University of Southern Queensland
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Tensile strength of sawdust reinforced vinyl ester composites

A dissertation submitted by

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Abstract

Vinyl ester composites have been widely used in the construction industry due to its superiority material properties. The purpose of this project to research, measure the tensile strength, yield strength and Young's modulus according to the tensile test to find the optimum percentage rate of the vinyl ester and fillers (sawdust). Tensile testing of tensile strength measurement was used to perform tests to find out the optimum percentage fillers by weight cured vinyl ester composites in conventional oven. The results show that the 20 percentage by weight sawdust vinyl ester composites are optimum. These type of samples have the highest tensile strength and yield strength. And 425 μm sawdust composites Young's modulus is constant. The results show that some important features of the fracture surface by using SEM microscopy. The micrographs show some important features such as particles elongation, resin dislocation and compaction of resins and fillers.

There are six specimens for each type of composites. At 20 % by weight of sawdust (300 μm), the tensile strength is highest (27.758 MPa). The highest yield strength (20.394 MPa) is obtained for the composites with 20 % by weight of sawdust (300 μm).

Keywords: Vinyl ester, tensile strength, Yield strength, Young's modulus, Microscope

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

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Date

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Chapter 1 Introduction

1.1 Introduction

There is a growing demand for composite materials in many industries due to their superior mechanical properties. Composite materials are produced when two or more materials or phases are combined to give a flexible combination of mechanical properties that cannot be obtained otherwise. Composites are extremely versatile and are being increasingly used in a wide range of applications such as aerospace, marine, transportation, mechanical and civil engineering. In order to reduce the costs of composites a wide range of fillers are being used and resulting properties explored.

In recent years, natural fibre-reinforced composites have attracted substantial interest as a potential structural material. The attractive features of natural fibres like jute, sisal, coir, banana have been their low cost, light weight, high specific modulus, renewability and biodegradability. Composites reinforced with such natural fibres have been the subject of intense study for low-cost application in contrast to the synthetic fibre-reinforced composites. Amongst the natural fibres, jute constitutes a major area of investigation.

1.2 Purpose of the study

This project will investigate the difference in tensile strength, yield strength and Young's modulus of 0 %, 5 %, 10 %, 15 %, and 25 % by weight of sawdust particulate reinforced vinyl ester composite. In this project, the sawdust is used as fillers because it is low cost and environment-friendly. In this study, the dielectric and thermal properties of the prepared composites will be measured and evaluated. Moreover, it is even more time consuming to carry out the tests and analyze the results. It is therefore necessary to develop a mathematical model that will predict the tensile strength and Young's modulus. By using a constant, the mathematical model of fracture toughness of the composites post-cured in microwaves can be generated from that post-cured conventionally and a lot of tedious experiments can be avoided to get the values of the tensile strength and Young's modulus of composites post-cured by microwave irradiation. However, it can be argued that the constant may not be valid if the filler is changed.

1.3 Research objectives

In this study, Hetron 922 PAW (vinyl ester resin used in winter) was used. The resin catalyst (MEKP) ratio used in the experiment was 98% resin by volume and 2% catalyst by volume (Astrom,1997),along with a percentage of filler. The filler used is a wood sawdust which is a waste material in the saw mill. The project requires six moulds to be produced that vary from a 0% to 25% 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 at the ratio of catalyst and resin is calculated therefore 264.6 grams of resin and 5.4 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 conventional oven 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 to reduce costs of the composites but at the same time maintain the mechanical properties.
Once an outcome is produced and strengths calculated they can then be related to those results that will be obtained from future studies on the effects of post-curing by microwave. 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 be reached. The following chapter will provide an in depth analysis into the background of vinyl ester, fillers and the testing that will be performed.

Chapter 2 Literature Review

2.1 Introduction

To cope with the obvious limitations of polymers, for example, low stiffness and low strength, and to expand their application in various sectors. Particulate fillers are added to modify the physical and mechanical properties of polymers in many ways. This review is concerned with the stiffness and strength. It is necessary to have some basic understanding of the stiffening, strengthening and toughening mechanisms of these composites.

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 according to Australian standards to extract meaning from the data. Post-curing methods of microwaving and conventional oven will be analysed in terms of how the specimen is affected. Besides, there are the assessment of consequential effects and the project risk assessment present at the end of this chapter.

2.2 Background of resin

Composites based on vinyl ester resins are finding new uses in military and commercial applications. Vinyl ester systems can be cured at room or elevated temperatures. It is clear that the cure conditions affect mechanical behaviour. Moreover, recent studies have shown that the cure behaviour of these systems is affected by the presence of reinforcement, suggesting that interfacial properties are affected by fiber-resin interactions (Palmese, G. R. & McCullough 1863).

Vinyl ester resins are formed by the copolymerization of styrene monomer and a dimethacrylate monomer based on the diglycidyl ether of bisphenol-A (see Fig. 2.1). Their resistance to degradation by corrosive and hostile environments leads to their use in many applications, such as in swimming pools, sewer pipes, and solvent storage tanks, and thus, vinyl ester resins are of considerable commercial interest (Muszynski L. C. 1988).

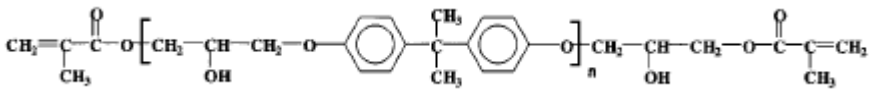


Figure 2.1 Structure of monomer system

There are three families of vinylesters. The first and most commonly used family is based on the reaction between methacrylic acid and diglycidylether of bisphenol A (DGEBPA), as shown in Figure 2.2 (Astrom 1997). If the corrosion is most considered, they resist a wide range of aggressive chicals well. In particular, their resistance to high PH caustic solutions outperforms that of other resins in the family. The second vinylester family uses a novolac epoxy resin as its starting point. Their cross-link densities are higher than bisphenol A epoxy

vinylester resins. In other words, it is more difficult for chemicals to penetrate the matrix, and they have improved resistance to organic solvents and mineral acids. The final category of vinylester resin is formed when tetrabromo bisphenol- A (TBBA) is used in the manufacture of the resin. Up to 20% of bromine is bound to its structure and is designed to have good fire retardancy (Pritchard, G. eds 1999).

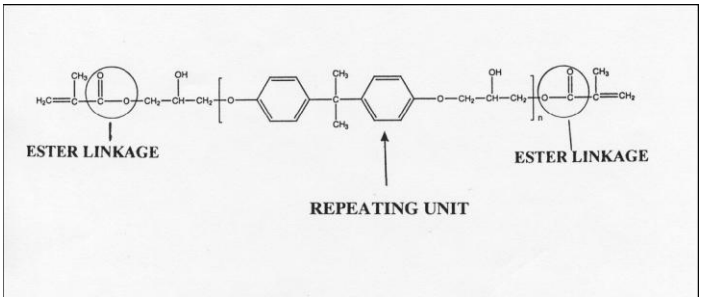


Figure 2.2 Structure of bisphenol A vinyl ester

2.3 The resin, fillers and catalyst used

The vinyl ester resin used is Hetron 922 PAS in summer and Hetron 922 PAW in winter. The vinyl ester is dissolved in 50% by weight of styrene. In this project, sawdust is used as fillers. Sawdust helps in increasing the tensile strength of the vinyl ester resin composites. Also it is commercially cheap to produce and hence, has tremendous potential in various fields such as civil, defense, automobile industry, etc. They are very commonly wasted material in the saw mill. The particle size of sawdust used is 300 μm, 300 ~ 425 μm and 425 ~ 1180 μm.

2.4 Review particulate fillers composites

It has been shown that dramatic improvements in mechanical properties can be achieved by incorporation of a few weight percentages (wt %) of inorganic exfoliated clay minerals consisting of layered silicates in polymer matrices (Fu et al. 2008). The large aspect rations of layered silicates are thought to be mainly responsible for the enhanced mechanical properties of particulate-polymer nanocomposites.

Polymer composites containing particles with a small aspect ratio of 1 or thereabout have also been studied extensively because of their technological and scientific importance. Many studies have shown that stiffness or Young's modulus can be readily improved by adding either micro- or nano-particles since rigid inorganic particles generally have much higher stiffness than polymer matrices (Fu et al. 2008). However, strength strongly depends on the stress transfer between the particles and the matrix. For well-bonded particles, the applied stress can be effectively transferred to the particles from the matrix (Hsueh C.H. 1987); this clearly improves the strength. On the other hand, for poorly bonded micro-particles, strength reduction occurs by adding particles (Fu et al. 2008).

The mechanical properties of particulate-polymer composites depend strongly on the particle size, particle-matrix interface adhesion and particle loading. Particle size has an obvious effect on these mechanical properties. For example, smaller particle size yields higher fracture toughness for calcium carbonate filled high density polyethylene (HDPE) (Bartczak Z. et al. 1999). Similarly, alumina trihydrate filled epoxy containing smaller particles show

higher fracture toughness (Radford 1971). Particle-matrix interface adhesion and particle loading are two important factors that also affect mechanical properties.

Polymer composites are noted to show mechanical properties which depend on time, rate and temperature (Alcock et al. 2007). Viscoelastic moduli are mainly governed by the volume fraction of particles (Kwon et al. 2006) and strain rate has important effects on matrix particulate interface adhesion and other mechanical properties (Nicolais et al. 1981).

2.5 Specimen

Hetron 922 PAS vinyl ester resin become main part of the composites and is dissolved in 50 % by weight of styrene. The resin hardener ratio used in the experiment was 98 % resin by volume and 2 % hardener by volume (Astrom, B. T. 1997). Moreover, the resin will be add with 0 %, 10 %, 15 % and 20 % by weight of fillers (sawdust) to synthesis the vinyl ester composites. An optimum percentage by weight of fillers (sawdust) will have a reasonable fluidity for casting combined with a good tensile strength in service.
As the raw materials of the composites are liquid, the tensile test specimens are cast to shape. The resin is first mixed with the fillers. And then methyl ethyl ketone peroxide (MEKP) is added into it. They are then mixed to give the uncured composites, which are then poured into the moulds for curing in ambient or micro-waved conditions (Ku, S. H. 2003).

2.6 Testing

2.6.1 Tensile testing

Testing Principle

The test specimen is extended along its major longitudinal axis at constant speed until the specimen fractures or until the stress (load) or the strain (elongation) reaches some predetermined value. During this procedure the load sustained by the specimen and the elongation are measured (1145.2 Australian Standard 2001).

Apparatus

The testing machine shall comply with ISO 5893, and meet the specifications given in 1 to 4, as follows:

1 Speeds of testing
The tensile-testing machine shall be capable of maintaining the speeds of testing as specified in Table 2.1.

Table 2.1 — Recommended testing speeds

Speed (mm/min)	Tolerance (%)
1	±20
2	±20

5	±20
10	±20
20	±10
50	±10
100	±10
200	±10
500	±10

2 Grips

Grips for holding the test specimen shall be attached to the machine so that the major axis of the test specimen coincides with the direction of pull through the centreline of the grip assembly. The clamping system shall not cause premature fracture at the grips.

3 Load indicator

The load indicator shall incorporate a mechanism capable of showing the total tensile load carried by the test specimen when held by the grips. The mechanism shall be essentially free from inertia lag at the specified rate of testing, and shall indicate the load with an accuracy of at least 1 % of the actual value.

4 Extensometer

The extensometer shall comply with ISO 5893. It shall be capable of determining the relative change in the gauge length on the test specimen at any time during the test. The instrument shall be essentially free from inertia lag at the specified speed of testing, and shall be capable of measuring the change of gauge length with an accuracy of 1 % of the relevant value or better. This corresponds to ±1 μm for the modulus, based on a gauge length of 50 mm. It is essential that there is no slippage between the extensometer and the test specimen.

Number of test specimens

A minimum of five test specimens shall be tested for each of the required directions of testing and for the properties considered. The number of measurements may be more than five if greater precision of the mean value is required.

Dumb-bell specimens that break within the shoulders or the yielding of which spreads Data from parallel-sided specimens where jaw slippage occurs, or where failure occurs within 10 mm of either jaw, or where an obvious fault has resulted in premature failure, shall not be included in the analysis. Repeat tests shall be carried out on new test specimens. Data, however variable, shall not be excluded from the analysis for any other reason, as the variability in such data is a function of the variable nature of the material being tested.

Testing procedures

Test atmosphere

Conduct the test in the same atmosphere used for conditioning the test specimen.

Dimensions of test specimen

Measure the width b to the nearest 0.1 mm and the thickness h to the nearest 0.02 mm at

the centre of each specimen and within 5 mm of each end of gauge length.
Record the minimum and maximum values for width and thickness of each specimen and make sure that they are within the tolerances indicated in the standard applicable for the given material.

Clamping
Tighten the grips evenly and firmly to avoid slippage of the test specimen.

Pre-stresses
The specimen shall not be stressed substantially prior to test.

Setting of extensometers
For the measurement of Possion's ratio, two elongation or strain measuring devices shall be provided to act in the longitudinal and normal axis simultaneously.

Testing speed
For the measurement of the modulus of elasticity, the selected speed of testing shall provide a strain rate as near as possible to 1 % of the gauge length per minute.

Recording of data
Record the force and the corresponding values of the increase of the gauge length and of the distance between grips during the test.

Calculations

Stress

$$\sigma = \frac{F}{A} \tag{1}$$

where

σ is the tensile stress value in megapascales
F is the measured force in newtons
A is the initial cross-sectional area of the specimen, expressed in square millimeters

Strain

$$\varepsilon = \frac{\Delta L_0}{L_0} \tag{2}$$

$$\varepsilon(\%) = \frac{\Delta L_0}{L_0} \tag{3}$$

where

ε is the strain value
L_0 is the gauge length of the test specimen in millimetres
ΔL_0 is the increase in the specimen length between the gauge marks in millimetres

Modulus calculation

$$E_t = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_2} \tag{4}$$

where

E_t is Young's modulus of elasticity in megapascals
σ_1 is the stress in megapascals, measured at the strain ε_1= 0.0005
σ_2 is the stress in megapascals, measured at the strain ε_2=0.0025

2.6.2 Yield strength

It is first stress at which an increase in strain occurs without an increase in stress. It is expressed in megapascals. Yield strength is calculated using the relationship below (Morgan, M. M. 2006):

$$\text{Yield strength} = \frac{Yield\_load}{Original\_cross-sectional\_area} \quad (5)$$

2.6.3 Tensile strength

The strength of a material is defined as the maximum stress that the material can sustain under uniaxial tensile loading. For micro- and nano-particulate composites this relies on the effectiveness of stress transfer between matrix and fillers.

The ultimate strength of a composite depends on the weakest fracture path throughout the material. Hard particles affect the strength in two ways. One is the weakening effect due to the stress concentration they cause, and another is the reinforcing effect since they may serve as barriers to crack growth. In some cases, the weakening effect is predominant and thus the composite strength is lower than the matrix; and in other cases, the reinforcing effect is more significant and then the composites will have strengths higher than the matrix (Fu et al. 2008).

It is clear that composite tensile strength increases as particle size decreases; this effect is more pronounced for large particles. This suggests that when the particle size is relatively large, reducing its size is very effective to improve the tensile strength of the composites. But if the particle size is already small, further reducing its size is ineffective to enhance the composite strength (Fu et al. 2008).

There are some phenomenological models and semi-empirical equations that use easily in practice and can give correct predictions for appropriate cases. Assuming that the stress cannot be transferred from the matrix to the filler and that the strength of a particulate-filled polymer composite is determined from the effective sectional area of load-bearing matrix in the absence of the particles, a very simple expression for the composite strength is give by (Danusso F. & Tieghi G. 1986)

$$\sigma_c = \sigma_m(1-V_p) \quad (6)$$

where σ_c and σ_m are, respectively, composite strength and matrix strength, and V_p is particle volume fraction. Eq. was proposed for poorly bonded particles. It indicates that the strength of a particulate composite decreases linearly with increasing particles loading. However, the real situation is not always linear even if a decreasing tendency was observed. A modified form of Eq.6 is thus obtained by replacing the particle volume fraction by a power law function of the volume fraction as (Nicolais L. & Nicodemo L. 1974)

$$\sigma_c = \sigma_m(1-aV_p^b) \quad (7)$$

where a and b are constants depending on particle shape and arrangement in the composite. Stress concentration depends on particle volume fraction and presented a modified form of Eq. as (Jancar et al. 1992)

$$\sigma_c = (1 - 1.21 V_p^{2/3}) S_t \tag{8}$$

where S_t is a strength reduction factor and varies in the range from 1.0 to 0.2 for low hang high volume fractions, respectively.

2.6.4 Young's modulus

Young's modulus is the stiffness (the ratio between stress and strain) of a material at the elastic stage of a tensile test. The Young's modulus can be calculated by calculating the slope of the initial linear portion of the stress-strain curve, where one can get the stress-strain curve through the test of the specimen. The Young's modulus (Morgan, M. M. 2006):

$$E = \frac{stress}{strain} = \frac{\sigma}{\varepsilon} \tag{9}$$

$$E = \frac{\frac{F}{A}}{\frac{\Delta L}{L}} \tag{10}$$

According to many studies and researches, it seems that there is a critical particle size above which there is no effect on composite modulus. When the particle size is below this critical value, the effect on composite modulus is more significant. The magnitude of this critical particle size cannot be predicted a priori for it depends on the particle, matrix and particle/matrix adhesion (Fu et al. 2008).

Since Young's modulus is measured at relatively low deformation, there is insufficient dilation to cause interface separation. Thus, it is easy to understand that the adhesion strength does not noticeably affect the elastic modulus. Interfacial adhesion has little effect on the Young's modulus of particulate-filled composites.

Also, the modulus increases with increasing particle loading. Addition of rigid particles to a polymer matrix can easily improve the modulus since the rigidity of inorganic fillers is generally much higher than that of organic polymers. The composites modulus consistently increases with increasing particle loading (Fu et al. 2008).

2.7 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). In this study, all specimens have been post-cured by way of oven.

2.7.1 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 et al. 2002). But 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. The microwave used must be modified to remove excess gases from inside the microwave and hence reduce the danger.

2.7.2 Conventional oven

Post-curing by way of conventional oven is a well-established technology compared to 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. Indeed, in the conventional oven curing process the thermal energy must diffuse through the composite layers to heat the joint interfaces, resulting in long and expensive processing time as well as wasted energy. At present, the most common curing technique for vinyl ester resin is by conventional oven curing and it takes prolonged period of time. This leads to study of alternate curing technique by using microwave heating, which is expected to shorten the curing period.

2.8 Assessment of consequential effects

Any engineering and spatial science technical activity will have outcomes and therefor some consequences will vary greatly. Many issues arise from the sustainability, safety and ethical dimensions that related to this research project. These issues must be addressed as there is a professional responsibility to up hold the public's trust within the profession.

2.8.1 Sustainability

Vinylester, is a resin produced by the esterification of an epoxy resin with an unsaturated monocarboxylic acid. The reaction product is then dissolved in a reactive solvent, such as styrene, to a 35 - 45 percent content by weight. In homebuilt airplanes, the Glasair and Glastar kit planes made extensive use of vinylester-reinforced fiberglass structures. It is a common resin in the marine industry due to its increased corrosion resistance and ability to withstand water absorption. The impact of this research project on finite resources will be minimal, as the resins, fillers and the catalyst are low danger to the environment and human beings. Epoxy vinyl ester resin makes buses 7,000 pounds lighter than traditional steel buses. These vehicles consume 10 percent less fuel and produce less exhaust. For 35 years, DERAKANE epoxy vinyl ester resins have helped modern windmills endure challenging weather conditions. It is the resin of choice that makes wind power possible (Sustainability is Key to Environment, Health and Safety at Dow 2003).

The fillers used here are wood sawdust, organic matter, which can be found as a waste by-product in all the saw mill. Styrene is the ideal monomer used for cross-linking polyester and

vinyl ester resins. Styrene is a common chemical compound found where we live and work. Indoor sources of styrene emissions include off-gassing of building materials and consumer products and tobacco smoke. Styrene's potential impact on aquatic and soil environments, it was concluded, is significantly mitigated by the rapid rate at which it evaporates and biodegrades in the environment. And finally, Martin Alexander, in his "The Environmental Fate of Styrene", concluded that transport of styrene in nature is "very limited" because of its volatility from soils and surface waters, its rapid destruction in air, and its biodegradation in soils and surface and ground waters (Alexander 1997).

2.8.2 Ethical and safety

Conducting this research project is to find the optimum percentage of organic matter as fillers to replace those such as fibre glass, glass powder and E-glass at the same strength and deformation, but with low cost and little environment impact. Minimal issues are raised due to this project. A safety issue is the only cause for alarm during the production of specimens.

2.9 Risk assessment

All engineering activities involve a risk to people and the environment, and it is the responsibility of the engineer to recognize and address them. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat (also called hazard). It consists in an objective evaluation of risk in which assumptions and uncertainties are clearly considered and presented. Part of the difficulty of risk management is that measurement of both of the quantities in which risk assessment is concerned - potential loss and probability of occurrence - can be very difficult to measure.

2.9.1 Identification

In conducting the production of specimens many risks may be encountered in the manufacture of both the mould itself, in handling the composite materials, and in the fracture testing processes. 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 mixing process involves chemical inhalation risk and skin irritation risk. 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.

2.9.2 Evaluation

Risks of styrene

Health concerns with vinyl ester resins are considered synonymous with the most common cross-linking agent, the styrene, and not with the polymers themselves. Styrene is volatile and evaporates easily and becomes an inhalation hazard. Styrene is not harmful in the very small amounts we sometimes may encounter in air or food. Someone working in an enclosed area with resin solutions containing styrene (patching the surface of a fiberglass boat, for example) may find the odor of styrene causes slight nausea. This goes away with exposure to fresh air, and there is no lasting effect. The reported levels that cause a specific acute reaction vary

widely, partly because tolerance is individual and depends on build up, and partly because reactions are subjective. At concentrations in the range of 20-100 parts per million (ppm), styrene is a mild, temporary irritant to respiratory tract and eyes. Above 100-200 ppm, styrene is a definite irritant causing central nervous system depression.
Besides, styrene is also high vapor concentrations; highly flammable may cause the explosions. Since the nose of human is extremely sensitive to the very characteristic styrene smell, the risk of acute styrene poisoning through inhalation is quite low; the odour threshold is approximately 0.1 ppm (Ku 2002). Long-term occupational exposure to styrene increases the frequency of chromosome damage in one type of blood cells and may possibly cause brain damage at concentrations as low as 10 ppm.

The listed risks are given below:

- 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

The listed safety procedures:

-Keep locked up.
-Keep container in well ventilated space
-Avoid exposure – obtain special instruction before use.
-Clean with water and detergent.
-Keep container closed tightly.
-Dispose of material and container in a safe way.
-In case of contact with eyes, rinse with plenty of water and contact doctor or poisoninformation centre.
-If you feel unwell contact doctor or poisons information centre.
In case of accident by inhalation: remove casualty to fresh air and keep at rest.

Risks of MEKP

In addition to styrene, the organic peroxide initiators used are toxic and may be severe irritants and sensitisers to skin and eyes and may be corrosive if the concentration is high. The organic peroxides are also highly flammable and may decompose with explosive violence if not handed correctly. MEKP is a colourless solution of methyl ethyl ketone peroxide in dimethyl phthalate, with 9% active oxygen. MEKP should be stored in the original closed container in a cool place away from all sources of sparks, heat, or flames, and out of direct sunlight. Exposure to high temperatures or contamination with foreign materials may result in explosive decomposition.

Risk:

Harmful by inhalation and if swallowed.
Causes burns.
Risk of serious damage to eyes.
Possible cancer causing agent.

Safety:

Do notstore it in unvented glass containers.
Do not store it in the vicinity of cobalt napthenate, dimethyl aniline, or other promoters, accelerators, acids, bases, or strong reducing agents.
Do not store it in the vicinity of food or drink.
Do not reuse the container.
Maximum storage temperature is 38℃. Decomposition temperature is 68℃

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. Risks associated with the tensile testing of specimens involve flying particles or chips, loose clothing being caught, material dropping hazards, and fingers being jammed.

2.9.3 Control

Various controls have been implemented to ensure the user is aware of all hazards. Booklets of vinyl ester resin and catalyst are provided for the user and consent of understanding is signed to ensure their awareness. 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. Caution should be exercised when fastening the test piece and whilst releasing to ensure no bodily harm occurs. Personal protective equipment includes covered footwear and safety goggles and also aid and initial briefing by a qualified operator.

Chapter 3 Research design and methodology

3.1 Introduction

This chapter discusses the correct manner to obtain the data from the tensile testing. Using the formulas have been mentioned is to calculate the tensile strength, yield strength and Young's modulus. Besides, there are in detailed mould design, specimens' production, curing and microscopic analysis in this chapter.

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. The second option consisted of three sheets of 6 mm plastic sheet bolted together on top of each other with the middle sheet containing cut outs of the test pieces. After the bolts were removed the mould could be split into the three parts, with the middle containing the cast resin pieces. These would then have to be removed manually from the sheet. This method yields a higher dimensional accuracy and surface finish while retaining very few pieces and ease of use.

3.3 Mould fastening

The mould was fastened with nine 4 mm bolts with wing type nuts. 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 bolts are readily available from all hardware stores as is the standard screwdriver required to fasten the screws.

3.4 Mould preparation

Before the resin could be poured, the mould was cleaned with running water and dried by 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. Also they 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 applied to reduce the surface friction when removing the test pieces from 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 not known and may warrant further research.

3.5 Manufacturing of test specimens

The test specimen of mould has been manufactured by the University of Southern Queensland according to Australian Standard. The mould consists two sheets of 6 mm PVC plastic. The top and bottom sheets are identical, while the middle sheet had the cut outs of the components required.

3.5.1 Sawdust sieving

Sawdust is a by-product of sawing process of wood and can be procured from a wood mill. In this study, the bulk of sawdust then needs to be manually sieved to segregate three different sizes of sawdust particles: 1.18 mm, 425 microns and 300 microns. If this needs to be done at a large or industrial scale, then the use of automated and mechanized equipment might be productive.

Figure 3.1 Sieves

3.5.2 Mixing of resin

The cost plays a important role in the decision making of production, hence it is essential to research all areas of the materials involved to enhance certain mechanical properties. The

vinyl ester 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.
Firstly the sawdust is mixed gradually with resin by stirring very carefully. A lot of care needs to be taken at this stage, since rapid mixing might allow air bubbles to get trapped into the mixture. The weighted catalyst is then added to this mixture and again mixing is done as described earlier. Typically mixing takes from 5- 10 minutes till a homogenous mixture can be seen.
Six specimen need to be produced per mould, with consideration of specimen dimensions 150 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

150 g Mixture				
% of filler	Resin (g)	Catalyst (g)	Total (g)	Filler (g)
0	147.5	2.5	150	-
5	145	2.5	155	7.5
10	144	2.5	162.5	16
15	145	2.5	173	25.5
20	144	2	182	36
25	139	2	187	46

3.5.3 Pouring

This mixture was poured into each space in the mould using a small plastic spoon. Slight excess was allowed in each space to minimize the formation of air bubbles while the resin cured. Once the mixture had reached an even consistency, it was poured into the mould through the use of a plastic spoon. Excessive mixture is poured in to eliminate the likelihood and affects of porosity and air bubbles. Most defects are in the top 1 mm 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. Overfilled molds would also pose difficulty when we try to take the specimens out from the molds.

3.5.4 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 to reduce it. By tightening the plastic screws in the correct sequence the air is expelled from the two sheets of the plastic mould. Tightening also allows for consistent pressure across the mould and hence ensures the material cures consistently, producing higher dimensionally correct specimens.
Just after pouring the resin, the top layer of the mould was placed over the bottom two layers and was located in the correct position using the two pre-fastened bolts and M5 hex nuts. Next, the other bolts were put in place and the wing nuts were attached and tightened up until they were just above the surface of the mould, making sure that none were tight enough to apply pressure.

3.5.5 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 some time, as the specimen, being small, have a low breakage point. Many methods were trialed because of 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.

3.6 Curing in oven

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 conventional oven.
Post curing is done in oven to further harden and set the cast vinyle ester resin composites and to increase its mechanical properties, etc. The post curing is done as per a specific temperature and time chart, which is given as below:

- 4 hours at 50 degree Celsius;
- 4 hours at 80 degree Celsius;
- 2 hours at 100 degree Celsius

After specimen cured in the oven, it was observed that a number of test pieces were developing a bow in middle. This bowing was between 1 mm and 4 mm in the middle of the piece and seemed to be exacerbated by the higher temperature baking processes. It was also noted that bowing was all in the same orientation; bowed around the “upper” (in relation to moulding) face of the test piece.
To counteract this, after the test pieces were removed from the oven, all pieces were subject to an approximate 2kg load while between two pieces of toughened glass. The time for this weighting was approximately 16 hours as they cured overnight.

3.7 Tensile testing

The tensile test must be conducted according to Australian Standard to share the results with others. The following paragraphs present in detail operating procedures.

3.7.1 Testing machine

The tensile testing machine used in the study measured mechanical properties of a material or component. The specimens acquired have to be tested for tensile strength. This is done in the University of Southern Queensland's engineering faculty laboratory. The equipment used is the Universal Testing Machine or Tensile Testing Machine. This is a hydraulically operated machine and uses a hydraulic power pack and set of valves to control the rate of operation. A load cell mounted on the top vice measures the load values during the experiment. The data obtained from this test can be used to calculate Young's modulus, yield strength and tensile strength. 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 3.2 Specimen held in the hydraulic wedge grips of Tensile Testing Machine (Ready for testing)

Figure 3.2 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 3.3 shows the full system setup and the computer used to control the machine. Results produced are provided in appendix B.

Figure 3.3 Tensile Machine, with outputs 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.

3.7.2 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).

3.7.3 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.

3.8 Microscopic analysis

The microscope is an extremely useful instrument in the examination of physical evidence. Most common is the optical microscope. With experience, a forensic microscopist can

determine many specimens including glass, fibers, hair, paint chips, minerals, food particles, and more and can also run small chemical identifications and spot tests. In this study, the findings provide evidence for further research.

3.8.1 Microscope

The types of optical microscopes are:

The compound microscope. Magnifications usually cover the range of about 100x to 1000x. This is the instrument most commonly used to examine small samples.
The comparison microscope. This is essentially two compound microscopes combined into one unit by a bridge incorporating a series of lenses and mirrors to observe two specimens in a side-by-side comparison.
The stereoscopic microscope provides magnifying powers from 10x to 125x allowing a distinctive three-dimensional image of an object and is useful in examining large, bulky items.
The polarizing microscope is a compound microscope fitted with two polarizing filters. The lower polarizing filter is placed in the light beam below the specimen and the second filter, the analyzer, is placed in the eyepiece. Normally, the two filters are crossed or almost crossed to allow identification of minerals, fibers, and small particles by their birefringence (i.e., different refractive indexes in different directions).
The microspectrophotometer is an optical microscope linked to a computerized spectrophotometer. Depending on the light source used, a forensic analyst can obtain both a visual image and a visible or infrared spectrum of a sample.
The scanning electron microscope (SEM) uses a beam of electron to produce images with a magnification from 10x to 100,000x with greater depth of field than an optical microscope.

Scanning electron microscope (SEM)

Scanning electron microscopes image the surface of samples. A focussed beam of electrons (approximately 2-50nm diameter) is used to scan the surface of the samples. Several types of detectors are used to obtain information from the sample and generate an image of the surface. The secondary electron detector provides high resolution topographical details. This is the most common method of viewing samples in the scanning electron microscope.
Scanning electron microscopes consist of a number of integrated systems

- illumination
- vacuum
- sample manipulation
- signal detection and imaging

Vacuum is needed to

increase the mean free path of electrons
prevent high voltage discharge in the gun region
prevent oxidation of the filament
remove contaminating gases

Sample preparation for scanning electron microscopy

Scanning electron microscopy allows imaging and analysis of the surface of specimens. Due to the construction and functional requirements of the scanning electron microscope, samples usually need some preparation before they can be successfully imaged or analysed.
Samples must be

dry = placed into high vacuum
clean = placed into high vacuum; imaging of sample surface
able to generate a signal = image (SEI –secondary electron imaging or BSI-backscattered electron imaging), analysis
conductive = dissipation of charge and heat

As a general rule, samples of approximately 1 to 2 centimeters diameter are used.
Coating of samples

The samples surface must be electrically and thermally conductive to provide a good image in the scanning electron microscope. (see Fig. 3.4) To improve conductivity, the sample is coated with a thin layer of metal or carbon. In my case, the sputter coating is used to gold coat samples for secondary electron imaging. It is a non-directional coating method: all surfaces of the sample are coated. For gold coating, the target is a gold foil. Metal atoms are dislodged from the target, and the dislodged atoms continue to interact with argon, producing a "cloud". Gold atoms preferentially deposit on the sample, and build up a metallic coating on the sample.

Figure 3.4 Gold coating specimens

Charging = voltage buildup on poorly conducting samples
-results in image distortion
-reduce by using a lower accelerating voltage (eg. Use 1-2 kV)
Depth of field = the depth of the sample surface that appears in focus at the same time.
A high depth of field is attained when all heights of a rough sample are in focus at same time
-requires small convergence angle
A high depth of field may be achieved by using
-small objective lens aperture
-long working distance

3.8.2 Conducting the analysis

Conducting the analysis required some knowledge of the program. It can be seen in figure 3.5 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 0%, 5% and 10%.

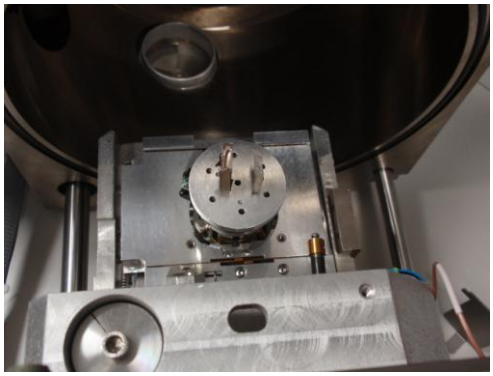


Figure 3.5 Specimens sit in the chamber are ready to view

3.9 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.

Chapter 4 Testing 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 and Young's modulus are given for the samples 0 % to 25 % of sawdust-filled vinyl ester composite mixture. Tensile strength has been found for a sample with no sawdust. This is for reference and to also compare the improvement in the tensile strength on addition of sawdust as fillers in phenolic resin composite materials.
The microscopic photos will demonstrate the effects on porosity and its formation. Please refer to Appendix B for the tables of results and data obtained during testing.

4.2 Tensile strength

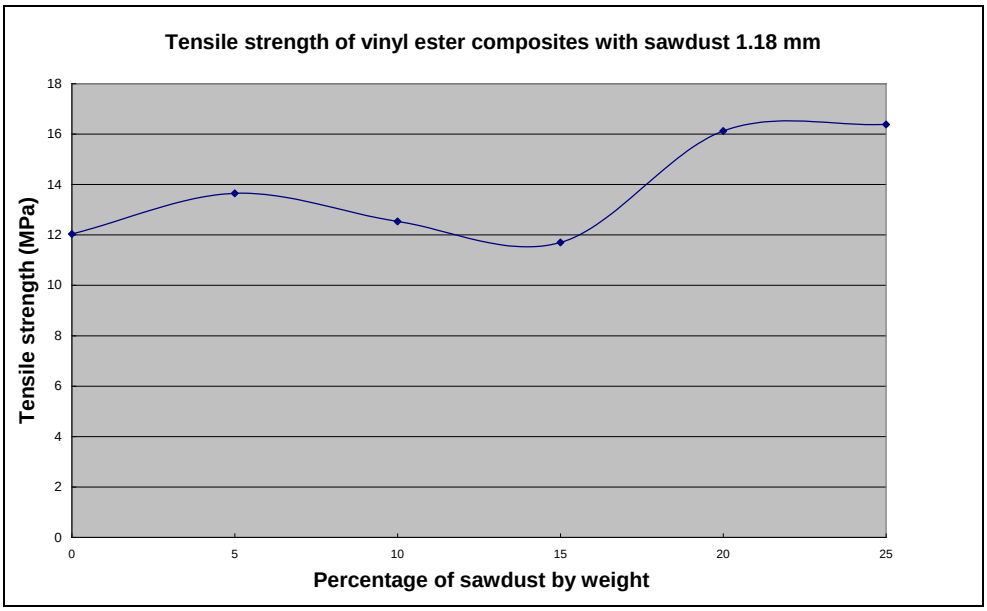
The following graphs provided in this section, are the mean of tensile strength for each percentage by weight of filler. Tensile strength was calculated for each specimen as discussed previously. Averages of the six were taken along with the standard deviation. Curves were generated to be used in comparison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

Table 4.1 Tensile strength for each specimen

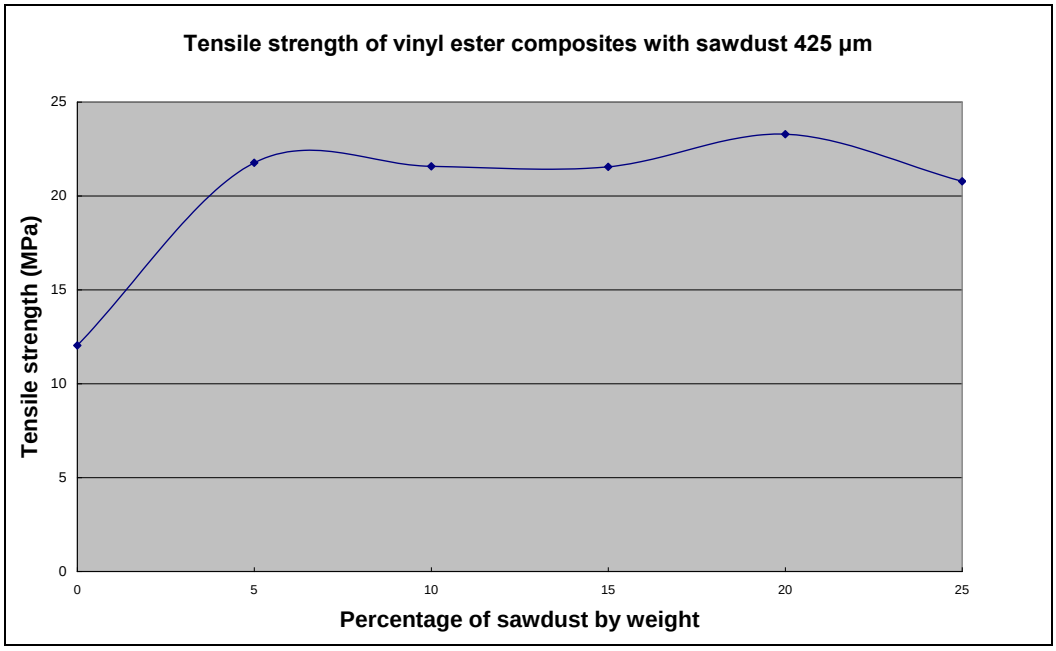
Values of tensile strength 1.18 mm						
Percentage	0	5	10	15	20	25
specimen 1	12.71	-	-	-	15.46	16.88
specimen 2	10.25	12.59	14.7	-	18.05	14.87
specimen 3	14.22	15.19	13.68	12.59	13.95	15.31
specimen 4	12.61	12.39	9.22	13.11	-	-
specimen 5	10.38	-	-	9.4	16	17.71
specimen 6		14.41	-	-	17.14	17.13
Mean	12.034	13.645	12.533	11.700	16.120	16.380
Std	1.695	1.374	2.914	2.009	1.575	1.225

Values of tensile strength			425 μm			
Percentage	0	5	10	15	20	25
specimen 1	12.71	-	-	-	-	-
specimen 2	10.25	21.35	22.98	22.07	20.18	23.08
specimen 3	14.22	-	17.63	20.87	-	23.17
specimen 4	12.61	17.73	20.77	23.59	25.19	16.08
specimen 5	10.38	22.44	-	19.66	24.06	-
specimen 6		25.54	24.91		23.71	
Mean	12.034	21.765	21.573	21.548	23.285	20.777
Std	1.695	3.223	3.126	1.680	2.164	4.068
Values of tensile strength			300 μm			
Percentage	0	5	10	15	20	25
specimen 1	12.71	-	-	20.86	-	9.98
specimen 2	10.25	19.68	-	27.72	28	14.98
specimen 3	14.22	19.35	21.33	-	-	-
specimen 4	12.61	15.76	17.57	27.68	26.71	11.52
specimen 5	10.38	23.02	17.76	26.36	29.28	11.93
specimen 6			25.07	25.23	27.04	
Mean	12.034	19.453	20.433	25.570	27.758	12.103
Std	1.695	2.968	3.543	2.828	1.153	2.094

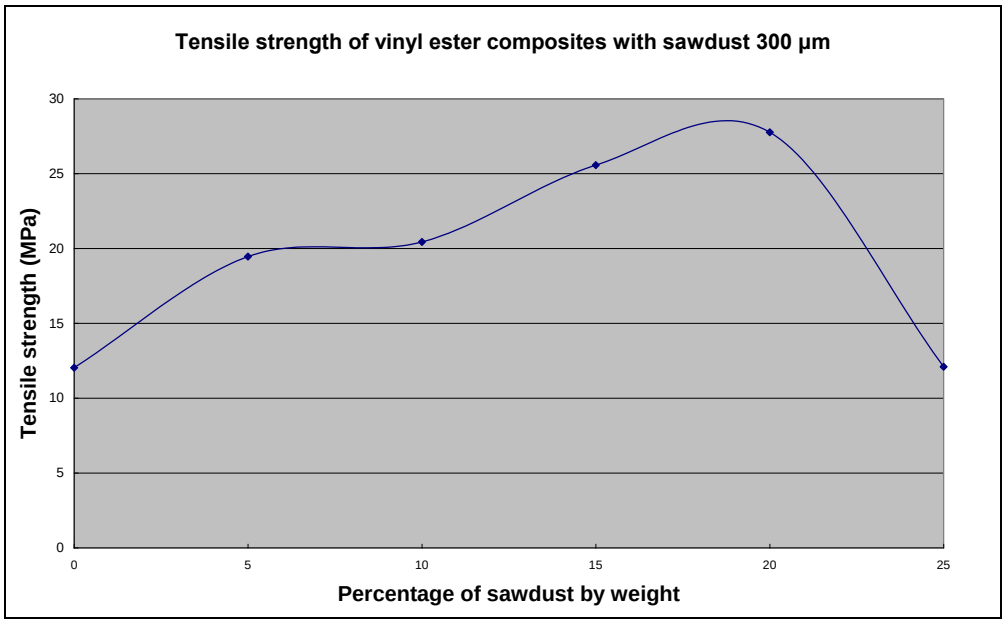
Table 4.1 demonstrates that there was no impact on the placement of specimens inside the microwave. The dashes (-) in the table represent specimen that had unusually low results, caused from premature failure, hence they are untrue results for this study. Table 4.1 shows the values of tensile strength mentioned above with their standard deviation. It can be found that the maximum tensile strength, 27.758 MPa, was obtained when the percentage by weight of filler (300 μm sawdust) is 20 %. As the standard deviations tensile strengths obtained in this study were low, it can be argued that the values were valid for the resin used.


Tensile strength of vinyl ester composites with sawdust 1.18 mm
Tensile strength (MPa)
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25
Percentage of sawdust by weight

(a)


Tensile strength of vinyl ester composites with sawdust 425 µm
Tensile strength (MPa)
0
5
10
15
20
25
0
5
10
15
20
25
Percentage of sawdust by weight

(b)



(c)

Figure 4.1a, b, c Tensile strength of post-curing by oven

4.3 Yield strength

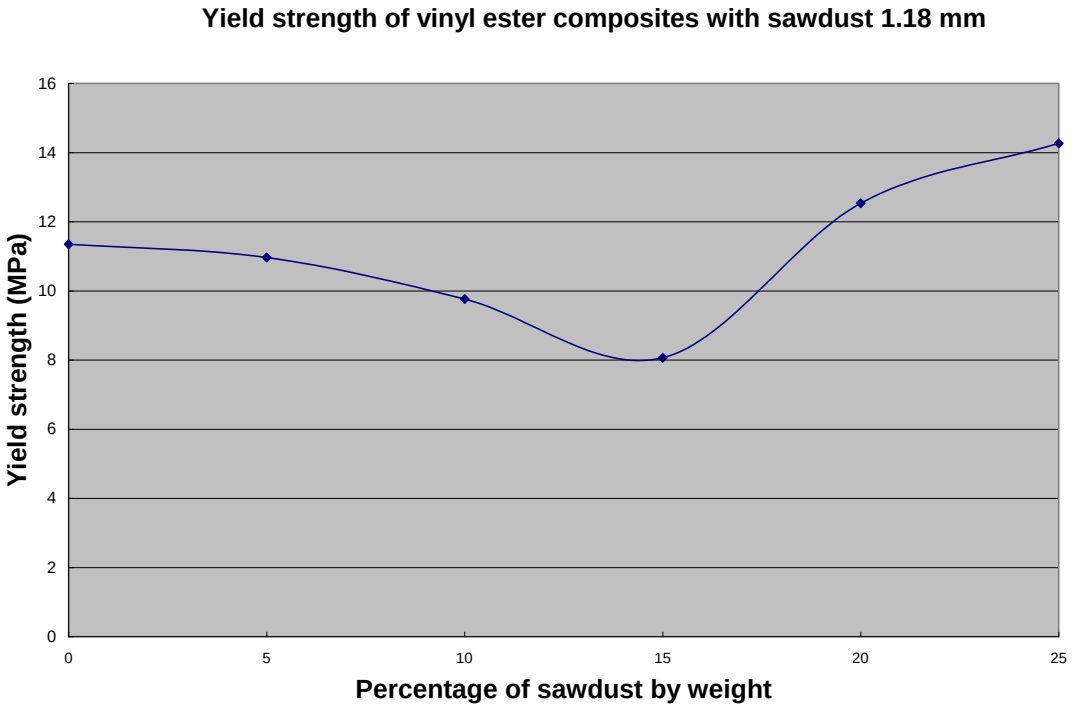
Yield strength had been calculated similarly to that of tensile strength. The following two sections will discuss the results found and demonstrate advantages and disadvantages.

Table 4.2 Yield strength for each specimen

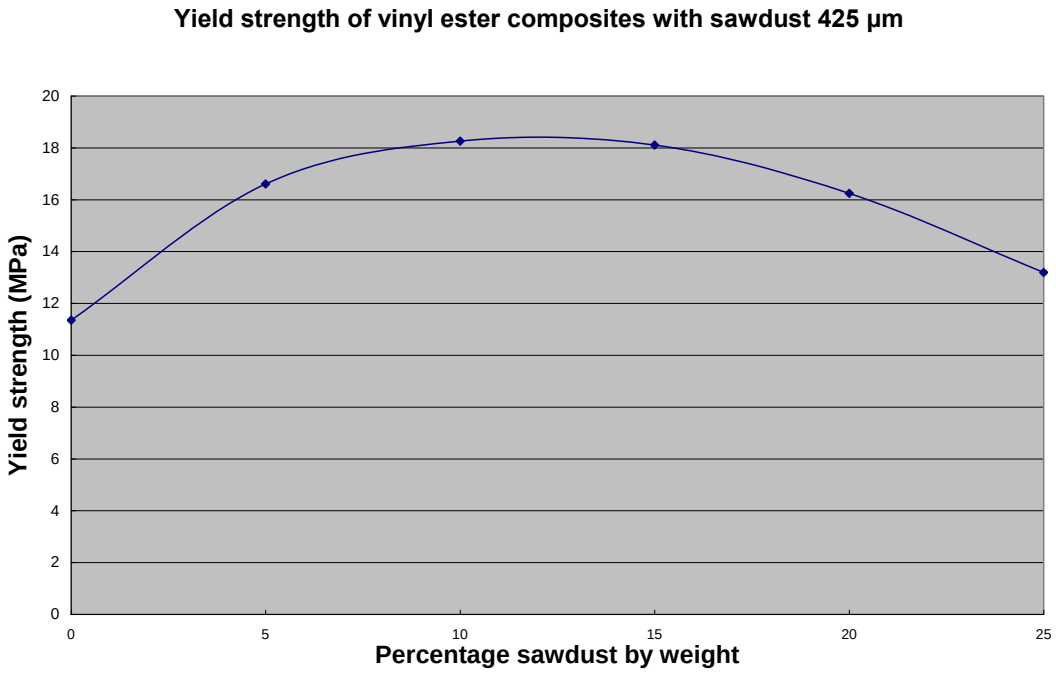
Values of yield strength			1.18mm			
Percentage	0	5	10	15	20	25
specimen 1	11.73	9.72	-	5.39	11.73	15.33
specimen 2	10.28	12.34	10.64	10.93	15.03	13.60
specimen 3	12.35	11.91	10.59	11.32	10.20	12.39
specimen 4	12.59	10.88	8.07	-	10.38	11.68
specimen 5	9.79	6.86		7.52	13.00	16.02
specimen 6		14.07		5.15	14.85	16.59
Mean	11.348	10.965	9.764	8.064	12.530	14.268
Std	1.250	2.483	1.470	2.947	2.122	2.013

Values of yield strength			425 μm			
Percentage	0	5	10	15	20	25
specimen 1	11.73	-	20.00	-	-	9.62
specimen 2	10.28	18.28	18.17	19.28	14.60	16.84
specimen 3	12.35	15.38	17.10	16.87	-	-
specimen 4	12.59	15.56	16.96	18.22	17.39	15.64
specimen 5	9.79	17.22	-	18.06	17.76	10.66
specimen 6		-	19.06		15.22	
Mean	11.348	16.607	18.259	18.106	16.241	13.193
Std	1.250	1.389	1.296	0.987	1.567	3.582

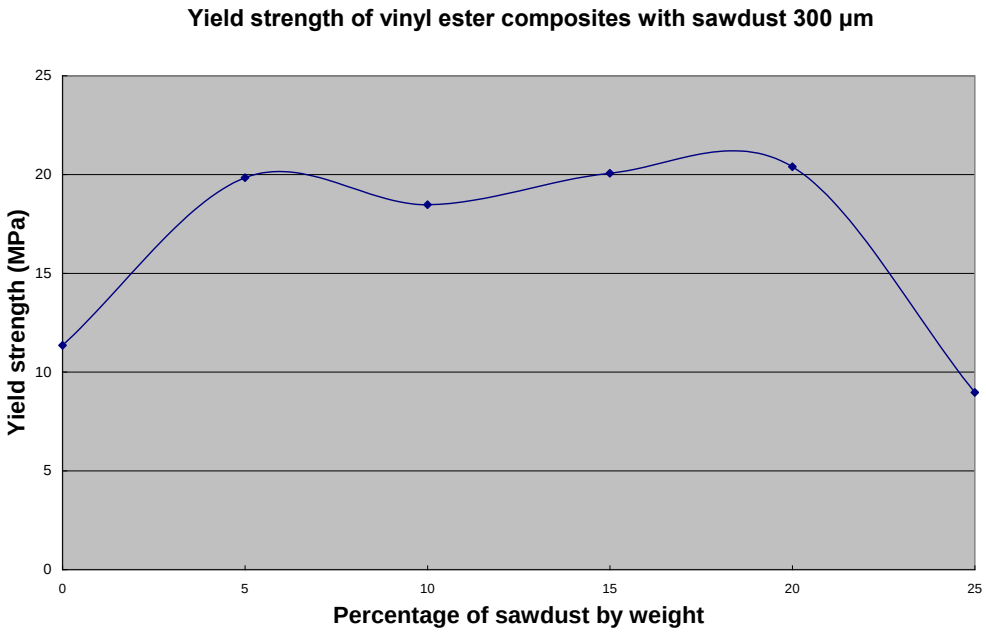
Values of yield strength			300 μm			
Percentage	0	5	10	15	20	25
specimen 1	11.73	21.98	19.57	-	18.58	8.80
specimen 2	10.28	17.81	19.88	21.38	20.90	-
specimen 3	12.35	19.43	16.67	18.18	18.98	8.65
specimen 4	12.59	-	-	21.68	21.21	9.19
specimen 5	9.79	20.14	-	-	21.45	9.21
specimen 6			17.78	19.00	21.25	
Mean	11.348	19.840	18.474	20.060	20.394	8.965
Std	1.250	1.726	1.520	1.733	1.272	0.282


Yield strength of vinyl ester composites with sawdust 1.18 mm
Yield strength (MPa)
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
Percentage of sawdust by weight

(a)


Yield strength of vinyl ester composites with sawdust 425 µm
Yield strength (MPa)
0
2
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
Percentage sawdust by weight

(b)



(c)

Figure 4.2a, b, c Yield strength of post-curing by oven

4.4 Young's modulus

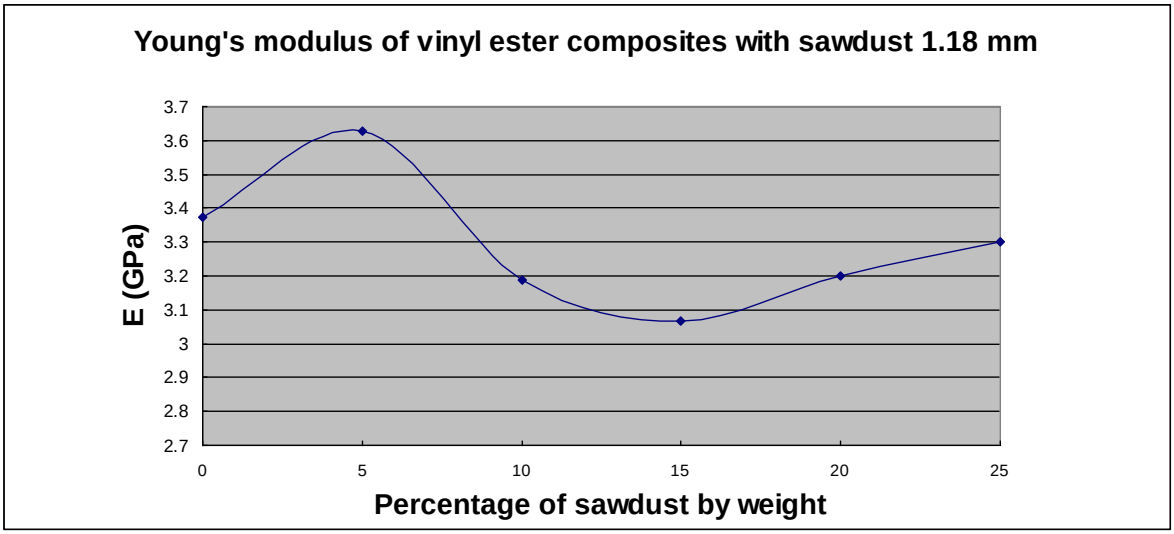
The following section discusses the results found by calculating Young's Modulus at each percentage of filler by weight. Again it will discuss the findings from post-curing by conventional oven.

Table 4.3 Young's modulus for each specimen

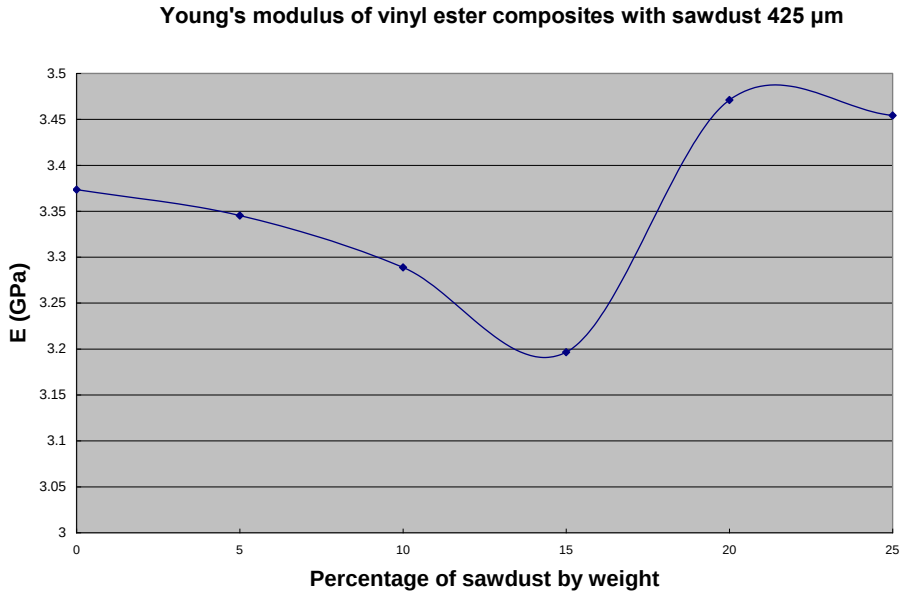
Values of young's modulus 1.18 mm						
Percentage	0	5	10	15	20	25
specimen 1	3.28	3.82	3.26	2.40	3.07	3.33
specimen 2	3.65	3.59	3.06	3.08	3.31	3.31
specimen 3	3.24	3.49	3.31	2.50	3.36	3.13
specimen 4	3.33	3.27	3.12	3.17	3.04	3.17
specimen 5	3.37	4.08	-	3.69	3.27	3.33
specimen 6	-	3.53	-	3.57	3.15	3.55
Mean	3.374	3.627	3.189	3.066	3.202	3.302
Std	0.160	0.282	0.116	0.532	0.132	0.146

Values of young's modulus	425 µm					
Percentage	0	5	10	15	20	25
specimen 1	3.28	3.26	3.24	3.31	3.54	3.71
specimen 2	3.65	3.18	3.42	3.17	3.50	3.15
specimen 3	3.24	3.57	3.43	3.08	3.65	3.58
specimen 4	3.33	3.53	3.30	3.25	3.17	3.44
specimen 5	3.37	3.30	3.12	3.17	3.52	3.40
specimen 6	-	3.24	3.22	-	3.45	-
Mean	3.374	3.345	3.289	3.197	3.471	3.454
Std	0.160	0.164	0.120	0.088	0.163	0.211

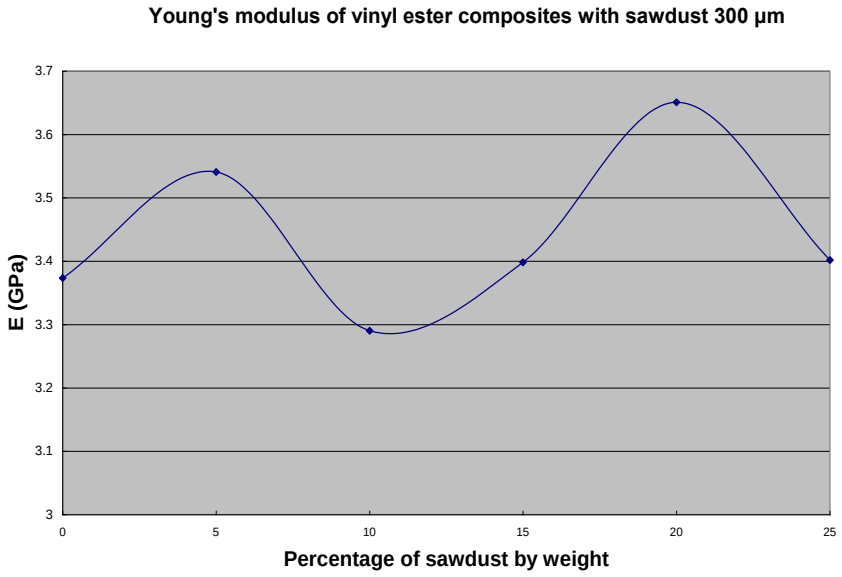
Values of young's modulus	300 µm					
Percentage	0	5	10	15	20	25
specimen 1	3.28	3.56	3.36	3.45	3.37	2.97
specimen 2	3.65	3.64	3.27	3.43	3.66	3.32
specimen 3	3.24	3.61	3.22	3.35	3.64	3.81
specimen 4	3.33	3.72	3.33	3.27	3.66	3.58
specimen 5	3.37	3.17	3.34	3.34	3.97	3.34
specimen 6	-	-	3.23	3.56	3.60	-
Mean	3.374	3.541	3.290	3.398	3.651	3.402
Std	0.160	0.214	0.062	0.101	0.193	0.315



(a)



(b)



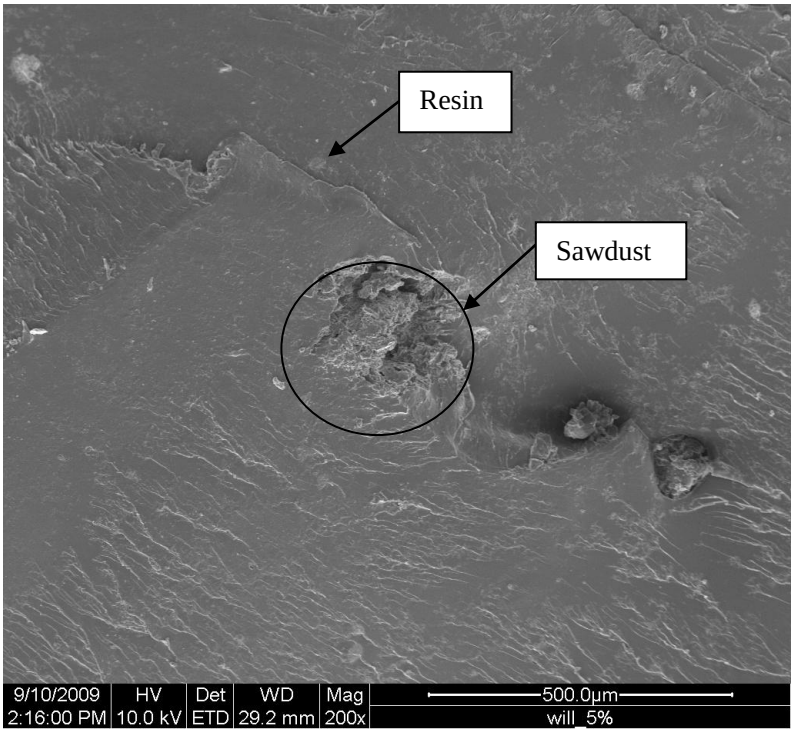
(c)

Figure 4.3a, b, c Young's modulus of post-curing by oven

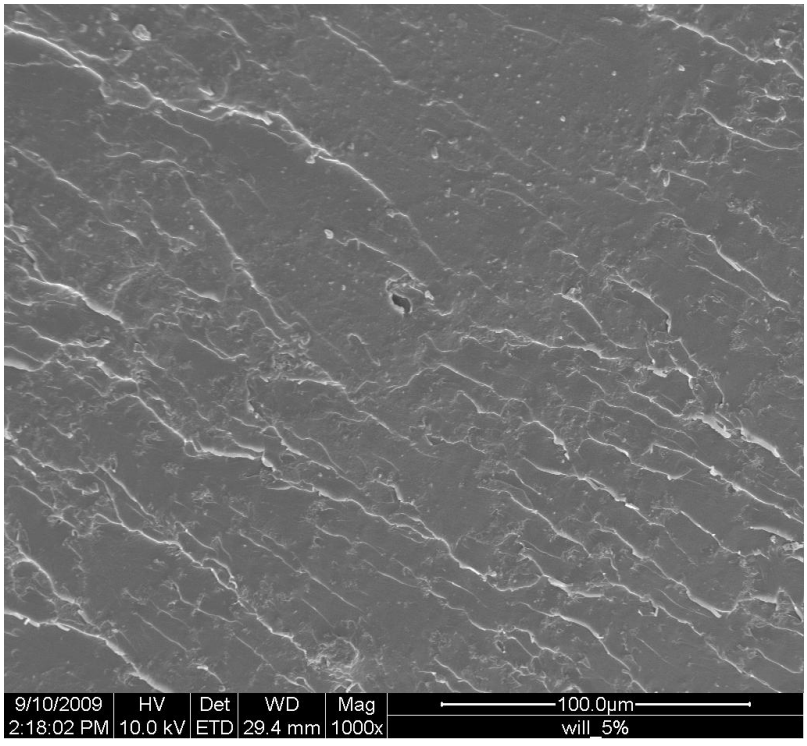
4.5 Microscopic analysis

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.

Five percentages of composites
Figure 4.4a shows the resin, sawdust and



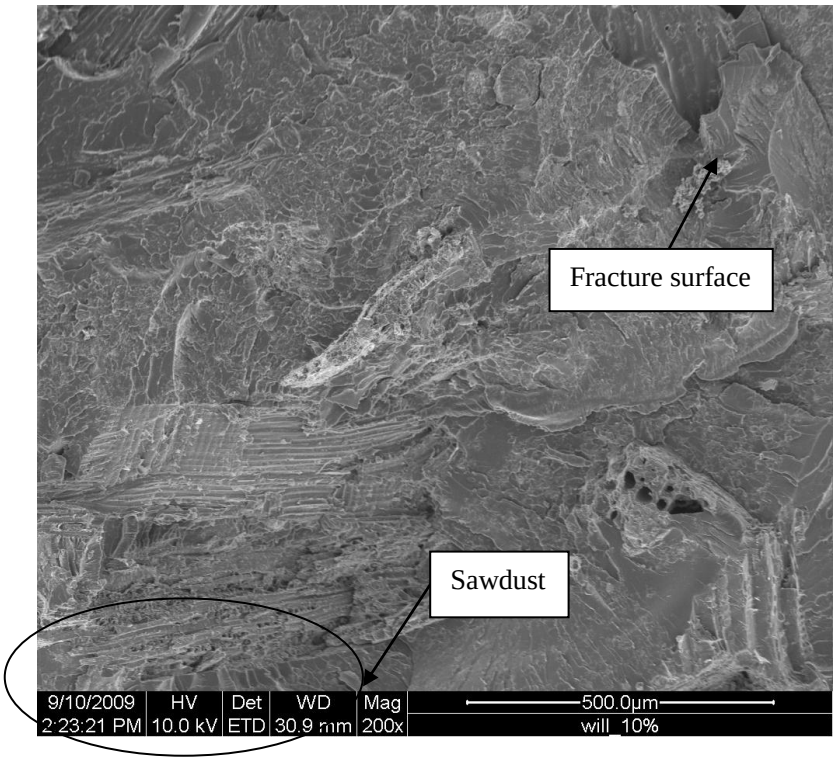
（a）



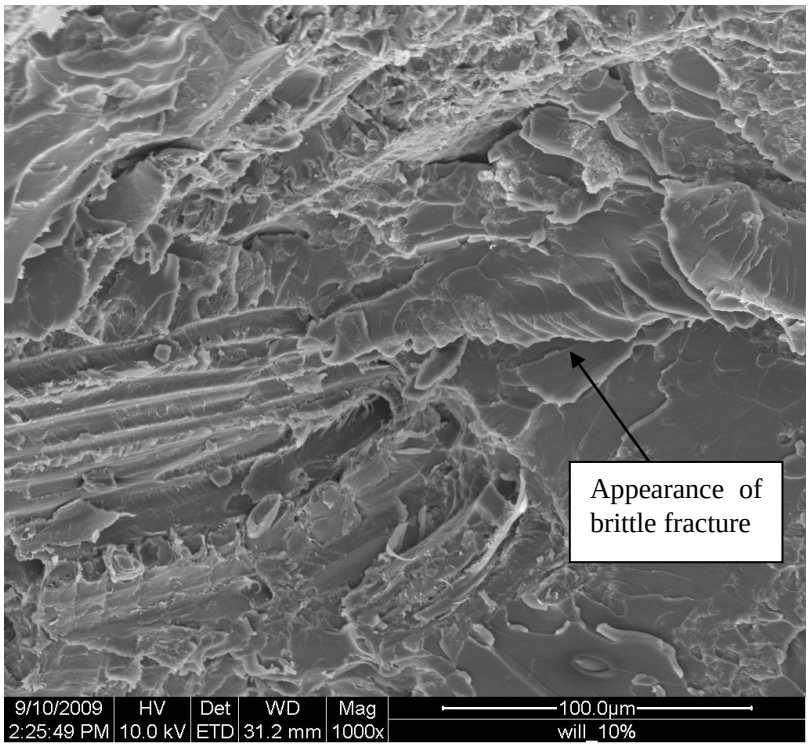
(b)

Figure 4.4 Microscopic view of specimen 5 % post-cured by conventional oven

Ten percentages of composites



(a)



(b)

Figure 4.5 Microscopic view of specimen 10 % post-cured by conventional oven

4.6 Concluding remarks

This chapter has shown the results found for the mechanical properties; tensile and yield strength and Young's modulus. 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 conventional oven that was extracted from testing please find the Appendix B attached.

Chapter 5 Results analysis and 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 conventional oven.

5.2 Analysis

Tensile strength

Referring back to chapter 4, Figure 4.1 showed a varying mean strength for the specimens corresponding to their percentage mixture of sawdust 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 12.53 to 27.758 MPa. The maximum mean tensile strength occurs 20 percentage by weight of 300 μm fillers. 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.

Yield strength

Figure 4.2 from the previous chapter shows a defined peak in the mean strength is 20.39 MPa at 20 % sawdust (300 μm). 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.

Young’s modulus

From Figure 4.3 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%.

5.3 Findings from the microscope

The microscopic views showed some very interesting findings. In all cases the conventional oven caused the porosity to be fine, both resins and fillers interact very well.

5.4 Final material recommendations

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 oven, percentage filler by weight of 15 % or 20 % is appropriate. These two samples produced high tensile properties, and both provide a savings in materials as discussed in previous chapters.

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 oven, 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

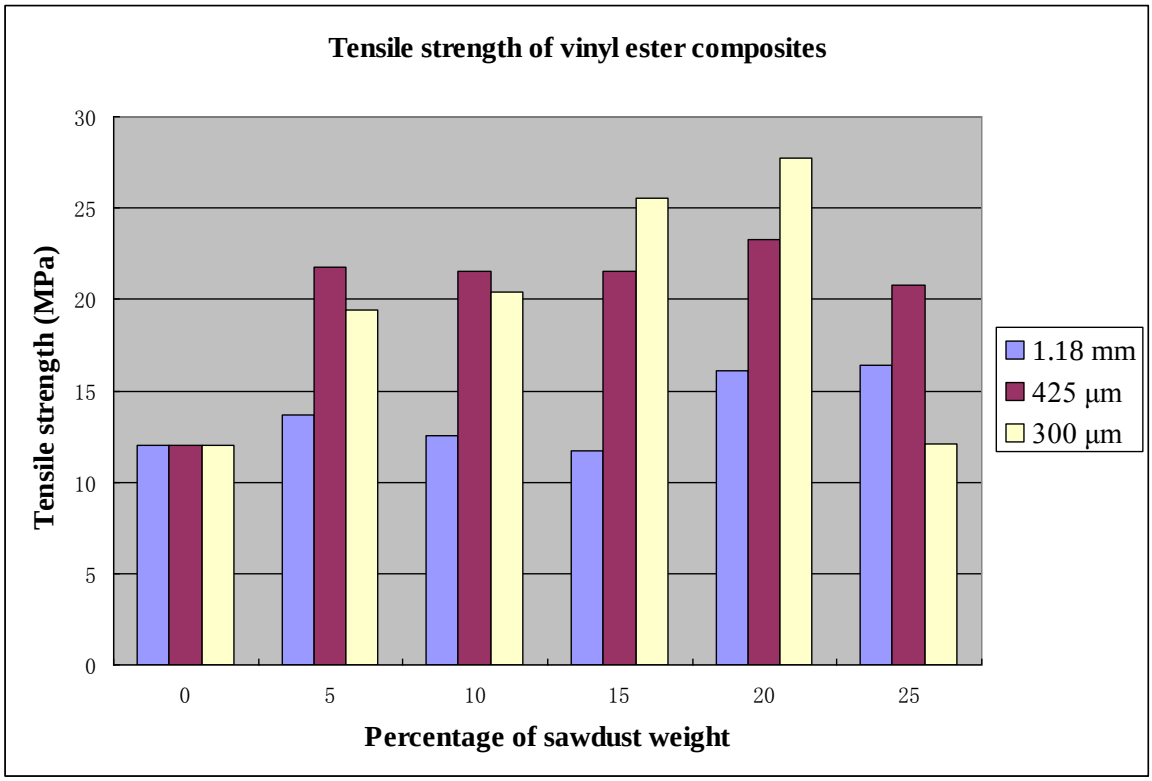


Figure 5.1 Tensile strength of varying percentage fillers specimens

The bar chart (Figure 5.1) given above depicts the values of tensile strength for comparison. Clearly the 300 µm sawdust gives the best results, the highest value being 20.76 MPa for 20 % sawdust. This clearly demonstrates that sawdust gives additional strength to the composite matrix due to its fibrous nature and significantly increases the strength. The addition of sawdust also brings down the overall cost of the composite material. The density of sawdust is less than the resin and catalyst and thus they can replace them in larger volume to cut down cost.

This study has evaluated the tensile strength, yield strength and Young's modulus of varying percentage by weight of sawdust reinforced vinyl ester resin; in all cases, the fluidity of the slurry composite was good and could be cast easily into the mould. The optimum percentage by weight of sawdust was 20 % for tensile properties of the composites.

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Appendix A - Project specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

Topic:	**Tensile strength of sawdust reinforced vinyl ester composites**
For:	Xiaoliang ZHONG- 00050062069
Supervisor:	Dr. Harry Ku
Co-Supervisor:	
Sponsorship:	Faculty of Engineering and Surveying
Enrolment:	ENG 4111- S1, D, 2009 ENG 4112- S2, D, 2009

Project Synopsis:

Vinyl ester composites are being increasingly used in a wide range of structures. In this project, sawdust will be used as fillers because of its low cost and the organic property. This project aims to find the optimal percentage by weight of sawdust by tensile testing. Those findings will have to be analysed to obtain tensile strength properties would enable us to establish behaviour trends of vinyl ester composites.

Program: Issue A, 21/Mar/2009

- Review composites material (especially vinyle ester) uses, properties and synthesis
- Design the manufacture process of phenolic composites by different filler sizes and different percentage weights of fillers
- Casting specimens for tensile testing
- Doing tensile test and work out the tensile strength, yield strength and Young's modulus
- Compare and analysis the results and then draw a conclusion

Timelines:

1. Literature reviews

   Begin : 03-Mar-2009
   Completion : 29-Mar-2009
   Approx. Hours : 50 hours

2. Familiarization of working environment and equipments.

   Begin : 09-Mar-2009
   Completion : 12-Mar-2009

   Approx. Hours : 5 hours

3. Design of manufacture process of a cast/mould for tensile tests.

   Begin : 16-Mar-2009
   Completion : 22-Mar-2009
   Approx. Hours : 20 hours

4. Casting Components.

   Begin : 30-Mar-2009
   Completion : 26-Apr-2009
   Approx. Hours : 15 hours

5. Testing Methods and examination of specimens.

   Begin : 27-Apr-2009
   Completion : 10-May-2009
   Approx. Hours : 80 hours

6. Analysis of results.

   Begin : 11-June-2009
   Completion : 30-June-2009
   Approx. Hours : 50 hours

7. Draw up conclusions and discussion about results with supervisor.

   Begin : 17-July-2009
   Completion : 27-July-2009
   Approx. Hours : 40 hours

8. Discussion for the thesis outline with supervisors.

Begin	: 28-July-2009
Completion	: 24-Aug-2009
Approx. Hours	: 10 hours

9. Thesis initial drafting – each chapter in draft form and shown to supervisors.
.

Begin	: 24-August 2009
Completion	: 28-Sep-2009
Approx. Hours	: 60 hours

10. Final draft of thesis, to incorporate modifications suggested by supervisor.

Begin	: 29-Sep-2009
Completion	: 07-Oct-2009
Approx. Hours	: 20 hours

11. Complete the thesis in requested format.

Begin	: 08-Oct-2009
Completion	: 29-Oct-2009
Approx. Hours	: 20 hours

AGREED:_____(Student) _____ (Supervisor)

(Date)___/___/___ (Date) ___/___/___

Appendix B: MTS 810 Tensile Testing System Data & Plots

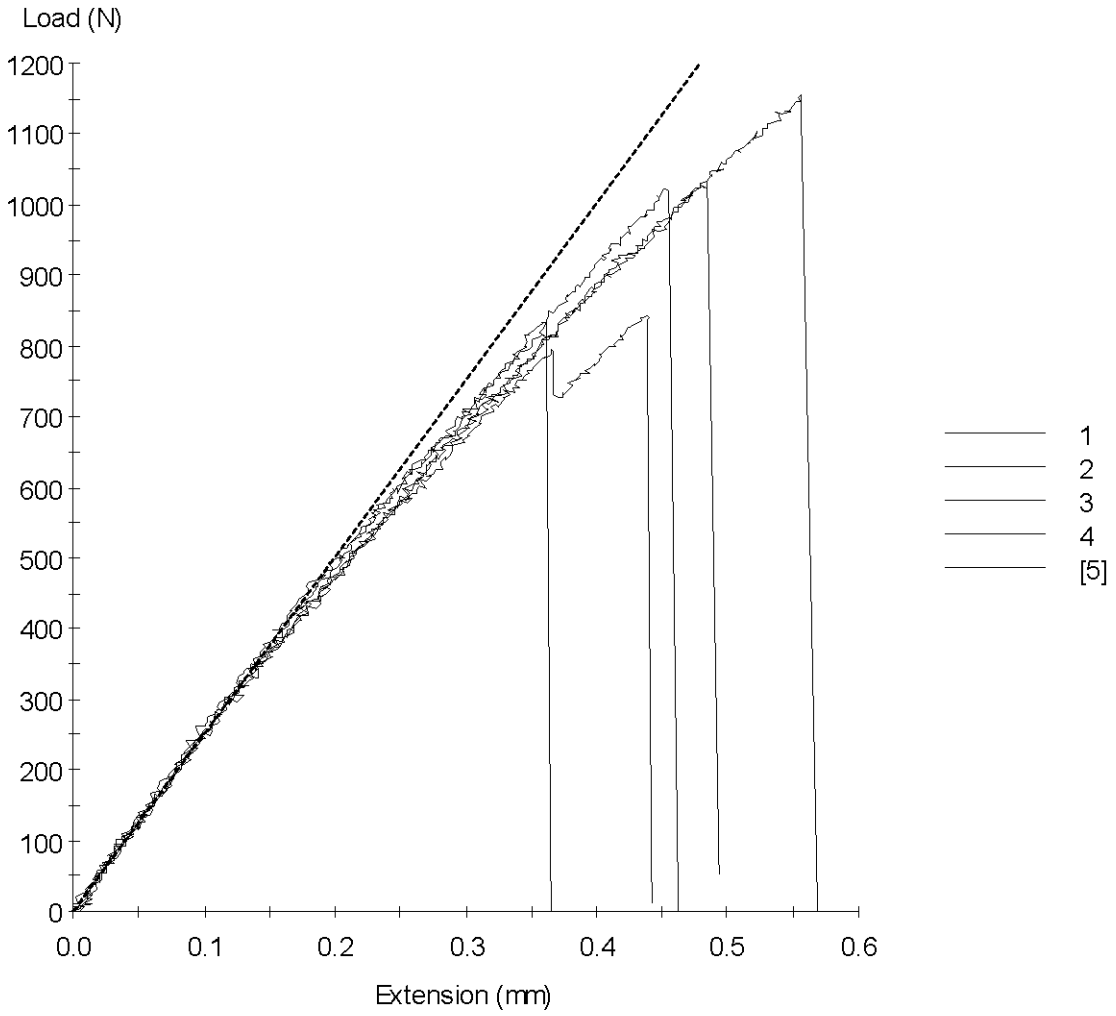
Report Date: 9/09/2009

Test Date : 9/09/2009
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	5.600	14.500	81	1032	12.71	1032	12.71
2	5.600	14.500	81	833	10.25	833	10.25
3	5.600	14.500	81	1155	14.22	1155	14.22
4	5.600	14.500	81	1024	12.61	1020	12.56
5	5.600	14.500	81	843	10.38	839	10.33
Mean	**5.600**	**14.500**	**81**	**977**	**12.04**	**976**	**12.02**
Std Dev	**0.000**	**0.000**	**0**	**138**	**1.70**	**138**	**1.70**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.485	9.302	755.333				
2	0.362	7.863	638.508				
3	0.556	8.889	721.763				
4	0.455	8.889	721.763				
5	0.441	6.904	560.625				
Mean	**0.460**	**8.369**	**679.598**				
Std Dev	**0.071**	**0.976**	**79.269**				


Load (N)
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1100
1000
900
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600
500
400
300
200
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0.2
0.3
0.4
0.5
0.6
Extension (mm)
1
2
3
4
[5]

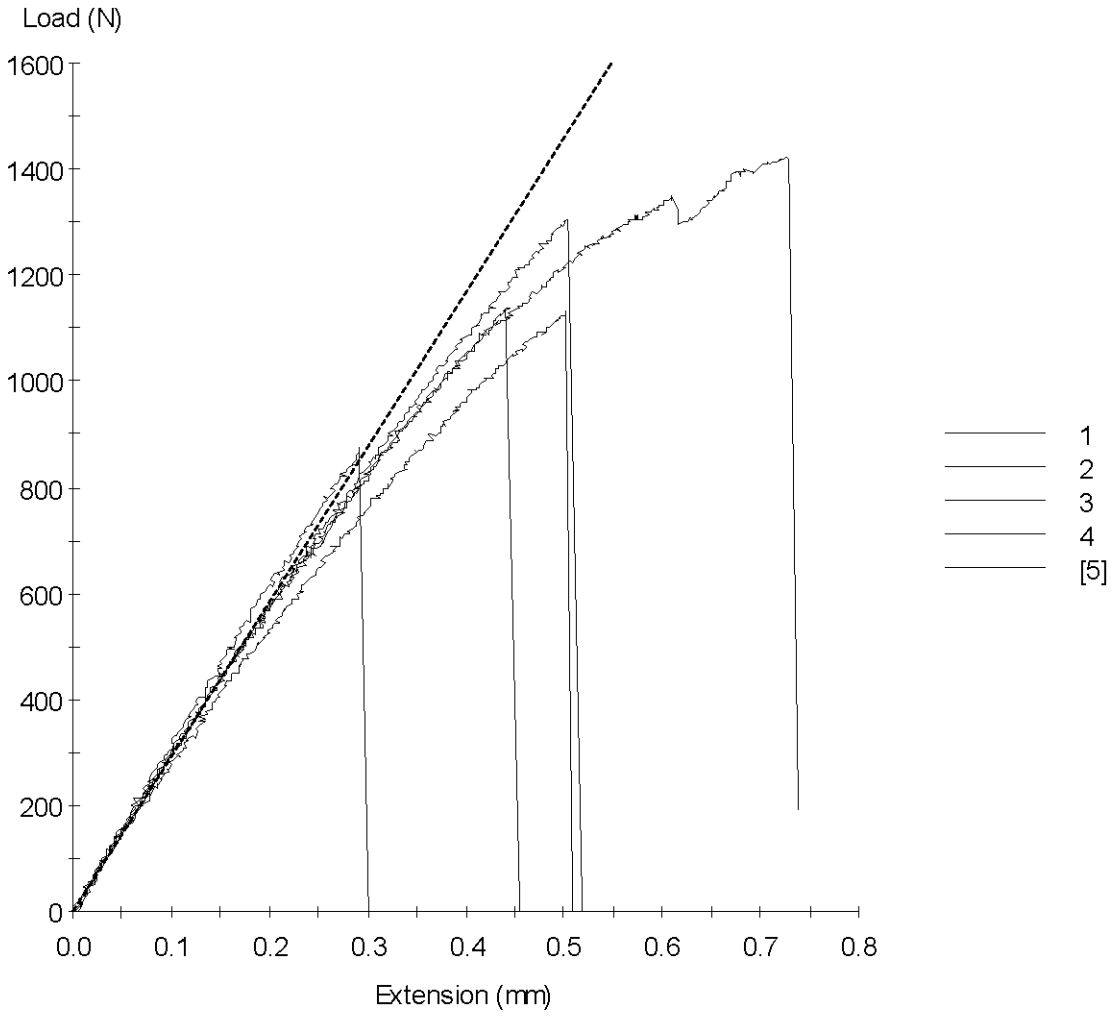
Report Date: 9/09/2009

Test Date : 9/09/2009
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	6.200	14.550	90	875	9.70	875	9.70
2	6.350	14.250	90	1139	12.59	1139	12.59
3	6.500	14.400	94	1422	15.19	1420	15.17
4	6.410	14.250	91	1131	12.39	1131	12.39
5	6.400	14.140	90	1304	14.41	1304	14.41
Mean	**6.372**	**14.318**	**91**	**1174**	**12.86**	**1174**	**12.85**
Std Dev	**0.110**	**0.159**	**1**	**207**	**2.13**	**206**	**2.12**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.292	-0.201	-18.128				
2	0.441	9.876	893.643				
3	0.729	10.258	960.112				
4	0.501	8.527	778.832				
5	0.505	11.056	1000.565				
Mean	**0.494**	**7.903**	**723.005**				
Std Dev	**0.157**	**4.622**	**422.721**				


Load (N)
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1400
1200
1000
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600
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200
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0.0
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0.5
0.6
0.7
0.8
Extension (mm)
1
2
3
4
[5]

Will-5%-300

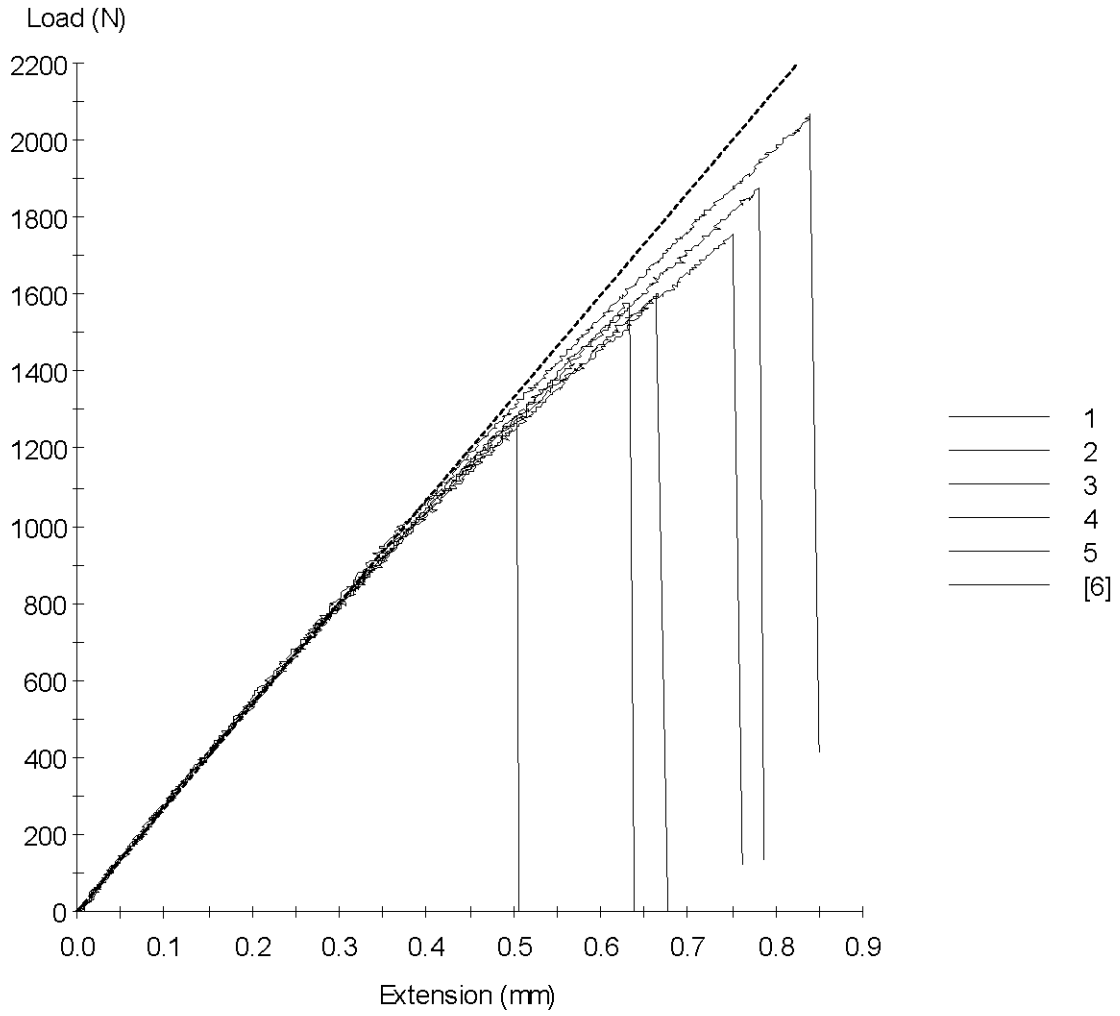
Report Date: 11/09/2009

Test Date : 11/09/2009
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	5.750	14.150	81	2066	25.40	2066	25.40
2	5.750	14.150	81	1601	19.68	1601	19.68
3	5.750	14.150	81	1756	21.58	1756	21.58
4	5.750	14.150	81	1574	19.35	1574	19.34
5	5.750	14.150	81	1282	15.76	1282	15.76
6	5.750	14.150	81	1873	23.02	1873	23.02
Mean	**5.750**	**14.150**	**81**	**1692**	**20.80**	**1692**	**20.80**
Std Dev	**0.000**	**0.000**	**0**	**271**	**3.33**	**271**	**3.33**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.840	13.238	1077.105				
2	0.663	9.760	794.107				
3	0.752	10.975	892.972				
4	0.632	10.414	847.316				
5	0.502	10.195	829.524				
6	0.781	11.553	939.970				
Mean	**0.695**	**11.023**	**896.832**				
Std Dev	**0.121**	**1.252**	**101.891**				


Load (N)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Extension (mm)
1
2
3
4
5
[6]

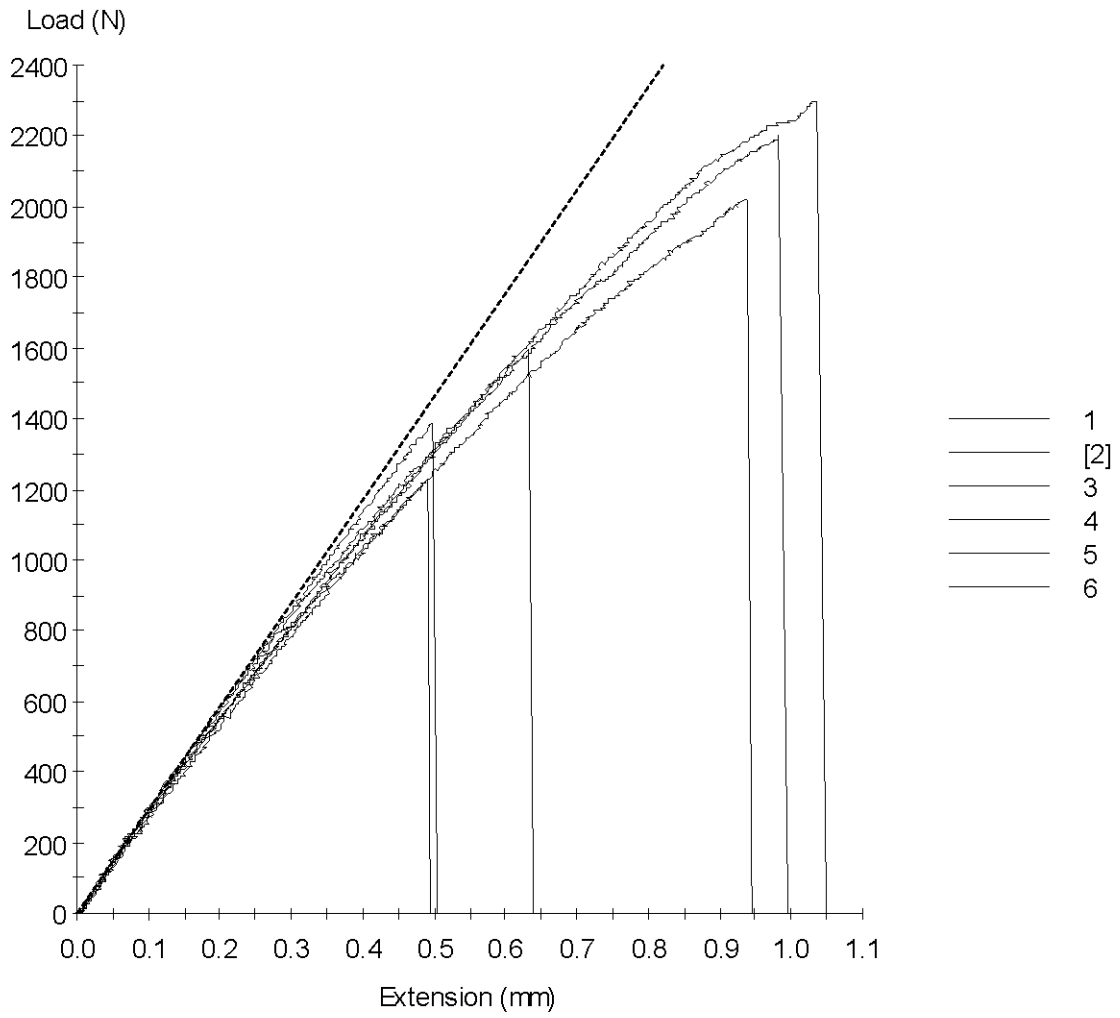
Report Date: 9/09/2009

Test Date : 9/09/2009
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	6.270	14.570	91	1229	13.46	1229	13.46
2	6.270	14.370	90	1384	15.37	1384	15.37
3	6.270	14.370	90	1597	17.73	1597	17.73
4	6.270	14.370	90	2022	22.44	2020	22.42
5	6.270	14.370	90	2301	25.54	2301	25.54
6	6.270	14.370	90	2202	24.43	2202	24.43
Mean	**6.270**	**14.403**	**90**	**1789**	**19.83**	**1789**	**19.82**
Std Dev	**0.000**	**0.082**	**1**	**447**	**5.01**	**447**	**5.01**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.491	10.525	961.455				
2	0.497	14.971	1348.857				
3	0.633	12.333	1111.179				
4	0.938	13.674	1232.032				
5	1.036	15.761	1420.026				
6	0.982	14.799	1333.415				
Mean	**0.763**	**13.677**	**1234.494**				
Std Dev	**0.251**	**1.950**	**171.493**				


Load (N)
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2200
2000
1800
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1400
1200
1000
800
600
400
200
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0.0
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0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Extension (mm)
1
[2]
3
4
5
6

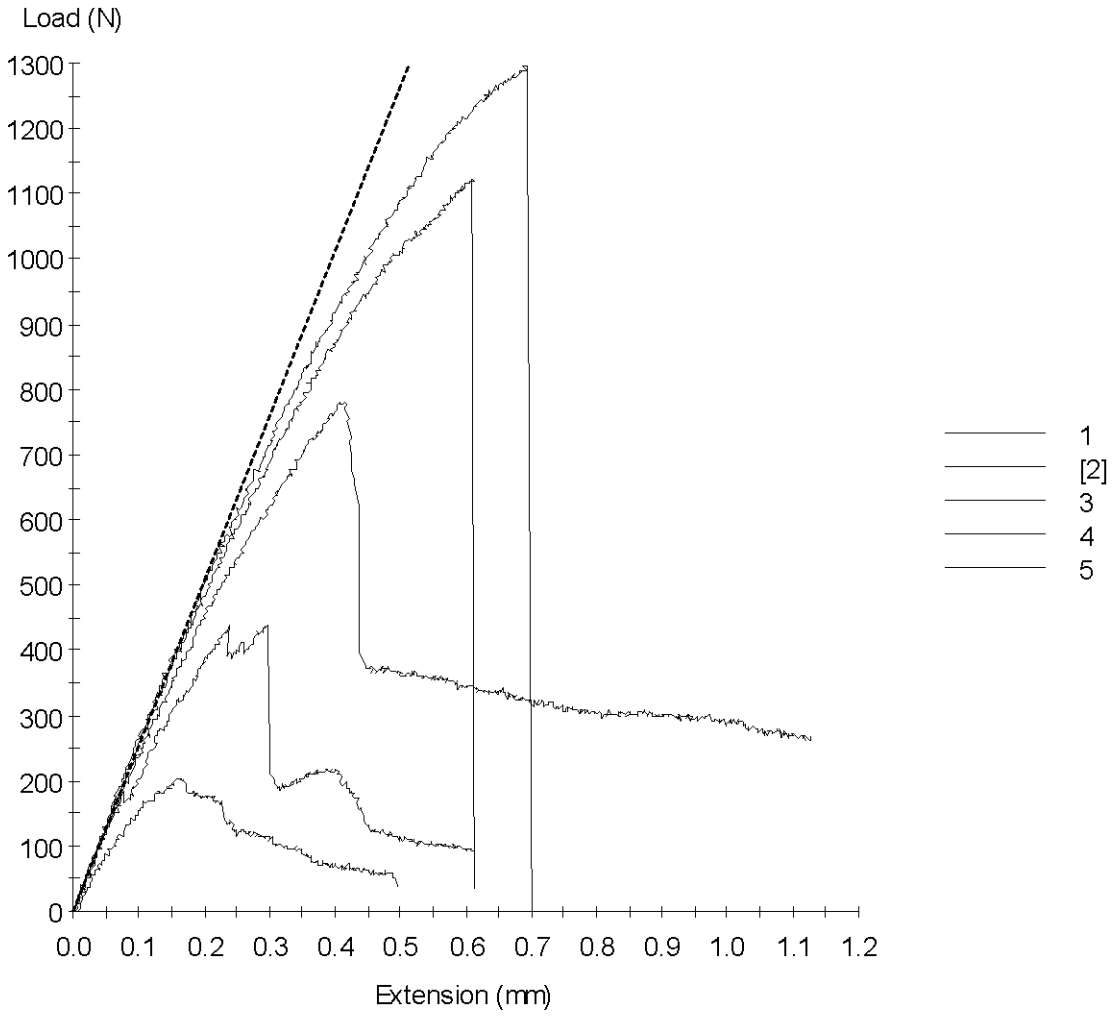
Report Date: 9/09/2009

Test Date : 9/09/2009
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	6.150	14.450	89	437	4.91	437	4.91
2	6.100	14.450	88	1296	14.70	1296	14.70
3	6.000	14.460	87	203	2.34	168	1.93
4	5.650	14.540	82	1124	13.68	1124	13.68
5	5.750	14.750	85	782	9.22	622	7.33
Mean	**5.930**	**14.530**	**86**	**768**	**8.97**	**729**	**8.51**
Std Dev	**0.220**	**0.129**	**3**	**457**	**5.37**	**471**	**5.54**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.239	2.291	203.604				
2	0.695	9.087	800.989				
3	0.229	1.130	98.025				
4	0.608	7.887	647.908				
5	0.437	6.082	515.809				
Mean	**0.442**	**5.295**	**453.267**				
Std Dev	**0.211**	**3.467**	**296.325**				


Load (N)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Extension (mm)
1
[2]
3
4
5

Will-10%-300

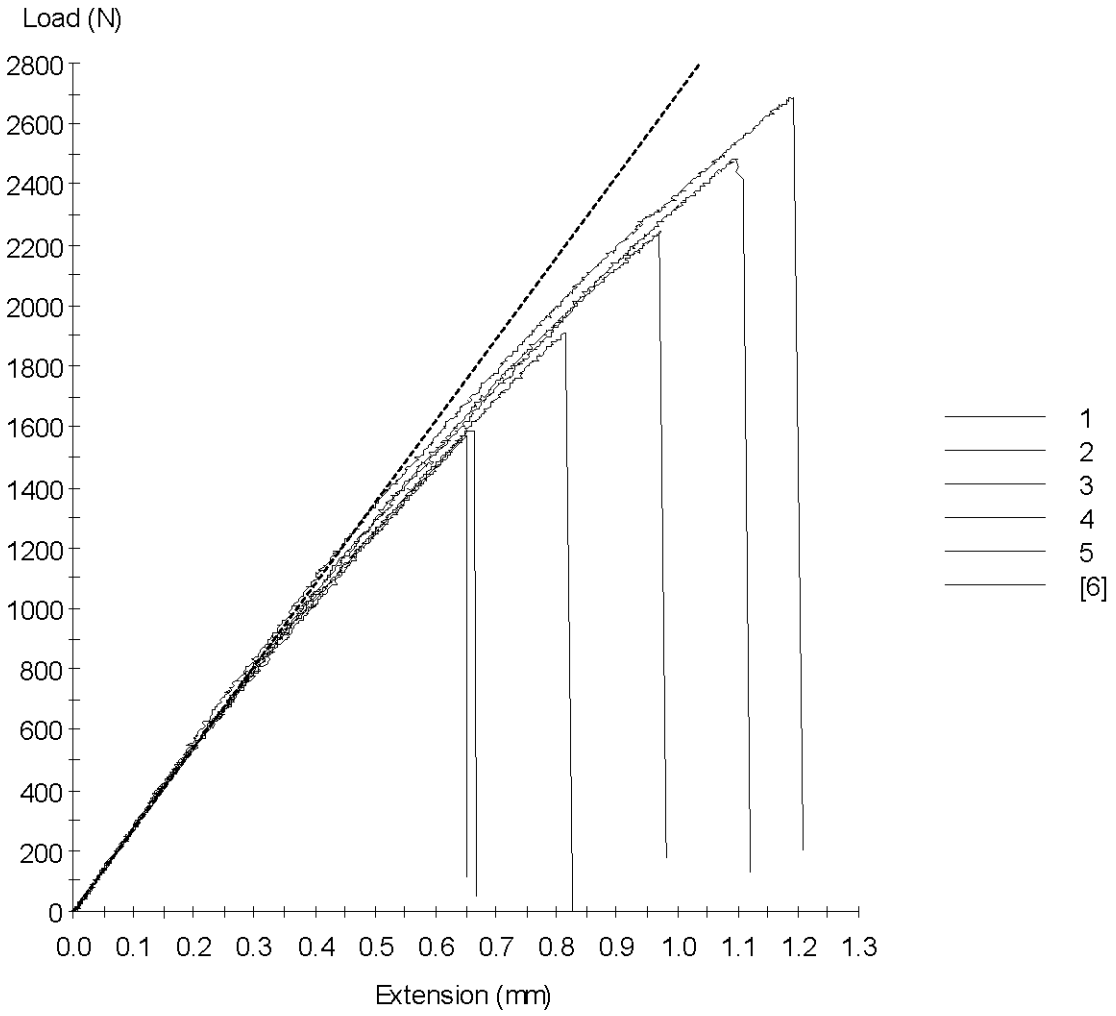
Report Date: 11/09/2009

Test Date : 11/09/2009
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	6.250	14.320	90	2688	30.03	2688	30.03
2	6.250	14.320	90	2486	27.78	2417	27.01
3	6.250	14.320	90	1909	21.33	1909	21.33
4	6.250	14.320	90	1572	17.57	1572	17.57
5	6.250	14.320	90	1589	17.76	1589	17.76
6	6.250	14.320	90	2244	25.07	2244	25.07
Mean	**6.250**	**14.320**	**90**	**2081**	**23.26**	**2070**	**23.13**
Std Dev	**0.000**	**0.000**	**0**	**467**	**5.21**	**455**	**5.09**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	1.192	13.968	1250.160				
2	1.109	13.391	1198.462				
3	0.815	10.842	970.351				
4	0.651	8.475	758.522				
5	0.662	8.693	777.993				
6	0.972	11.834	1059.145				
Mean	**0.900**	**11.200**	**1002.439**				
Std Dev	**0.228**	**2.311**	**206.837**				


Load (N)
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
Extension (mm)
1
2
3
4
5
[6]

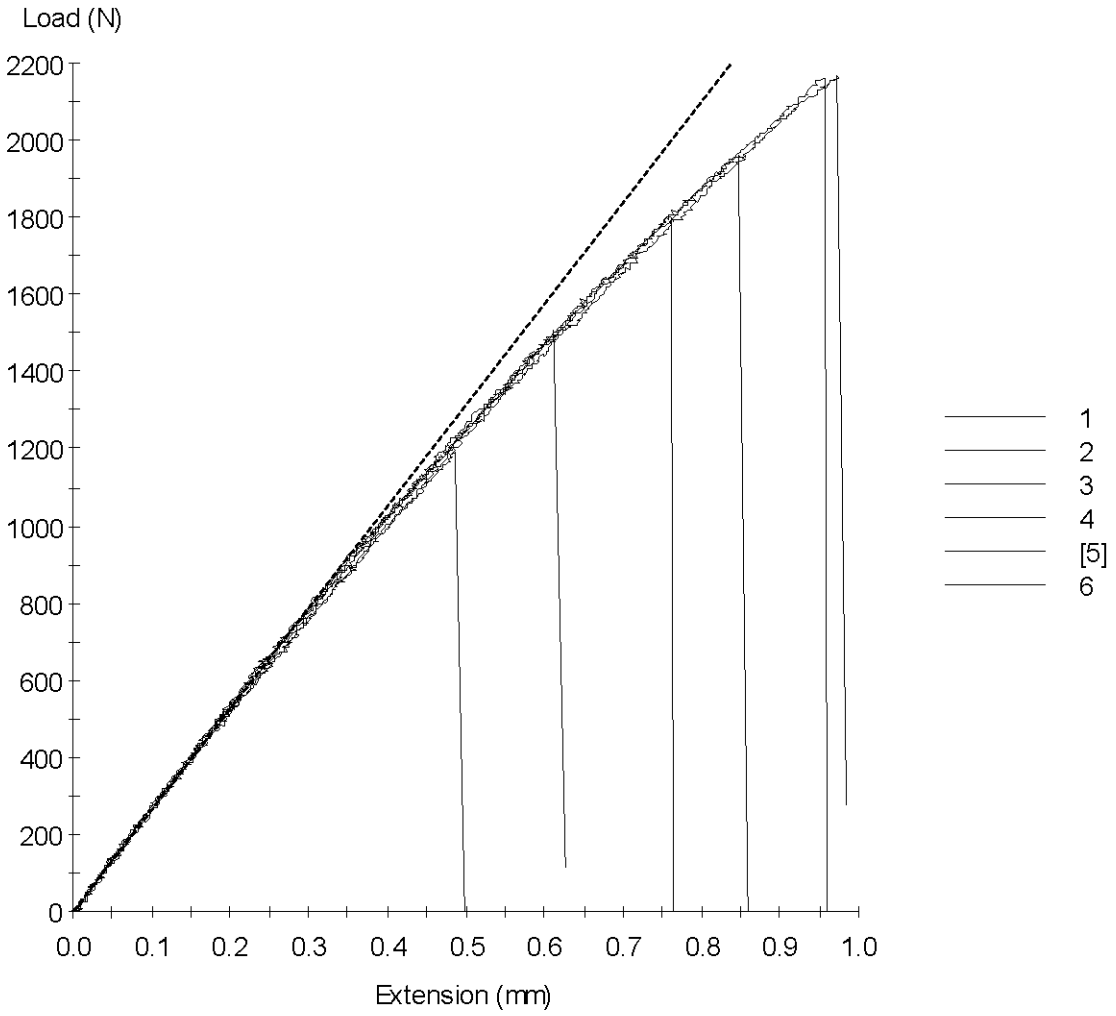
Report Date: 9/09/2009

Test Date : 9/09/2009
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	5.900	14.470	85	2166	25.37	2166	25.37
2	5.900	14.470	85	1962	22.98	1962	22.98
3	5.900	14.470	85	1505	17.63	1505	17.63
4	6.000	14.470	87	1803	20.77	1803	20.77
5	6.000	14.470	87	1192	13.73	1192	13.73
6	6.000	14.470	87	2163	24.91	2163	24.91
Mean	**5.950**	**14.470**	**86**	**1798**	**20.90**	**1798**	**20.90**
Std Dev	**0.055**	**0.000**	**1**	**387**	**4.53**	**387**	**4.53**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.973	16.059	1371.013				
2	0.848	13.212	1127.964				
3	0.613	11.852	1011.811				
4	0.761	13.294	1154.149				
5	0.487	11.035	958.098				
6	0.958	14.616	1268.960				
Mean	**0.773**	**13.345**	**1148.666**				
Std Dev	**0.194**	**1.820**	**154.540**				


Load (N)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Extension (mm)
1
2
3
4
[5]
6

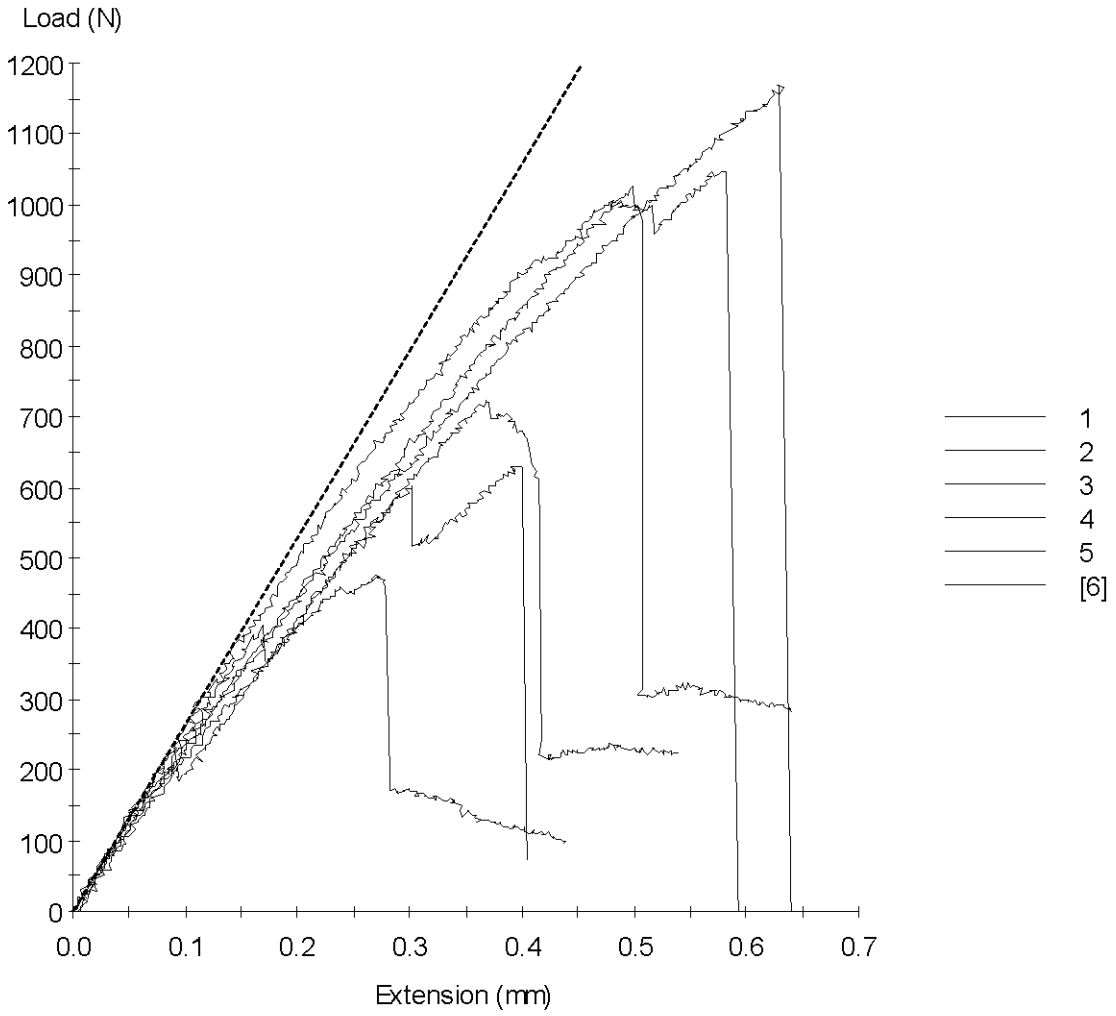
Report Date: 9/09/2009

Test Date : 9/09/2009
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	14.750	86	477	5.57	469	5.48
2	5.600	14.500	81	1170	14.40	1170	14.40
3	5.470	14.620	80	1007	12.59	980	12.26
4	5.500	14.540	80	1048	13.11	1048	13.11
5	5.250	14.650	77	723	9.40	612	7.95
6	5.700	14.500	83	629	7.61	629	7.61
Mean	**5.553**	**14.593**	**81**	**842**	**10.45**	**818**	**10.13**
Std Dev	**0.193**	**0.099**	**3**	**272**	**3.47**	**284**	**3.59**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.279	5.172	442.457				
2	0.630	7.938	644.551				
3	0.506	8.715	696.921				
4	0.582	10.050	803.674				
5	0.415	4.583	352.489				
6	0.399	2.234	184.637				
Mean	**0.469**	**6.449**	**520.788**				
Std Dev	**0.130**	**2.939**	**234.018**				


Load (N)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Extension (mm)
1
2
3
4
5
[6]

Will-15%-300

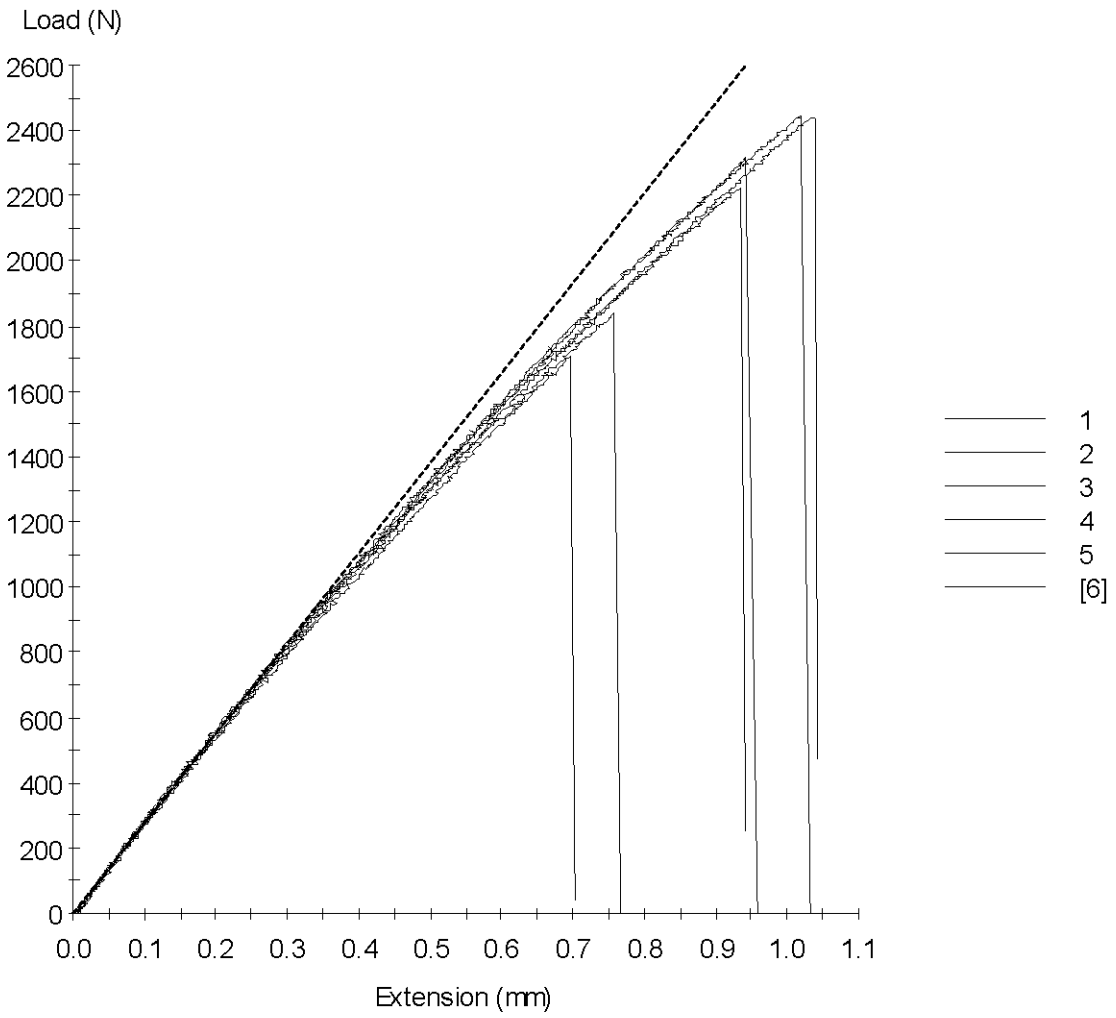
Report Date: 11/09/2009

Test Date : 11/09/2009
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	6.100	14.450	88	1839	20.86	1839	20.86
2	6.100	14.450	88	2444	27.72	2444	27.72
3	6.100	14.450	88	1712	19.42	1712	19.42
4	6.100	14.450	88	2440	27.68	2440	27.68
5	6.100	14.450	88	2323	26.36	2323	26.36
6	6.100	14.450	88	2224	25.23	2224	25.23
Mean	**6.100**	**14.450**	**88**	**2164**	**24.55**	**2164**	**24.55**
Std Dev	**0.000**	**0.000**	**0**	**314**	**3.56**	**314**	**3.56**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.758	11.947	1053.102				
2	1.018	14.149	1247.139				
3	0.697	10.513	926.710				
4	1.038	14.333	1263.420				
5	0.941	14.124	1244.957				
6	0.934	12.292	1083.483				
Mean	**0.898**	**12.893**	**1136.469**				
Std Dev	**0.139**	**1.555**	**137.033**				


Load (N)
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Extension (mm)
1
2
3
4
5
[6]

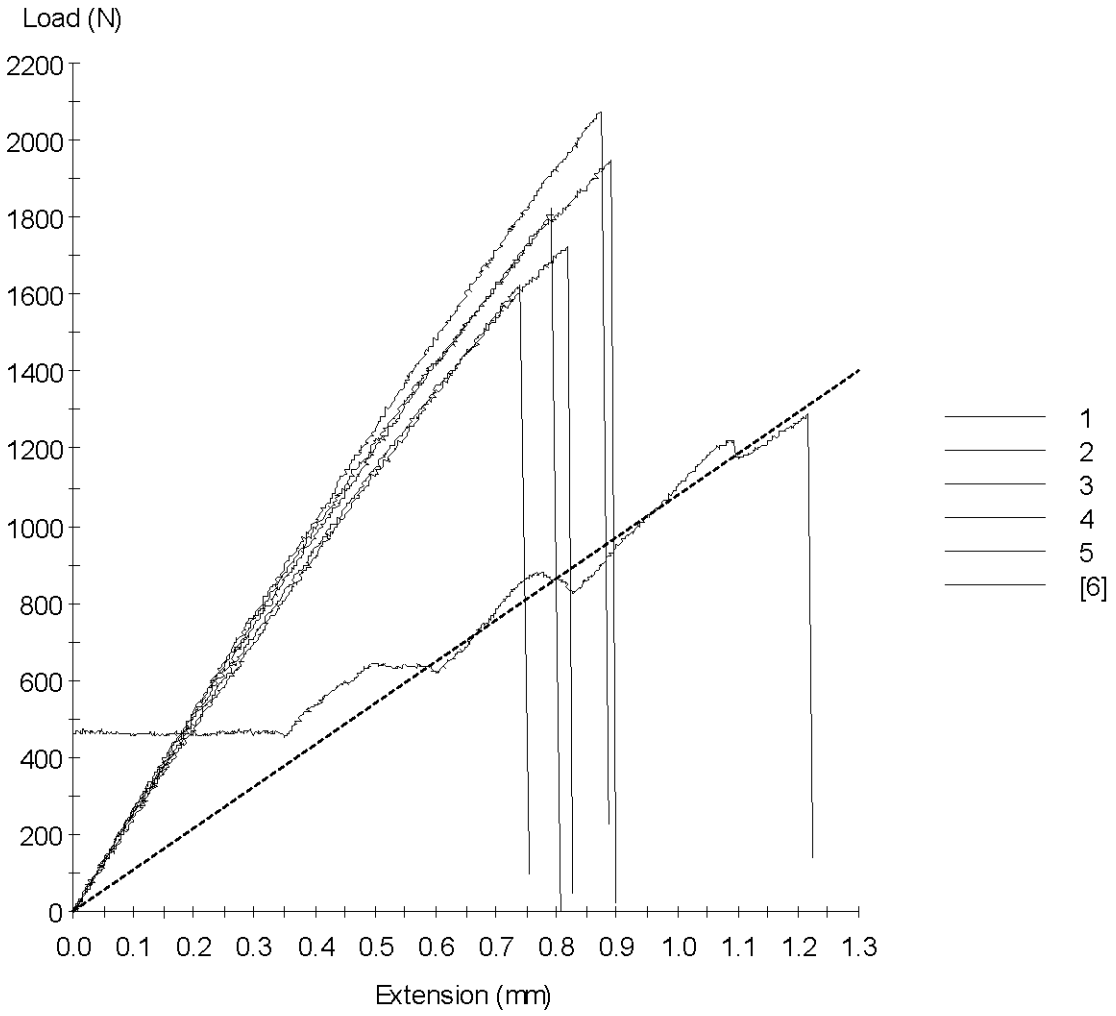
Report Date: 9/09/2009

Test Date : 9/09/2009
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	5.750	14.380	83	2073	25.07	2073	25.07
2	5.750	14.380	83	1825	22.07	1825	22.07
3	5.750	14.380	83	1726	20.87	1726	20.87
4	5.750	14.380	83	1950	23.59	1950	23.59
5	5.750	14.380	83	1625	19.66	1623	19.63
6	5.750	14.380	83	1292	15.63	1292	15.63
Mean	**5.750**	**14.380**	**83**	**1749**	**21.15**	**1748**	**21.14**
Std Dev	**0.000**	**0.000**	**0**	**274**	**3.31**	**274**	**3.32**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.874	17.174	1420.026				
2	0.793	14.007	1158.177				
3	0.819	13.191	1090.701				
4	0.889	14.251	1178.320				
5	0.741	12.351	1021.210				
6	1.217	15.347	1268.960				
Mean	**0.889**	**14.387**	**1189.566**				
Std Dev	**0.170**	**1.699**	**140.460**				


Load (N)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3
Extension (mm)
1
2
3
4
5
[6]

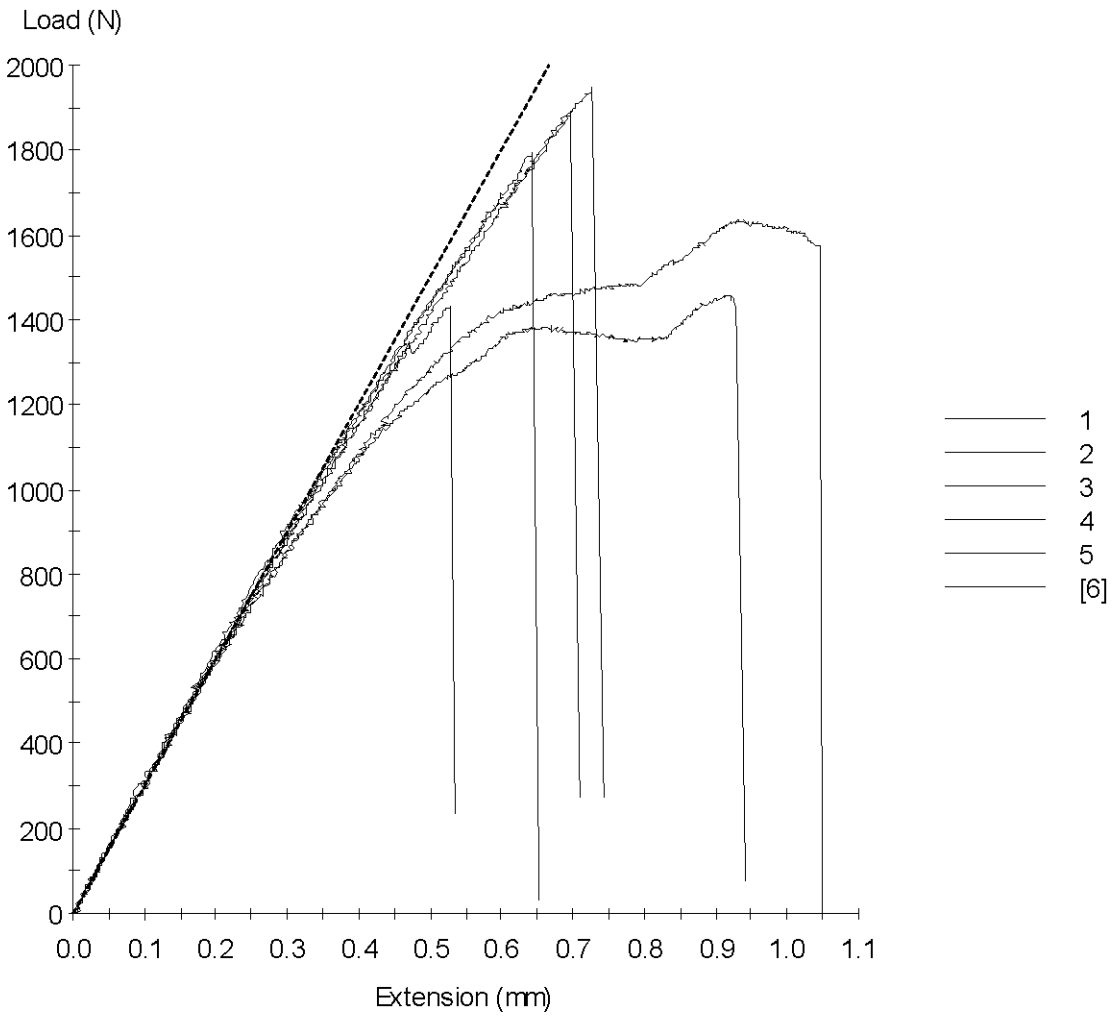
Report Date: 9/09/2009

Test Date : 9/09/2009
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	7.200	14.690	106	1635	15.46	1572	14.87
2	7.010	15.100	106	1457	13.76	1447	13.67
3	6.700	15.120	101	1893	18.69	1893	18.69
4	6.700	14.580	98	1948	19.94	1948	19.94
5	6.700	14.580	98	1798	18.41	1798	18.41
6	6.700	14.580	98	1432	14.66	1432	14.66
Mean	**6.835**	**14.775**	**101**	**1694**	**16.82**	**1682**	**16.71**
Std Dev	**0.218**	**0.263**	**4**	**221**	**2.51**	**227**	**2.61**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	1.045	10.068	1064.852				
2	0.926	8.690	919.828				
3	0.696	13.202	1337.443				
4	0.727	13.863	1354.228				
5	0.644	14.537	1420.026				
6	0.529	13.506	1319.315				
Mean	**0.761**	**12.311**	**1235.949**				
Std Dev	**0.190**	**2.355**	**197.146**				


Load (N)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Extension (mm)
1
2
3
4
5
[6]

Will-20%-300

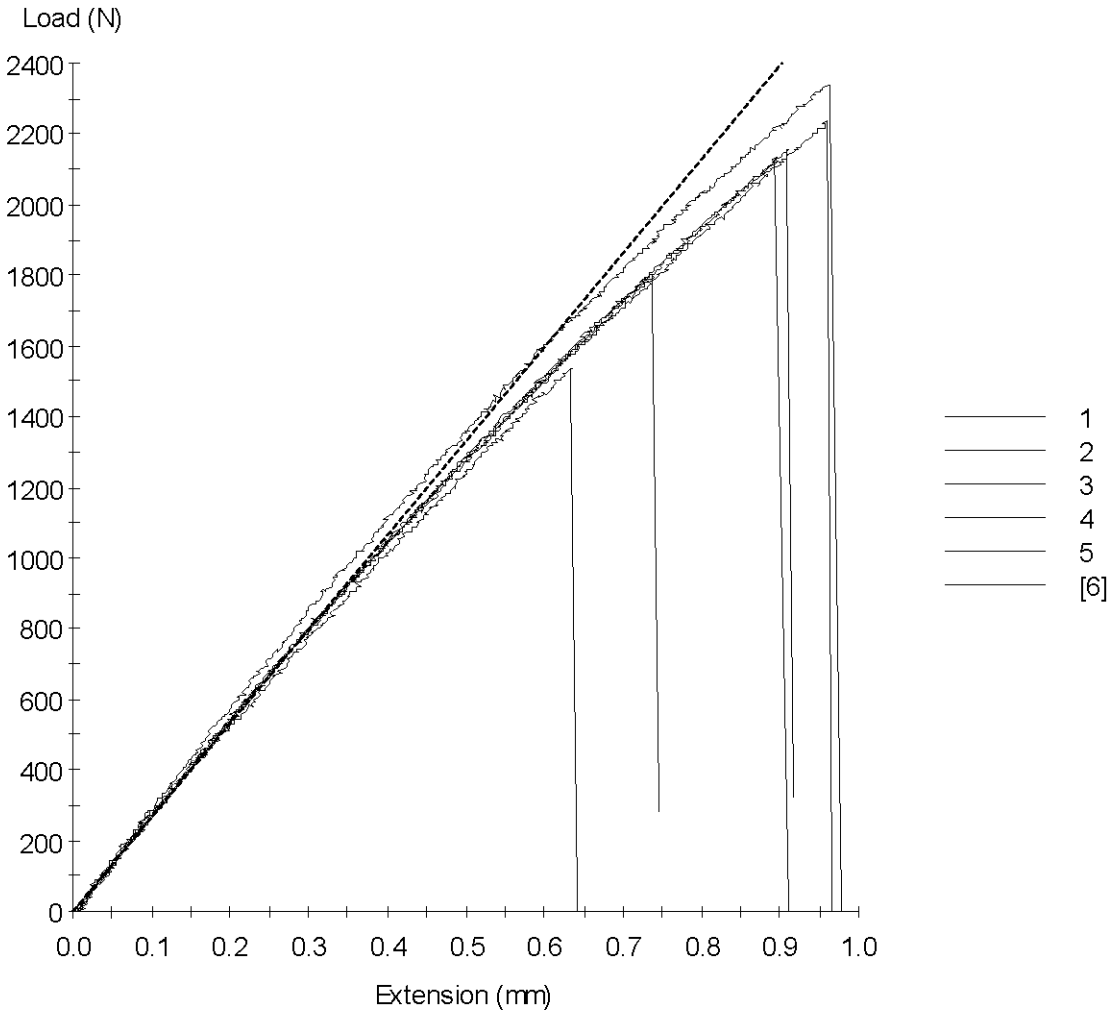
Report Date: 11/09/2009

Test Date : 11/09/2009
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	6.100	14.450	88	1803	20.45	1803	20.45
2	5.500	14.510	80	2234	28.00	2234	28.00
3	5.500	14.510	80	1538	19.27	1538	19.27
4	5.500	14.510	80	2132	26.71	2132	26.71
5	5.500	14.510	80	2336	29.28	2336	29.28
6	5.500	14.510	80	2158	27.04	2158	27.04
Mean	**5.600**	**14.500**	**81**	**2034**	**25.12**	**2034**	**25.12**
Std Dev	**0.245**	**0.024**	**3**	**302**	**4.19**	**302**	**4.19**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.738	11.429	1007.447				
2	0.961	13.490	1076.601				
3	0.633	10.096	805.689				
4	0.896	13.661	1090.197				
5	0.963	13.110	1046.220				
6	0.908	12.746	1017.182				
Mean	**0.850**	**12.422**	**1007.223**				
Std Dev	**0.134**	**1.389**	**103.860**				


Load (N)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Extension (mm)
1
2
3
4
5
[6]

Will-20%-425

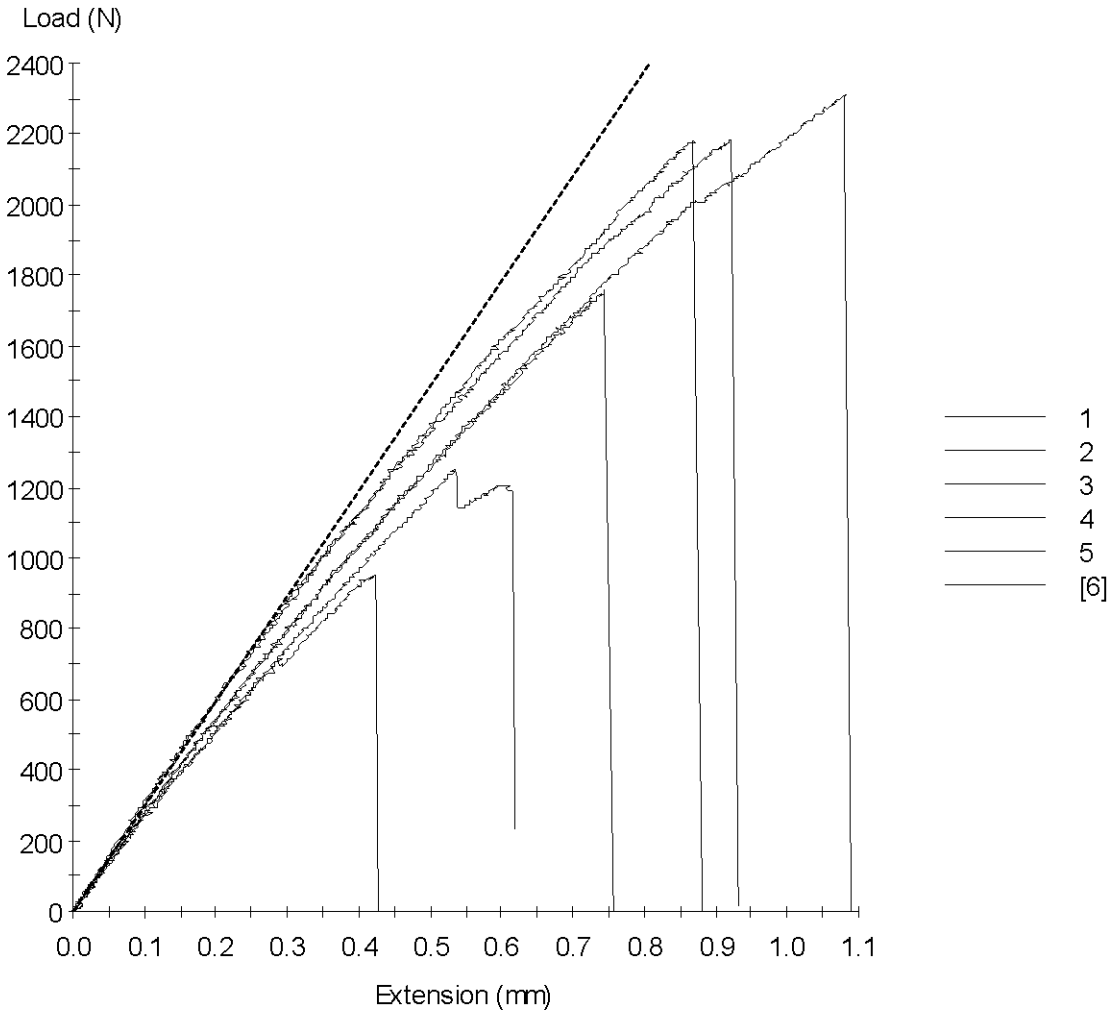
Report Date: 11/09/2009

Test Date : 11/09/2009
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	5.750	14.550	84	1250	14.94	1192	14.25
2	6.000	14.550	87	1762	20.18	1762	20.18
3	6.000	14.550	87	950	10.88	950	10.88
4	6.300	14.550	92	2309	25.19	2309	25.19
5	6.300	14.410	91	2184	24.06	2184	24.06
6	6.410	14.360	92	2182	23.71	2182	23.71
Mean	**6.127**	**14.495**	**89**	**1773**	**19.83**	**1763**	**19.71**
Std Dev	**0.251**	**0.087**	**3**	**561**	**5.76**	**572**	**5.88**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.615	4.895	409.558				
2	0.743	6.960	607.624				
3	0.423	3.159	275.781				
4	1.084	10.767	986.969				
5	0.868	11.095	1007.279				
6	0.922	10.467	963.469				
Mean	**0.776**	**7.891**	**708.446**				
Std Dev	**0.235**	**3.388**	**322.059**				


Load (N)
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Extension (mm)
1
2
3
4
5
[6]

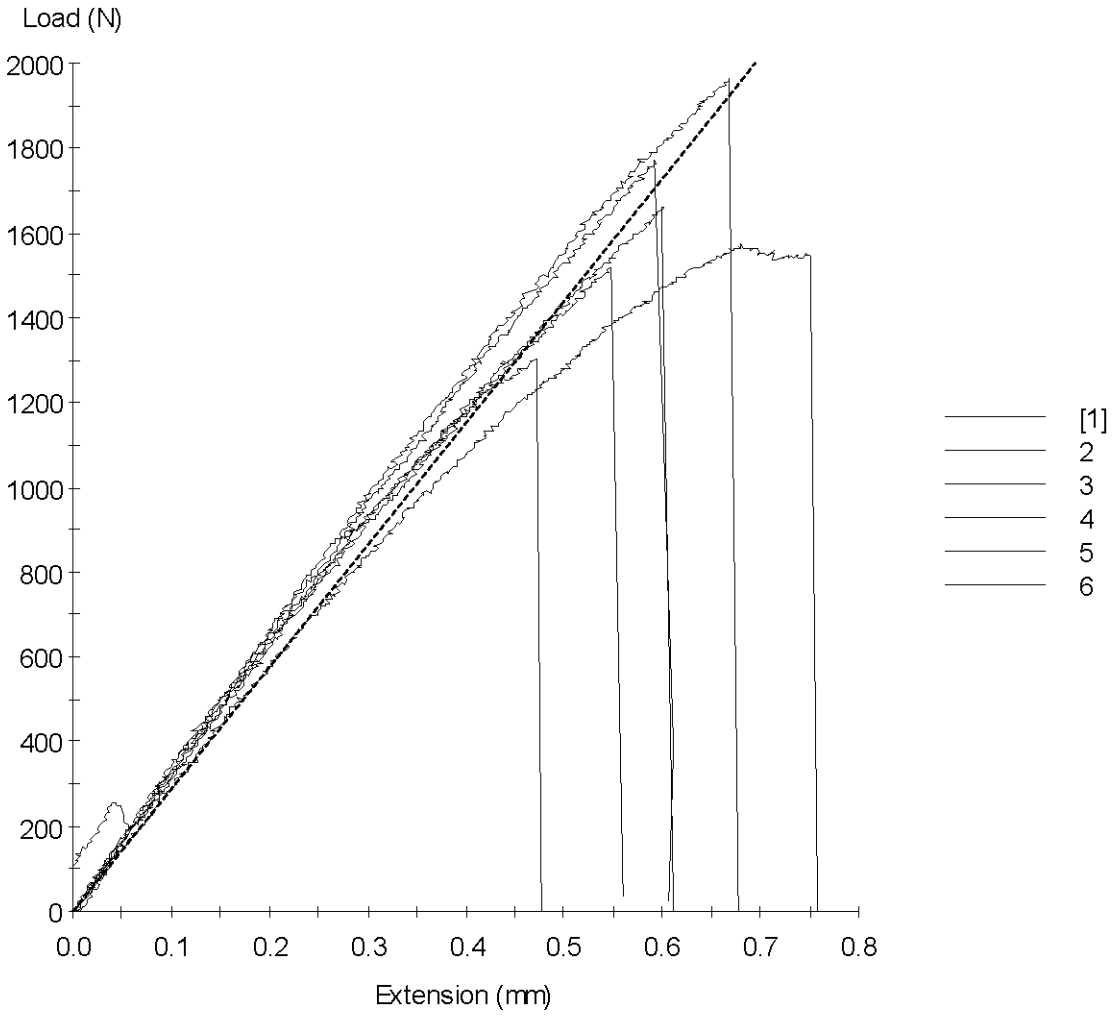
Report Date: 9/09/2009

Test Date : 9/09/2009
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	6.800	15.120	103	1574	15.31	1546	15.04
2	7.200	15.200	109	1301	11.89	1301	11.89
3	7.200	15.400	111	1963	17.71	1963	17.71
4	6.850	15.120	104	1774	17.13	1774	17.13
5	6.850	15.120	104	1662	16.04	1662	16.04
6	6.850	14.860	102	1516	14.89	1516	14.89
Mean	**6.958**	**15.137**	**105**	**1632**	**15.49**	**1627**	**15.45**
Std Dev	**0.188**	**0.174**	**4**	**227**	**2.06**	**228**	**2.07**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.751	10.644	1094.394				
2	0.473	10.767	1178.320				
3	0.668	13.261	1470.382				
4	0.592	13.127	1359.600				
5	0.602	10.884	1127.293				
6	0.548	10.943	1113.864				
Mean	**0.605**	**11.604**	**1223.975**				
Std Dev	**0.096**	**1.236**	**154.569**				


Load (N)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Extension (mm)
[1]
2
3
4
5
6

Will-25%-300

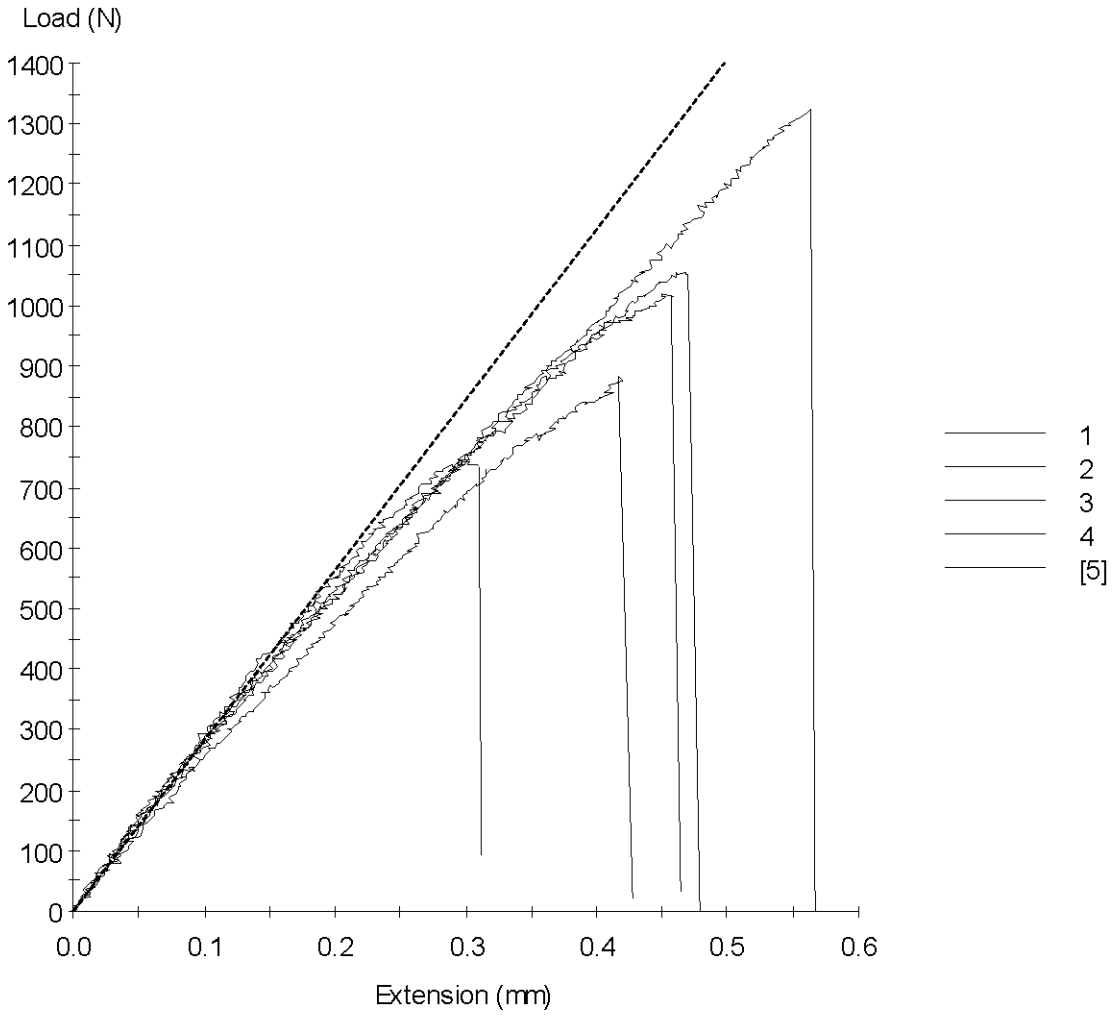
Report Date: 11/09/2009

Test Date : 11/09/2009
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	6.100	14.510	89	883	9.98	883	9.98
2	6.100	14.510	89	1326	14.98	1326	14.98
3	6.100	14.510	89	745	8.42	732	8.27
4	6.100	14.510	89	1019	11.52	1017	11.49
5	6.100	14.510	89	1056	11.93	1056	11.93
Mean	**6.100**	**14.510**	**89**	**1006**	**11.36**	**1003**	**11.33**
Std Dev	**0.000**	**0.000**	**0**	**217**	**2.45**	**221**	**2.50**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.416	4.475	396.130				
2	0.562	7.017	621.052				
3	0.310	4.834	427.854				
4	0.460	4.933	436.583				
5	0.469	6.019	532.762				
Mean	**0.443**	**5.456**	**482.876**				
Std Dev	**0.092**	**1.046**	**92.569**				


Load (N)
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Extension (mm)
1
2
3
4
[5]

Will-25%-425

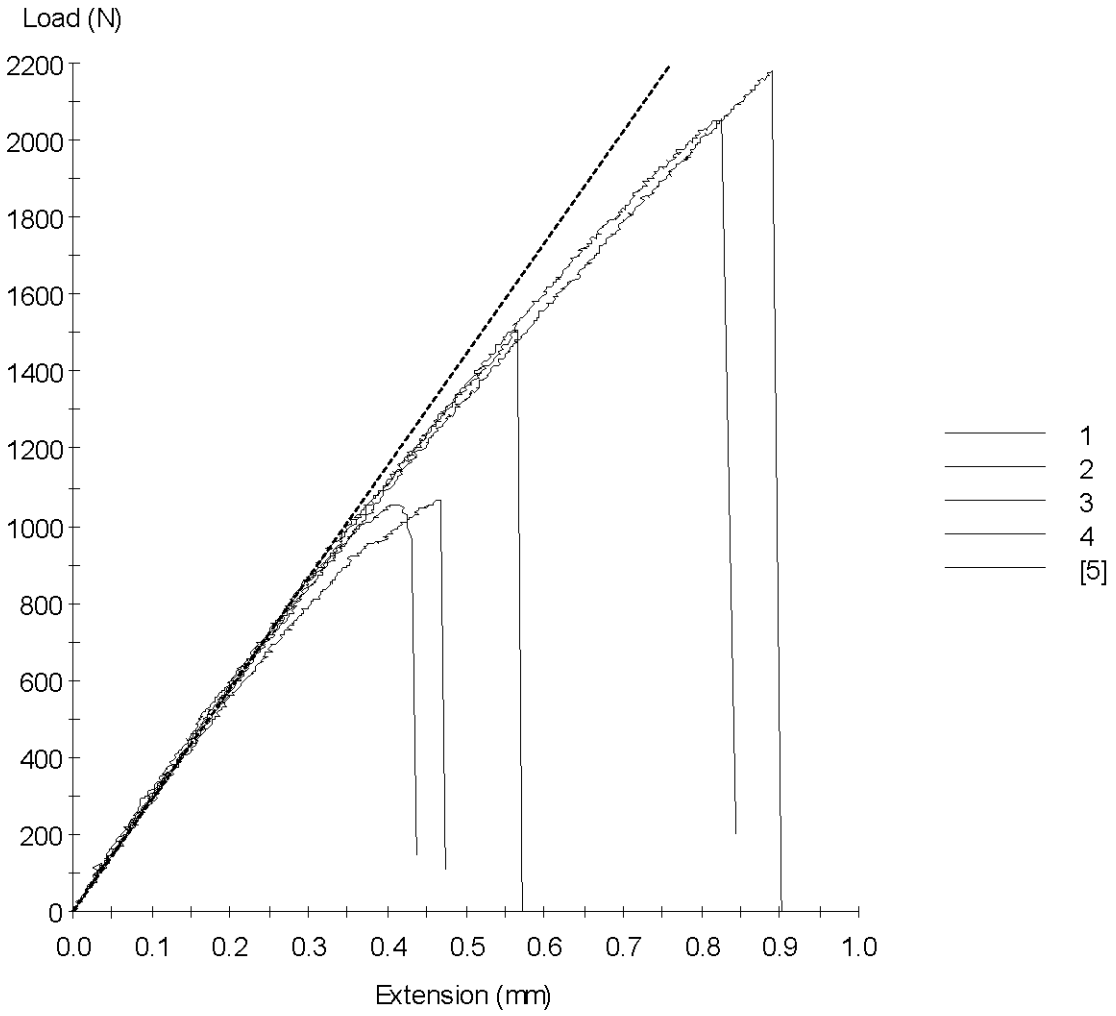
Report Date: 11/09/2009

Test Date : 11/09/2009
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	6.500	14.560	95	1056	11.16	966	10.20
2	6.500	14.560	95	2184	23.08	2184	23.08
3	6.100	14.560	89	2058	23.17	2058	23.17
4	6.500	14.450	94	1511	16.08	1511	16.08
5	6.200	14.450	90	1068	11.93	1068	11.92
Mean	**6.360**	**14.516**	**92**	**1575**	**17.08**	**1557**	**16.89**
Std Dev	**0.195**	**0.060**	**3**	**533**	**5.82**	**556**	**6.08**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.432	4.638	438.932				
2	0.890	10.606	1003.754				
3	0.827	10.470	929.899				
4	0.564	10.258	963.469				
5	0.467	6.895	617.695				
Mean	**0.636**	**8.573**	**790.750**				
Std Dev	**0.210**	**2.687**	**249.143**				


Load (N)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Extension (mm)
1
2
3
4
[5]

Appendix C: Composite Mixture Table

Real Input	Catalyst (ml)	Real Input	Fillers Weights	Real Input	Total (g)	Date
142.5g	17	2.5ml	0	0	1000	3.8.2009
142.5g	16	2.5ml	50	7.5g	1000	3.8.2009
135g	15	2.5ml	100	15g	1000	5.8.2009
136g	14	2.5ml	150	24g	1000	5.8.2009
136g	13	2ml	200	34g	1000	5.8.2009
135g	12.5	2ml	250	45g	1000	5.8.2009
142.5g	16	2.5ml	50	7.5g	1000	31.7.2009
135g	15	2.5ml	100	15g	1000	31.7.2009
136g	14	2.5ml	150	24g	1000	31.7.2009
136g	13	2ml	200	34g	1000	3.8.2009
135g	12.5	2ml	250	45g	1000	3.8.2009
145g	16	2.5ml	50	7.5g	1000	31.7.2009
144g	15	2.5ml	100	16g	1000	21.7.2009
145g	14	2.5ml	150	25.5g	1000	21.7.2009
144g	13	2.5ml	200	36g	1000	22.7.2009
139g	12.5	2.5ml	250	46g	1000	31.7.2009
144g	13	2.5ml	200	36g	1000	7.8.2009
136g	13	2ml	200	34g	1000	7.8.2009
136g	13	2ml	200	34g	1000	7.8.2009
136g	13	2ml	200	34g	1000	7.8.2009

Appendix D: Strength calculation table

Specimen	Tensile strength	Yield strength	0.05% offset load	Area	F	Extension length	Origin length	E
0%_1	12.71	11.7284	950	81	205.1	0.085	110	3.2768
0%_2	10.25	10.28395	833	81	241.7	0.09	110	3.6471
0%_3	14.22	12.34568	1000	81	308	0.129	110	3.2424
0%_4	12.61	12.59259	1020	81	270	0.11	110	3.3333
0%_5	10.38	9.790123	793	81	173.6	0.07	110	3.3679
5%_1.18_1	9.7	9.722222	875	90	396.7	0.127	110	3.8178
5%_1.18_2	12.59	12.34444	1111	90	242	0.0825	110	3.5852
5%_1.18_3	15.19	11.90957	1119.5	94	482.9	0.162	110	3.4882
5%_1.18_4	12.39	10.87912	990	91	319	0.118	110	3.2678
5%_1.18_5	6.9	6.861798	610.7	89	128.6	0.039	110	4.0755
5%_1.18_6	14.41	14.07111	1266.4	90	398.6	0.138	110	3.5303
5%_300_1	25.4	21.97531	1780	81	740	0.282	110	3.5636
5%_300_3	19.68	17.80988	1442.6	81	557.4	0.208	110	3.6392
5%_300_4	19.35	19.4321	1574	81	485.9	0.183	110	3.6058
5%_300_5	15.76	15.82716	1282	81	274.2	0.1	110	3.7237
5%_300_6	23.02	20.14444	1631.7	81	289.7	0.124	110	3.1727
5%_425_1	13.46	13.50549	1229	91	310	0.115	110	3.2585
5%_425_2	21.35	18.27957	1700	93	641.7	0.239	110	3.1757
5%_425_3	15.37	15.37778	1384	90	507.9	0.174	110	3.5676
5%_425_4	17.73	15.55556	1400	90	468.3	0.162	110	3.5331
5%_425_5	22.44	17.21556	1549.4	90	617.7	0.229	110	3.2968
5%_425_6	25.54	20.16667	1815	90	737	0.278	110	3.2402
5%_425_7	24.43	18.57778	1672	90	737	0.27	110	3.3362
10%_1.18_1	4.91	4.162921	370.5	89	97.73	0.037	110	3.2646
10%_1.18_3	14.7	10.63636	936	88	372	0.152	110	3.0592
10%_1.18_5	13.68	10.5878	868.2	82	263.7	0.107	110	3.306
10%_1.18_6	9.22	8.067059	685.7	85	198	0.082	110	3.1248
10%_300_1	30.03	19.57111	1761.4	90	951.4	0.346	110	3.3608
10%_300_2	27.78	19.88111	1789.3	90	668	0.25	110	3.2658
10%_300_3	21.33	16.66667	1500	90	644.7	0.245	110	3.2162
10%_300_4	17.57	15.07444	1356.7	90	498.7	0.183	110	3.3307
10%_300_5	17.76	14.90444	1341.4	90	527.7	0.193	110	3.3418
10%_300_6	25.07	17.77778	1600	90	792	0.3	110	3.2267
10%_425_1	25.37	20	1700	85	826.9	0.33	110	3.2427
10%_425_2	22.98	18.17412	1544.8	85	551.7	0.209	110	3.4161
10%_425_3	17.63	17.09647	1453.2	85	440.4	0.166	110	3.4333
10%_425_4	20.77	16.96322	1475.8	87	605	0.232	110	3.2972
10%_425_5	13.73	13.70115	1192	87	397.7	0.161	110	3.1232
10%_425_6	24.91	19.06207	1658.4	87	687.6	0.27	110	3.2199
15%_1.18_1	5.57	5.393023	463.8	86	183.7	0.098	110	2.3976
15%_1.18_2	14.4	10.9321	885.5	81	297	0.131	110	3.0789
15%_1.18_3	12.59	11.32125	905.7	80	372.3	0.205	110	2.4971
15%_1.18_4	13.11	13.1	1048	80	352.5	0.153	110	3.1679

15%_1.18_5	9.4	7.523377	579.3	77	322.7	0.125	110	3.688
15%_1.18_6	7.61	5.150602	427.5	83	115.7	0.043	110	3.566
15%_300_1	20.86	17.46591	1537	88	592.6	0.215	110	3.4453
15%_300_2	27.72	21.375	1881	88	833.3	0.304	110	3.4264
15%_300_3	19.42	18.18182	1600	88	516.7	0.193	110	3.3465
15%_300_4	27.68	21.68182	1908	88	864	0.33	110	3.2727
15%_300_5	26.36	22.125	1947	88	748	0.28	110	3.3393
15%_300_6	25.23	19	1672	88	726	0.255	110	3.5588
15%_425_1	25.07	22.51446	1868.7	83	727.3	0.291	110	3.3123
15%_425_2	22.07	19.27711	1600	83	586.7	0.245	110	3.1737
15%_425_3	20.87	16.86747	1400	83	560	0.241	110	3.0795
15%_425_4	23.59	18.22289	1512.5	83	669.2	0.273	110	3.2487
15%_425_5	19.66	18.05783	1498.8	83	444.7	0.186	110	3.1687
20%__1.18_1	15.46	11.73113	1243.5	106	576.5	0.195	110	3.068
20%__1.18_2	18.05	15.0268	1457.6	97	642.4	0.22	110	3.3113
20%__1.18_3	13.95	10.19896	979.1	96	334.3	0.114	110	3.3601
20%__1.18_4	13.76	10.37736	1100	106	484	0.165	110	3.044
20%__1.18_5	16	13	1300	100	630.7	0.212	110	3.2725
20%__1.18_6	17.14	14.845	1484.5	100	602.1	0.21	110	3.1539
20%__1.18_7	23.63	17.87143	1626.3	91	444.4	0.152	110	3.5341
20%_300_1	20.45	18.57614	1634.7	88	698	0.259	110	3.3687
20%_300_2	28	20.9	1672	80	836	0.314	110	3.6608
20%_300_3	19.27	18.975	1518	80	440	0.166	110	3.6446
20%_300_4	26.71	21.2125	1697	80	838.4	0.315	110	3.6597
20%_300_5	29.28	21.45	1716	80	682	0.236	110	3.9735
20%_300_6	27.04	21.25	1700	80	798	0.305	110	3.5975
20%_425_1	14.94	11.97619	1006	84	291.7	0.108	110	3.5369
20%_425_2	20.18	14.59885	1270.1	87	478.4	0.173	110	3.4964
20%_425_3	10.88	8.508046	740.2	87	101.1	0.035	110	3.6522
20%_425_4	25.19	17.3913	1600	92	705.1	0.266	110	3.1694
20%_425_5	24.06	17.75824	1616	91	737.4	0.253	110	3.5232
20%_425_6	23.71	15.21739	1400	92	634.5	0.22	110	3.4484
25%_1.18_1	16.88	15.32871	1548.2	101	625.9	0.205	110	3.3252
25%_1.18_2	14.87	13.60288	1414.7	104	535.1	0.171	110	3.3098
25%_1.18_3	15.31	12.38835	1276	103	601.3	0.205	110	3.1325
25%_1.18_4	11.89	11.67798	1272.9	109	707.1	0.225	110	3.1715
25%_1.18_5	17.71	16.02072	1778.3	111	751.7	0.224	110	3.3256
25%_1.18_6	17.13	16.58654	1725	104	600	0.179	110	3.5453
25%_300_1	9.98	8.803371	783.5	89	132	0.055	110	2.9663
25%_300_2	14.98	13.78315	1226.7	89	411	0.153	110	3.3201
25%_300_3	8.42	8.651685	770	89	154	0.05	110	3.8067
25%_300_4	11.52	9.193258	818.2	89	217.2	0.075	110	3.5793
25%_300_5	11.93	9.213483	820	89	305	0.113	110	3.336
25%_425_1	11.16	9.622105	914.1	95	192	0.06	110	3.7053
25%_425_2	23.08	16.84211	1600	95	787.9	0.29	110	3.1459
25%_425_3	23.17	18.72697	1666.7	89	666.7	0.23	110	3.5827
25%_425_4	16.08	15.64468	1470.6	94	485.3	0.165	110	3.4418

25%_425_5	11.93	10.66222	959.6	90	277.8	0.1	110	3.3953