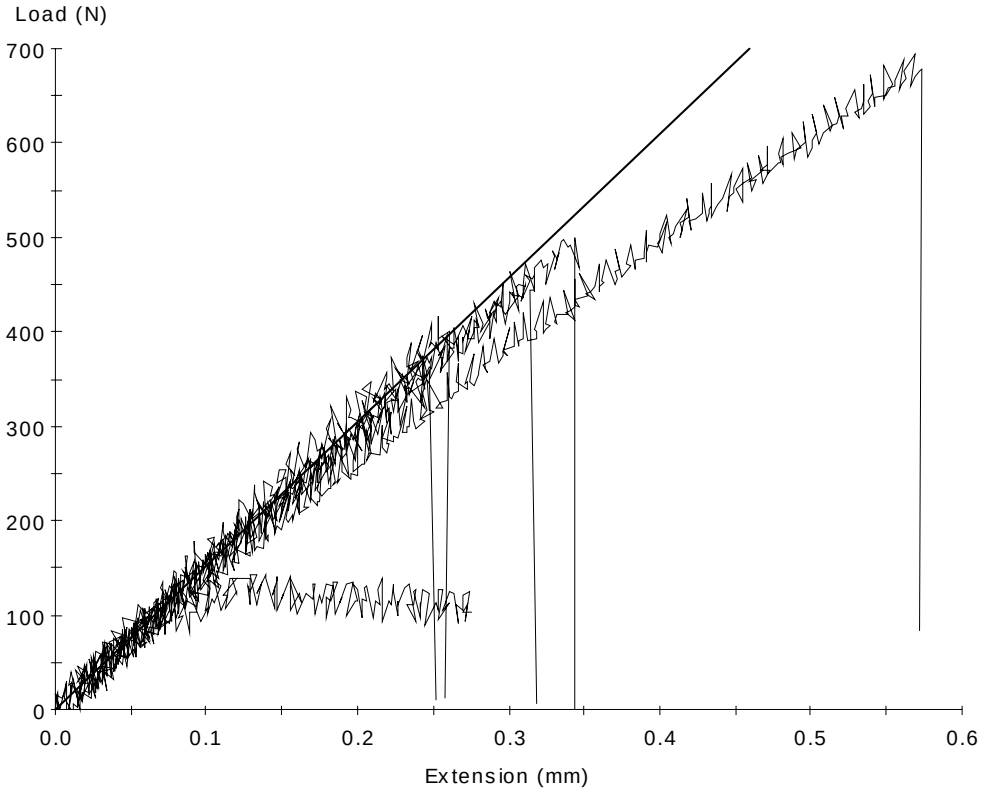
Report Date: 14-Jun-07

Test Date : 14-Jun-07
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	5.480	15.150	83	472	5.69	443	5.34
2	5.410	15.340	83	694	8.36	675	8.14
3	5.530	15.110	83	500	5.99	500	5.99
4	5.790	15.240	88	143	1.62	143	1.62
5	5.600	15.160	85	417	4.92	401	4.72
6	5.430	14.920	81	359	4.43	359	4.43
Mean	**5.540**	**15.153**	**84**	**431**	**5.17**	**420**	**5.04**
Std Dev	**0.140**	**0.140**	**2**	**181**	**2.20**	**175**	**2.13**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.317	3.263	270.913				
2	0.572	3.591	297.987				
3	0.344	2.390	199.744				
4	0.129	0.736	64.925				
5	0.261	2.438	206.995				
6	0.247	1.802	145.964				
Mean	**0.312**	**2.370**	**197.755**				
Std Dev	**0.147**	**1.028**	**84.633**				



Tom2 10%

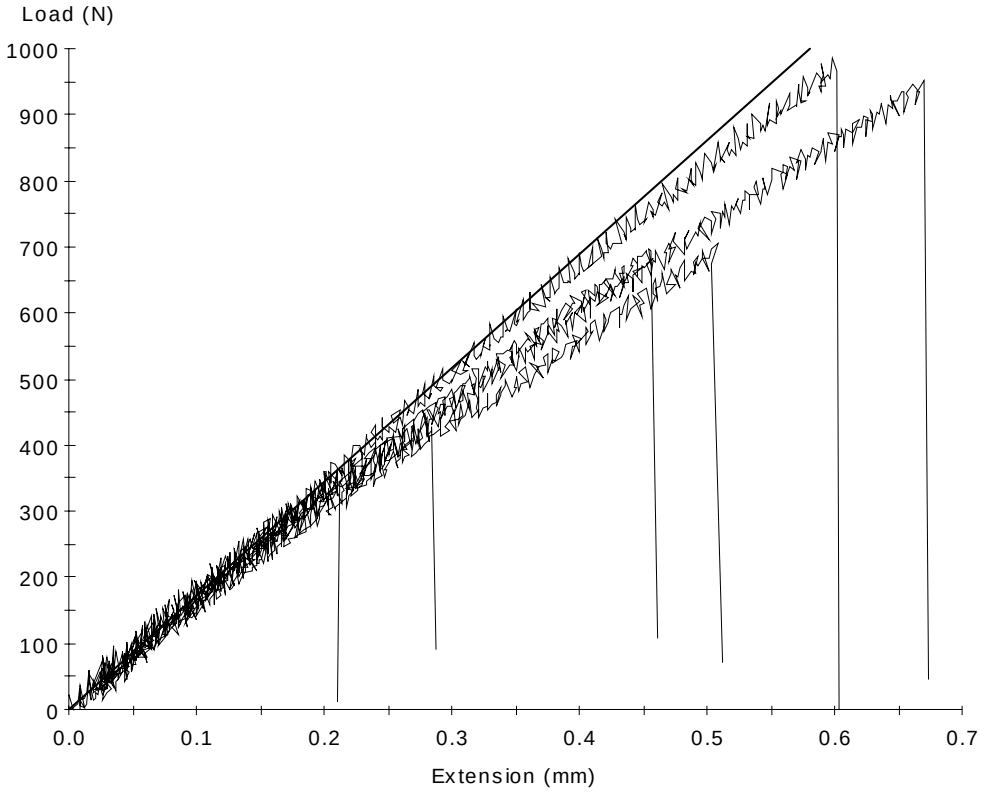
Report Date: 14-Jun-07

Test Date : 14-Jun-07
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	5.410	15.010	81	704	8.68	704	8.68
2	5.410	15.120	82	953	11.65	953	11.65
3	5.590	15.120	84	697	8.25	693	8.20
4	5.860	15.030	88	985	11.19	965	10.96
5	5.570	14.900	83	359	4.33	341	4.12
6	5.550	14.990	83	442	5.31	421	5.06
Mean	**5.565**	**15.028**	**84**	**690**	**8.23**	**680**	**8.11**
Std Dev	**0.165**	**0.084**	**2**	**256**	**2.98**	**260**	**3.04**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.509	3.785	307.337				
2	0.670	5.711	467.132				
3	0.455	4.080	344.868				
4	0.602	6.171	543.521				
5	0.212	1.463	121.458				
6	0.284	3.065	254.967				
Mean	**0.455**	**4.046**	**339.880**				
Std Dev	**0.178**	**1.731**	**150.775**				



Tom-15%

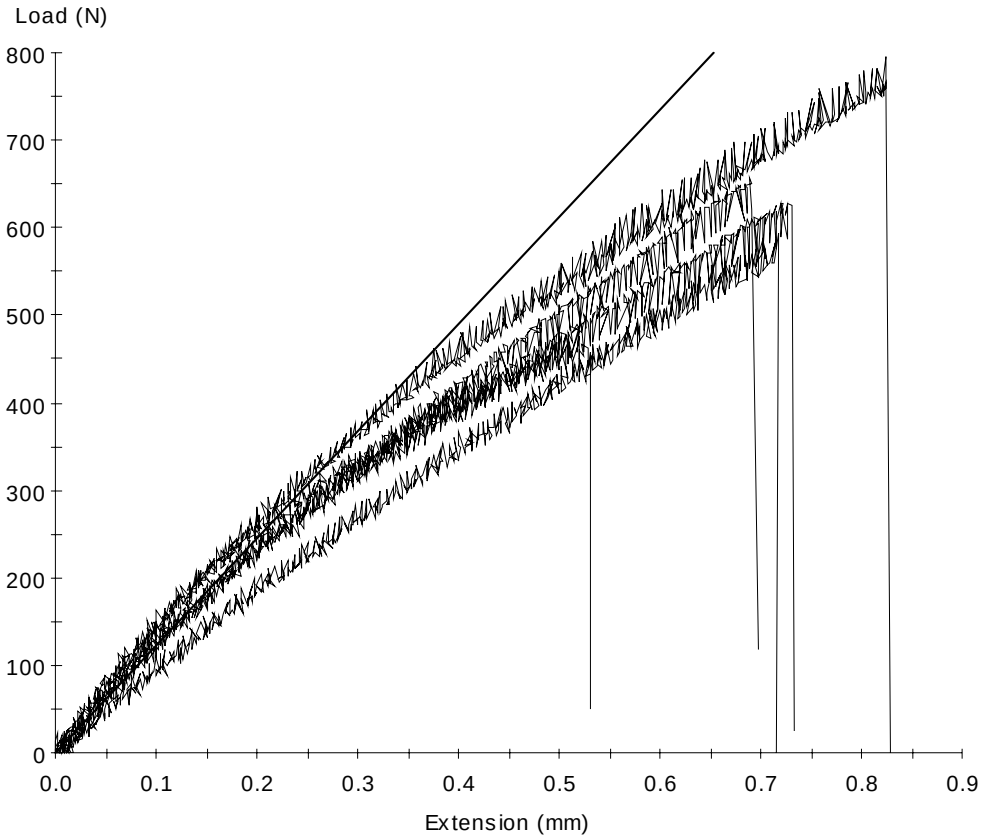
Report Date: 27-Mar-07

Test Date : 27-Mar-07
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	4.800	14.800	71	476	6.70	457	6.44
2	5.250	14.670	77	657	8.54	620	8.05
3	5.000	14.770	74	796	10.78	796	10.78
4	4.900	14.890	73	595	8.15	595	8.15
5	5.000	14.700	73	628	8.55	626	8.52
Mean	**4.990**	**14.766**	**74**	**630**	**8.54**	**619**	**8.39**
Std Dev	**0.167**	**0.087**	**2**	**115**	**1.46**	**120**	**1.56**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.530	2.124	150.888				
2	0.691	3.470	267.216				
3	0.825	4.639	342.576				
4	0.718	3.304	241.084				
5	0.730	2.853	209.726				
Mean	**0.699**	**3.278**	**242.298**				
Std Dev	**0.107**	**0.922**	**70.878**				



Tom2 20%

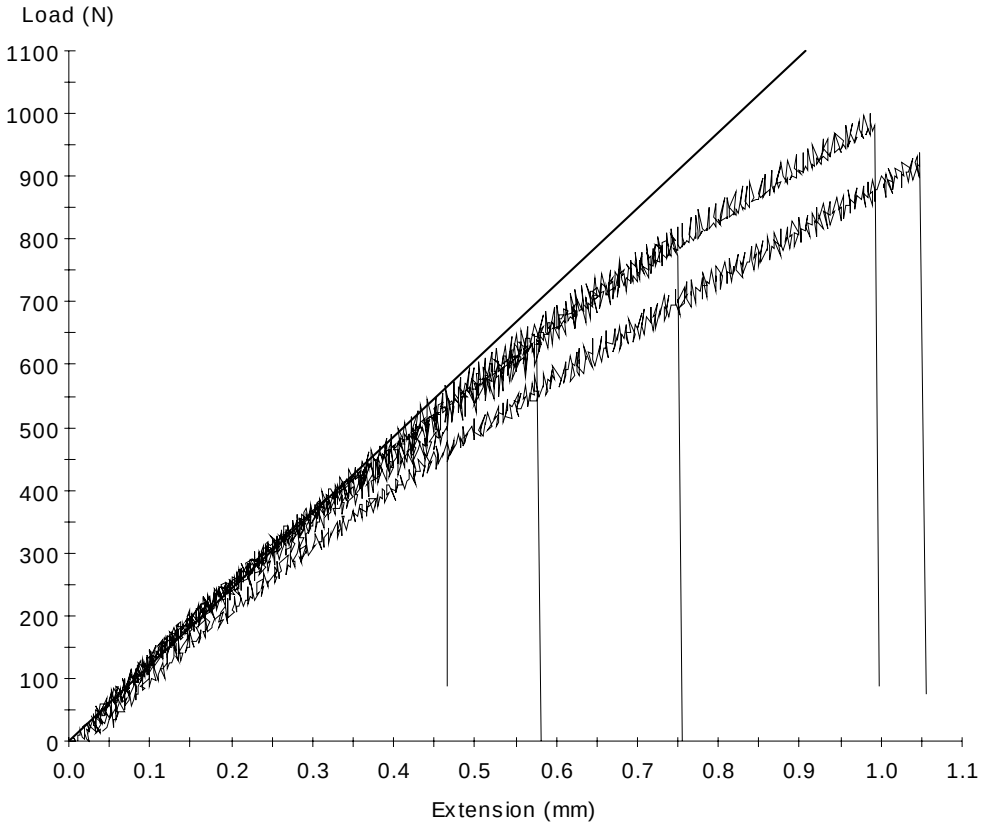
Report Date: 06-Jun-07

Test Date : 06-Jun-07
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	5.620	15.550	87	807	9.23	774	8.85
2	5.490	15.710	86	1000	11.60	982	11.38
3	5.440	15.710	85	639	7.48	639	7.48
4	5.490	15.510	85	939	11.03	939	11.03
5	5.490	15.520	85	501	5.88	501	5.88
Mean	**5.506**	**15.600**	**86**	**777**	**9.04**	**767**	**8.92**
Std Dev	**0.067**	**0.101**	**1**	**207**	**2.39**	**202**	**2.34**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.750	4.432	387.301				
2	0.992	5.686	490.429				
3	0.576	3.297	281.790				
4	1.047	5.563	473.678				
5	0.465	2.824	240.632				
Mean	**0.766**	**4.360**	**374.766**				
Std Dev	**0.253**	**1.294**	**111.753**				



Tom 25%

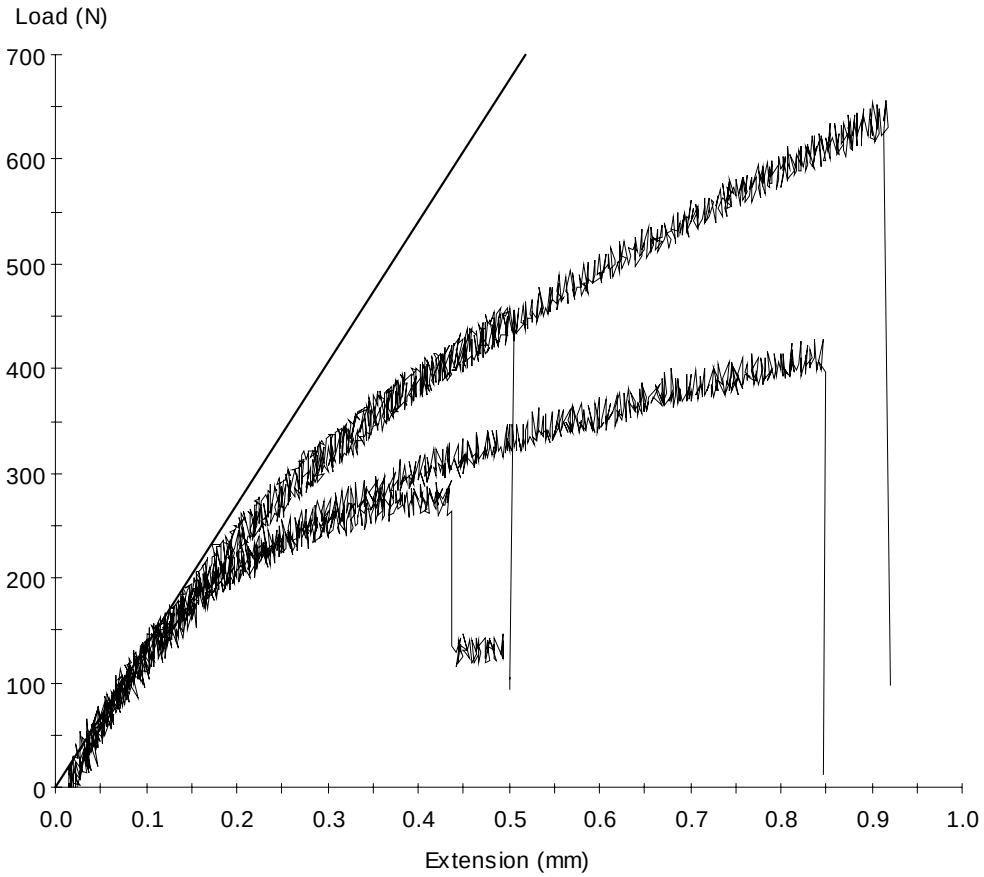
Report Date: 22-May-07

Test Date : 27-Mar-07
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	5.230	14.830	77	294	3.79	294	3.79
2	5.490	14.760	81	655	8.09	655	8.09
3	5.540	14.710	81	458	5.62	455	5.58
4	5.430	14.760	80	428	5.34	396	4.94
Mean	**5.422**	**14.765**	**80**	**459**	**5.71**	**450**	**5.60**
Std Dev	**0.136**	**0.049**	**2**	**149**	**1.78**	**152**	**1.82**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.436	1.778	137.904				
2	0.915	3.557	288.216				
3	0.506	2.635	214.731				
4	0.850	2.329	186.695				
Mean	**0.677**	**2.575**	**206.886**				
Std Dev	**0.241**	**0.744**	**62.828**				



Tom2 30%

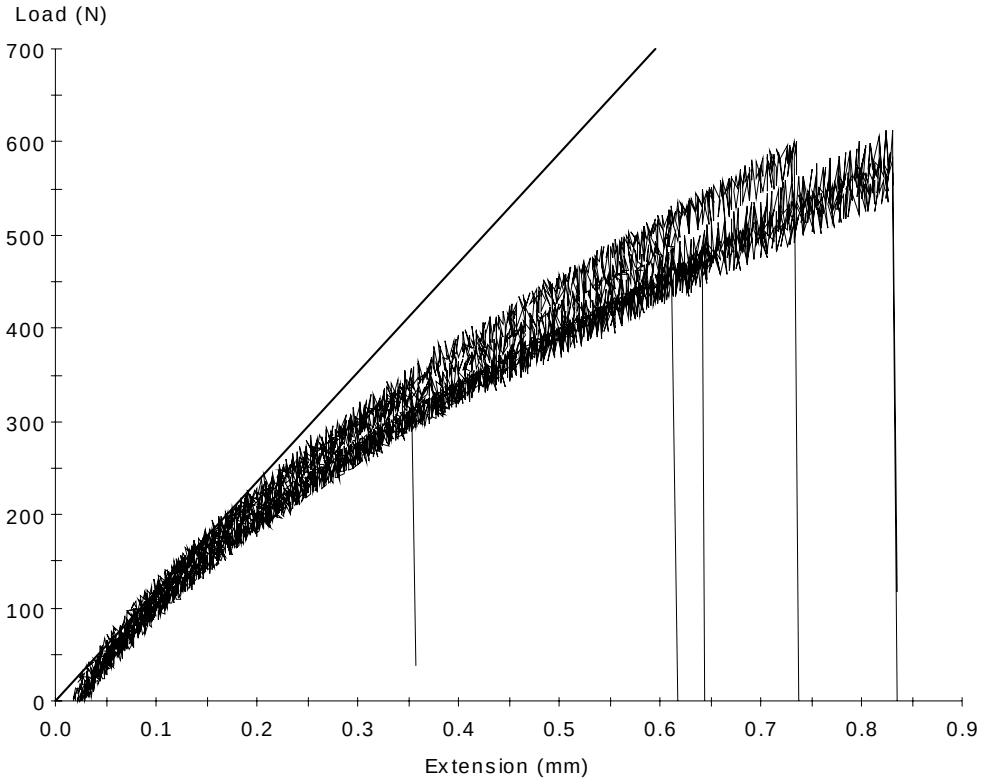
Report Date: 30-May-07

Test Date : 30-May-07
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	6.010	15.150	91	600	6.59	584	6.41
2	5.960	15.150	90	613	6.79	612	6.78
3	5.850	15.010	88	503	5.73	503	5.73
4	5.480	14.900	82	581	7.12	553	6.78
5	5.580	14.930	83	484	5.82	468	5.62
6	5.790	14.990	87	346	3.99	340	3.92
Mean	**5.778**	**15.022**	**87**	**521**	**6.00**	**510**	**5.87**
Std Dev	**0.210**	**0.107**	**4**	**101**	**1.13**	**98**	**1.08**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.736	3.182	289.712				
2	0.832	3.185	287.564				
3	0.616	2.896	254.262				
4	0.831	3.434	280.396				
5	0.642	2.580	214.968				
6	0.354	1.898	164.713				
Mean	**0.668**	**2.862**	**248.602**				
Std Dev	**0.179**	**0.556**	**49.839**				



Tom 35%

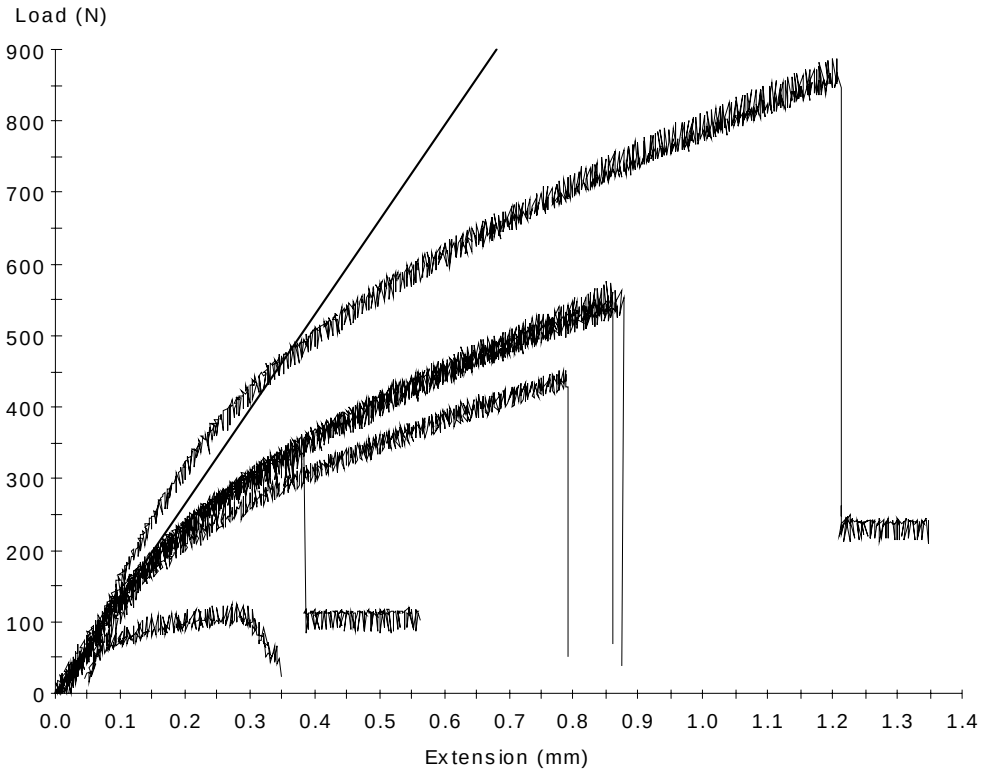
Report Date: 23-May-07

Test Date : 23-May-07
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	5.650	15.110	85	575	6.74	545	6.39
2	6.070	15.240	92	563	6.08	553	5.97
3	4.930	14.980	74	337	4.56	337	4.56
4	6.080	15.010	91	887	9.72	847	9.28
5	5.290	14.840	78	452	5.75	428	5.45
6	5.680	15.430	88	125	1.42	125	1.42
Mean	**5.617**	**15.102**	**85**	**490**	**5.71**	**472**	**5.51**
Std Dev	**0.448**	**0.209**	**7**	**256**	**2.72**	**242**	**2.56**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.859	3.566	304.483				
2	0.877	2.395	221.564				
3	0.384	1.530	113.031				
4	1.213	4.709	429.717				
5	0.792	2.376	186.567				
6	0.274	0.367	32.144				
Mean	**0.733**	**2.491**	**214.584**				
Std Dev	**0.347**	**1.519**	**140.567**				



Tom oven 5%

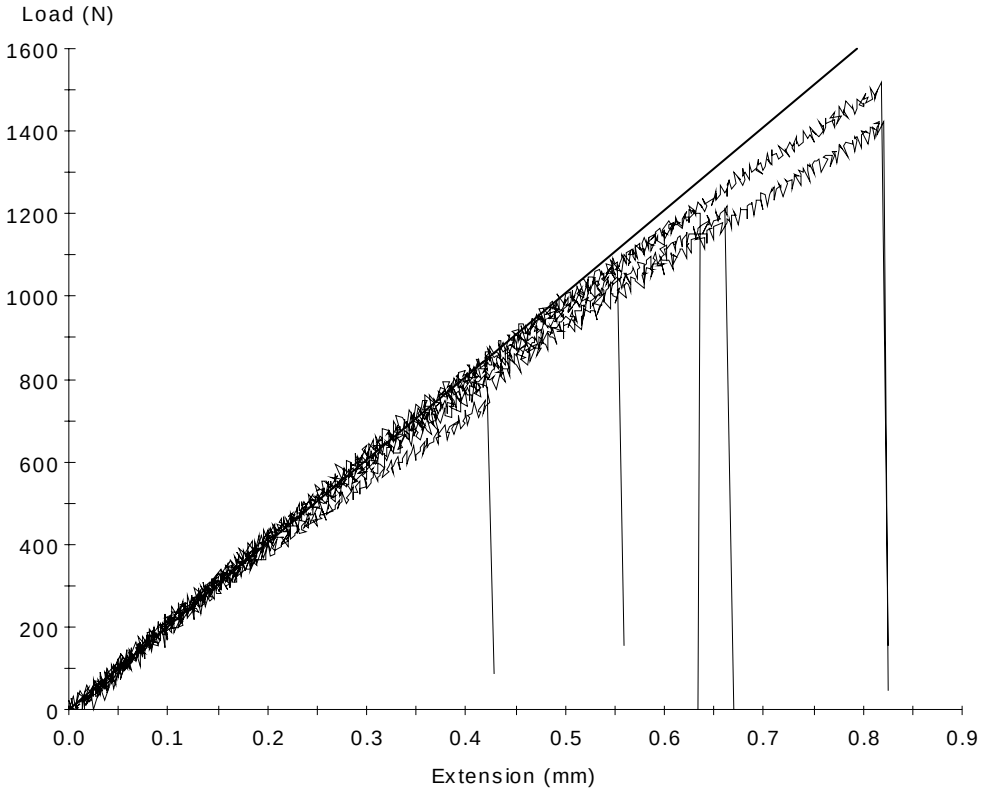
Report Date: 14-Jun-07

Test Date : 14-Jun-07
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	5.800	15.010	87	1072	12.32	1072	12.32
2	5.770	14.880	86	1519	17.69	1519	17.69
3	5.650	14.980	85	1211	14.31	1201	14.19
4	5.400	15.040	81	1425	17.54	1425	17.54
5	5.490	15.040	82	765	9.27	765	9.27
6	5.670	14.930	85	1220	14.42	1220	14.42
Mean	**5.630**	**14.980**	**84**	**1202**	**14.26**	**1200**	**14.24**
Std Dev	**0.157**	**0.064**	**2**	**267**	**3.20**	**267**	**3.20**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.553	6.171	537.210				
2	0.819	8.807	756.139				
3	0.636	7.185	608.127				
4	0.821	8.328	676.409				
5	0.422	4.553	375.954				
6	0.663	6.400	541.742				
Mean	**0.652**	**6.907**	**582.597**				
Std Dev	**0.155**	**1.552**	**131.148**				



Tom oven 15%

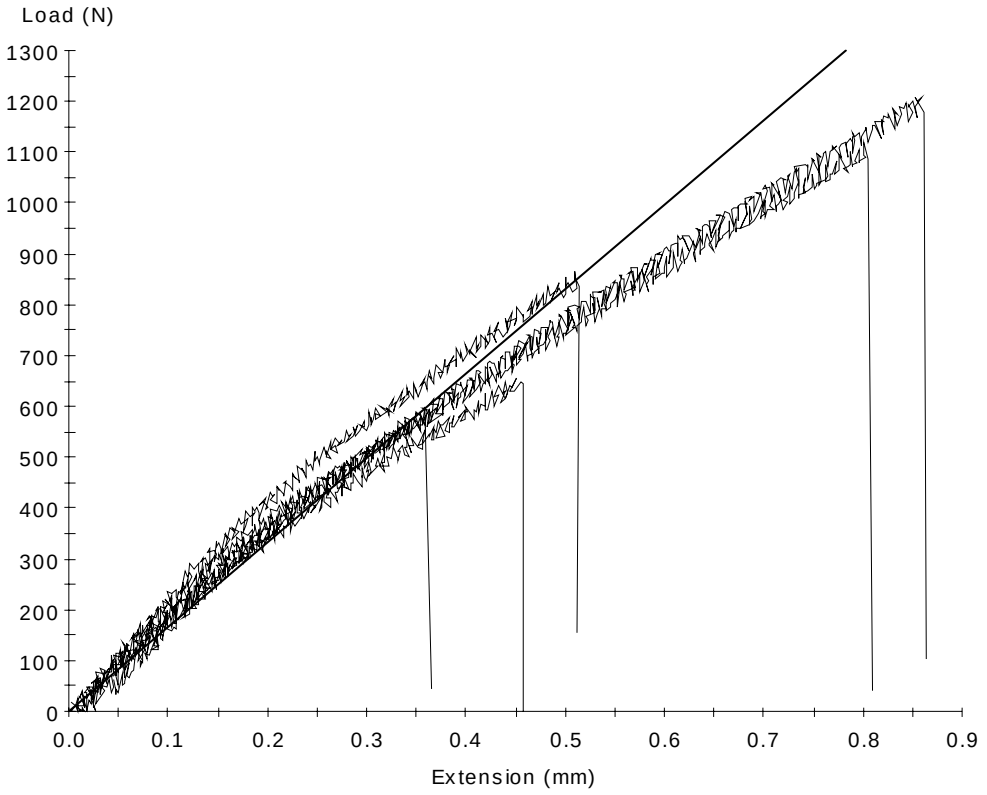
Report Date: 14-Jun-07

Test Date : 14-Jun-07
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	5.510	14.850	82	596	7.29	596	7.29
2	5.810	15.120	88	864	9.83	835	9.50
3	5.500	15.320	84	1209	14.35	1179	13.99
4	5.160	15.120	78	654	8.38	646	8.28
5	5.310	15.010	80	1119	14.04	1086	13.63
Mean	**5.458**	**15.084**	**82**	**888**	**10.78**	**869**	**10.54**
Std Dev	**0.244**	**0.172**	**4**	**272**	**3.25**	**259**	**3.09**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.358	3.523	288.269				
2	0.515	4.850	426.075				
3	0.862	6.643	559.769				
4	0.458	3.408	265.877				
5	0.806	7.118	567.339				
Mean	**0.600**	**5.108**	**421.466**				
Std Dev	**0.222**	**1.722**	**143.507**				



Tom oven 25%

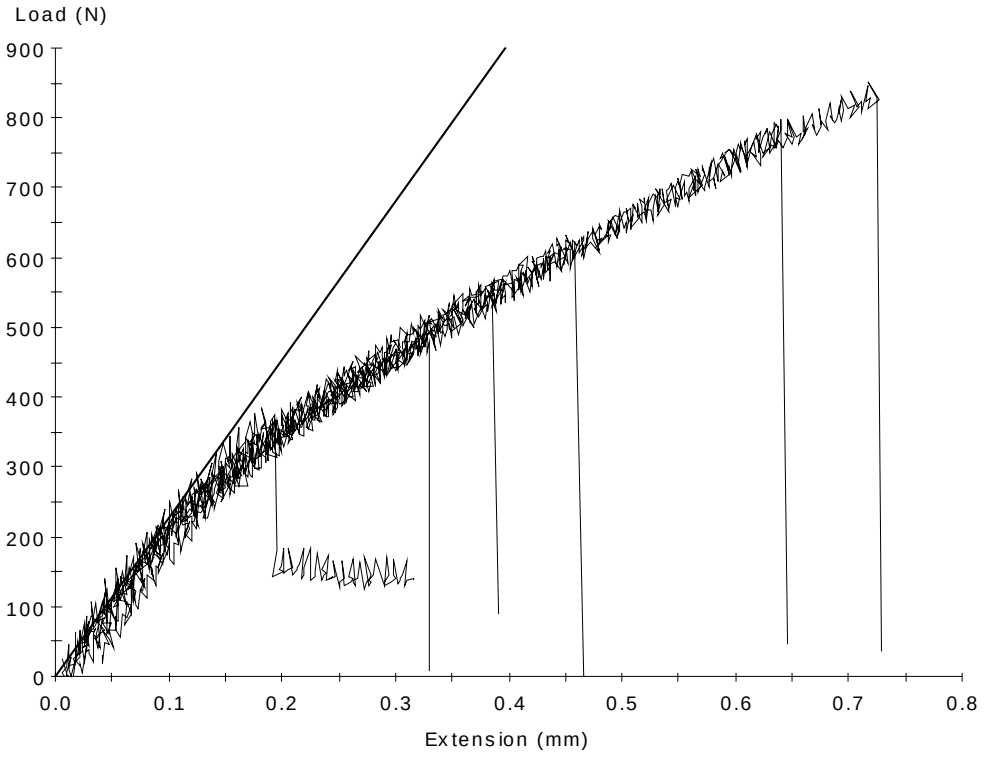
Report Date: 14-Jun-07

Test Date : 14-Jun-07
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	5.660	15.450	87	799	9.14	799	9.14
2	5.630	15.180	85	851	9.96	828	9.69
3	5.460	15.180	83	493	5.95	479	5.78
4	5.690	15.400	88	631	7.20	601	6.86
5	5.600	15.430	86	568	6.58	568	6.58
6	5.680	15.130	86	386	4.49	386	4.49
Mean	**5.620**	**15.295**	**86**	**621**	**7.22**	**610**	**7.09**
Std Dev	**0.085**	**0.146**	**2**	**178**	**2.03**	**175**	**1.99**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.640	4.715	412.294				
2	0.725	4.373	373.756				
3	0.330	2.760	228.782				
4	0.459	3.176	278.298				
5	0.386	3.287	284.005				
6	0.182	3.026	260.086				
Mean	**0.454**	**3.556**	**306.204**				
Std Dev	**0.201**	**0.793**	**71.008**				



Appendix I – Tables of Results

All Tables of results in Appendix I are those that were post-cured using a conventional oven

Yield Strength

	5	15	25
1	12.01	6.46	6.32
2	15.23	8.125	5.88
3	14.11	9.52	4.93
4	14.87	6.85	5.11
5	0	10.5	5.63
6	13.58	**-**	0
Mean	11.63333	8.291	4.645

Young's Modulus

	5	15	25
1	1.81	1.92	1.81
2	1.831	1.78	1.85
3	1.85	1.875	1.897
4	1.94	2.019	1.789
5	1.92	1.968	1.83
6	1.85	-	1.83
Mean	1.8668	1.9124	1.8343

Tensile Strength

	5	15	25
1	12.32	7.29	9.14
2	17.69	9.83	9.96
3	14.31	14.35	5.95
4	17.54	8.38	7.2
5	9.27	14.04	6.58
6	14.42		4.49
Mean	14.26	10.78	7.22

Appendix J – Calculations of Material Costs

To calculate the cost of each sample some initial calculation needed to be conducted. All resin and catalyst were bought in bulk litres, whilst sample production was weighed in grams.

Therefore the density of the two was essential to find; listed below.

Resin

1 litre = 1.225 kilograms

Therefore 1/1.225 = 0.81632

$3.50 per litre = $0.0035 per millilitre

Catalyst

1 litre = 1.056 kilograms

Therefore 1/1.056 = 0.947

$8.00 per litre = $0.0080 per millilitre

To calculate the cost of materials of the sample 0% of filler by weight the following would take place:

0% is made up of	0.29411kg of resin	= 0.29411x0.81632 = 0.24 litres
	0.00588kg of catalyst	= 0.00588x0.94700 = 0.0055 litres

Therefore: Resin = 240x0.0035 = $0.84

Catalyst = 5.5x0.008 = $0.044

Total = $0.884

This method was carried out for each sample, the results of all samples can be found in Table 4.4