University of Southern Queensland

Faculty of Engineering and Surveying

Fracture toughness of phenolic resins composite by using saw dust as filler of percentage by weight

A dissertation submitted by

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Abstract

Phenol formaldehyde based resole thermosetting resin supplied by Borden Chemical Australia Pty was used as composite matrix binder enforce with saw dust grains as fillers to evaluate the fracture toughness. This is a pilot study of using saw dust as fillers at three different grain sizes and percentage of weight varies from 5% to 25%. By testing fracture toughness and viscosity at ranges of filler sizes and mixtures percentage ratio by weight, the best possible mixture ratio was able to determine the workability, cost and performance. The composites obtained were post-cured in a conventional oven. It was found that the maximum value of fracture toughness of the samples in this study occurs at the grain size of 425 μm. The shape of the curves obtained by plotting the values of fracture toughness against percentage by weight of saw dust was also different. The possible reasons for their difference were also explained. The maximum viscosity recorded was possible mixtures that were able to obtain were up to 20%.

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Certification

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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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_____ Signature

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Nomenclature

PPE	Personal Protective Equipment
FCDD	Fibre Composite Design and Development
CEEFC	Centre of Excellence in Engineered Fiber Composites
LEFM	Linear Elastic Fracture Mechanics
SENB	Single Edge Notch Bend
MSDS	Material Safety Data Sheet
CFRP	Carbon Fiber Reinforced Plastic
GFRP	Lass Fiber Reinforced Plastic
PF	Phenol Formaldehyde (resin)
HP	Hexicon Phencat (catalyst)
SWD	Saw Dust (filler)

Chapter 1

Introduction

Composite is a mixture of two or more materials (fillers, and composite matrix binder), differing in form or composition on an overall scale. The constituents retain their identities, that is, they do not dissolve completely into one another although they act in concert. Normally, the components can be physically identified and show an interface between one another. The interest in using natural fibres such as different plant fibres and wood fibres as reinforcement in plastics has increased dramatically during last few years. Thinking of environment it would be very exciting to use natural fibres such as wood fibres as reinforcement for certain structural applications instead of other manufactured material such as glass. Wood or natural fibres have many advantages compared to glass, for examples they have low density, they are recyclable and biodegradable. Saw dust at present is a waste product of timber manufacturing and freely available.

In the scope of this research fracture toughness of phenol-formaldehyde based resins were investigated using short bar specimen. Phenol-formaldehyde resin [2] (composite binder), saw dust (filler) were the materials used to form the composite and Hexion Phencat 15 [3] (catalyst) was used to improve the curing process. The compositions of these three materials were measured by weight percentages. Phenol-formaldehyde resins (phenolic resins), the first thermosetting plastics, are considered to be the first truly synthetic commercially available plastic resins. Work on phenol-formaldehyde resins began in 1872 [1].Unlike celluloid's, the first man-made plastics resins first created in 1856 [1], phenolic resins are made from purely synthetic materials. Phenol-formaldehyde resins are formed by the chemical reaction between phenols and formaldehyde solutions, a condensation of polymerization reaction between phenol and formaldehyde. The condensation reaction for phenolic can be carried out under two different conditions, resulting in two different materials. One of the intermediates is called resoles and other intermediate materials. One of the

intermediates is called resoles and other novalacs [9, 10]. Thermosetting resins are often liquid at some stage in their manufacture or processing which are cured by heat, catalysis, or other chemical means. After being fully cured, thermosets cannot be resoftened by heat. Some plastics which are normally thermoplastic can be made thermosetting by means of cross linking with other materials.

There are three major categories of composites and each category depends on the geometrical orientation:

- Laminar: Plywood contains layers of wood layer positioned for increased strength and versatility.
- Fibre: Fibreglass is an example of fibre composite as it contains an array of glass fibres arranged to give a lightweight, thin but strong material.
- Particulate: Composites like concrete which is a mixture of cement and gravel to form a tough material.

Particulate composites can further be broke down into many more groups. The groups of interest are polymer thermosets and thermoplastics. Phenolic resin is a type of thermoset as once cured it cannot once again become a liquid unlike thermoplastics. Phenolics were the first thermoset material to be synthesized under the name of Bakelite^{TM} by Leo Bakeland in 1907 [13] Therefore the ideas about commercialising composites and their application have been around for about a century. However, it is only quite recently that a lot of research effort has gone into understanding the properties of composites as their application has dramatically increased and become widely accepted by engineers and consumers.

1.1 Project aim

The aim is to analyse the fracture toughness of the saw dust phenolic composites and investigate on the results. The fracture toughness will be determined by using the material plane strain critical intensity factor equation 4. In the experiment there will be three different grain size of saw dust 300 μm , 425 μm and 1.18mm.

The specimen will be in the form of short bar test with the sizes refer to figure 7 Appendices B, The project will involve production of four different percentages by weight of filler, 5%, 10%, 15%, 20%, among the three grain size of the filler. The ratio of 1:50 catalyst to resin will be used. The testing will be carried out in the universal testing machine refer to figure 1 Appendices C.

In the experiment the specimen will be subjected to two different curing process, first the natural curing where the specimen will be left for 24 hrs after casting and later cooked in a industrial oven for certain duration at various temperature.

1.2 Project Objectives

The objectives of the project include the following:

- Research on the background on fracture testing and the theory associated with.
- During the production and testing of the specimens high level of safety awareness and approach must be taken and necessary personal protective equipment must be used at all times.
- Carry out accurate measurements on the proportional of constituents according to the ratio and the percentages determined, also mixing of constituents must be done at a slow rate to avoid air bumbles formed in the mixture this including the pouring of mixture in to the mould, but it must also be noted that the mixture will be developing to cure so rate of pouring must also considering this.
- The required temperature and number of hours during post curing process must be accurately followed.
- Fracture toughness will; be evaluated by means of short bar tests. Findings can be analysed in detail to establish behavioural trends and formulas that can be used to theoretically predict filled polymer behaviour.
- Research ethics must be followed at all times.

1.3 Risk Evaluation

Firstly risks assessment or evaluation must be carried out before commencement of a task. From the assessment carried out in undertaking this project high level of awareness and safety must be taken while conducting the following tasks:

- Handling chemicals
- Operating oven furnace
- Operating Universal Testing machine

The process of casting of specimen must be done in a well ventilated room or environment, access to cleaners and water is readily available. There are three components in making the specimens that could potentially cause bodily harm if not protected against correctly. The three components are the filler (saw dust), which is fine particles of wood dust that could possibly be inhaled in come into contact with eyes. The phenol formaldehyde resin solution J-2027L, and the phenolic resin hardener catalyst both of which are hazardous.

1.3.1 Saw Dust (Filler)

Saw dusts are composed of particles of wood. The material is produced from cutting with a saw, hence its name, a by-product of manufacturing timber. For this project it is being used as filler. During the preparation stages of saw dust sieving in particular the possibility of inhaling the dust particle is very high which if excessive taken may cause dry and sore throat, for this reason a well ventilated room and also using of PPE such as respirators is highly recommended.

It also can be classified as a flammable material it burns easily when contact with fire; therefore care must be taken when working near a naked flame or any source of fire.

1.3.2 Hexicon Phenecat 15 (Catalyst)

These information are extracted from the MSDS supplied by the supplier [3]

Statement of Hazardous Nature: Hazardous substance, Dangerous goods.

Poison Schedule: None

Risk:

- Harmful by inhalation and if swallowed.
- Causes burns.

- Risk of serious damage to eyes.
- Possible cancer causing agent.

Safety:

- Keep locked up.
- Keep container in well ventilated space
- Avoid exposure – obtain special instruction before use.
- Clean with water.
- Keep container closed tightly.
- Take off immediately all contaminated clothing.
- If you feel unwell contact doctor or poisons information centres.

Further information can be obtained from [3] information sheet.

1.3.3 Hexicon Cellobond J202L (Resin)

Statement of Hazardous Nature: Hazardous substance, non-dangerous goods.

Poison Schedule: S6

Risk:

- Toxic by inhalation, in contact with skin and if swallowed.
- Causes burns.
- Risk of damage to eyes.
- Risk of serious damage to eyes.
- Risk of irreversible effects.

Safety:

- 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 poison
- Information centre.

- If you feel unwell contact doctor or poisons information centres.
- In case of accident by inhalation: remove casualty to fresh air and keep at rest.

Further information can be obtained from [2]

The above chemicals require caution when handling and personal protective equipment to be worn at all times, this includes safety goggles, a respirator, gloves, covered footwear and a long sleeve shirt.

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

1.4 Dissertation Overview

This dissertation is structured in this manner

Chapter 2:

Is a literature review of the history of Composites, classification of composites, the advantages and disadvantages. All the items that were used in this project, which include the chemicals, resin, catalyst, and filler. The various testing apparatus, MTS 810 Material Testing System, and Brookfield RDVD –II+ Viscosity testing machine, include the Industrial Oven, and the mould, also the short Bar Test.

Chapter 3

This chapter covers the detailed process an procedures that were carried out during the production of the specimen, including the natural and the post curing process.

Chapter 4

Specifically explained on the process and approach that was used when handling MTS 810 Material Testing during the testing process, what sorts of results were obtained and further improvements can be done

Chapter 5

Contains the discussion regarding the results, and evaluation of results from the previous chapters

Chapter 6

Conclusion and few ideas to stimulate further research on the study of saw dust as filler in the phenolic resin composites.

Appendix A

Project Specification

Appendix B

Contains the table which shows information regarding the mixtures of the constituents of the composites

Appendix C

Contains the MTS 810 Material testing results

Appendix D

Shows the dimensions of the short bar specimen that were used in this project

Appendix E

Contain the dimension of the specimen recorded after the test and the dimensions were taken by the callipers

Appendix F

Contains table with fracture toughness results.

Chapter 2

Literature Review

2.1 Introduction to Composite Material

Composite materials are engineered materials made from two or three constituent materials, the properties of each material combined together to form a new material in which the chemical, mechanical and physical properties differs from its original status. The main aim of combining these materials is to produce a significant improvement on the properties of the overall material compared to initial status of the individual.

Composites are two-phase material in which one phase acts to reinforce the second phase. Normally the second phase is called the matrix. Composites are lighter, higher strength and stiffer than conventional materials. This is due to the adaptive nature of fibers, which can align themselves in the direction to carry the load. The matrix transfers external loads evenly throughout the fibres, and also helps to protect them from the environment. The second phase or matrix can be polymers, metals, ceramics, and they are generally classified by the matrix material. The classifications of composites will be discussed in the later section of this report.

In this project the materials to be analysed are phenolic resin and Saw dust. The composite will made from 5%, 10%, 15%, 20% of filler (saw dust). Resin will be in a ratio of 50:1over the catalyst.

2.2 History of Composites

These ideas of using composites material have been used many years ago and it is not new, the Romans used a primitive form of concrete in order to build structures, some we can witness that still exist today. There are many forms of naturally occurring composites like abalone shell, wood bone and teeth [5]. Historically there are three

key factors that contribute towards the possible production of composites [15]. The historical explanation below will start at the modern era and roughly trace back the years of how the composites developed.

1. Fiber composites began to expand after the 1970s, this happen due to the new existence of fibres and matrices, different manufactures opt for different techniques of developing and due to completion amongst them integration innovative ideas, now composites have reached a new level now whereby it is now being used in very sophisticated places like some substructures of the aircraft where speed, manoeuvrability and weight in which composites beat other recently available materials.

2. In the late 1960 and early 1970s strong carbon fibres were developed, it was also coinciding with the development of resin especially the Phenolics,1969 and many other important thermosetting resins available today for example

- Expoxies,

  Epoxies are polymers with three member rings on the ends of the polymer chains. The rings are bonding sites for a wide variety of materials. Crosslinks are created when the bonding sites react with the polymer and form a bridge to another polymer. Epoxies are stiff and strong and are commonly used as adhesives. They are also used as the resin in advanced composite applications with carbon fibre, which requires a higher performance from the resin than can be obtained with polyesters.

- Phenolics

  Phenolics were the first thermoset materials to be synthesized, under the name of Bakelite™ by Leo Bakeland in 1907. They are among the most widely used thermosets, undoubtedly because they are some of the lowest cost engineering materials on a cost per volume basis. Phenolics are formed from the condensation polymerization reaction between

phenol, an aromatic molecule, and formaldehyde, a small organic compound often used as a solvent or as a preservative [13]

- Polyurethenes

Are created by the reaction between polylos and isocyanates, accomplished simply by mixing the two reactants, which form urethane linkage. No condensation product is made. Urethanes can be both exist in thermoset and thermopalstics although the thermosets are important in commercial application. Generally flexible, these materials can be easily adjusted for stiffness and strength versus flexibility and toughness. This is done by changing the aromatic content of the monomers. This freedom of choice in properties along with their generally excellent abrasion resistance and durability, has led to a rapid increase in use of polyurethanes, perhaps the most important being as the principal material in athletics shoes.

- Polymides

Polymides crosslink by condensation polymerization between molecules that contain the aimide group. The imide group is similar to aromatic group, like phenolics, but they are even stiffer and stronger. Polymides are stiff materials with extremely high thermal stabilities.

2.3 Classifications of Composites Material

Composite materials can be classified by the following:

- Fiber Reinforced Polymers (FRPs)
- Reinforced carbon-carbon.
- Metal Matrix composite MMC.
- Ceramic matrix composite
- Organic matrix /ceramic composites

Generally, composites are polymer matrix, either thermosetting or thermoplastic reinforced with fiber or other material with a sufficient aspect ratio (length thickness) to provide a superficial reinforcing function in one or more direction. However not all plastics are composites. In fact, the majority of plastic materials today are pure plastic and not some form of composite. Many products such as toys, decorative products, household goods and similar applications require only the strength of the plastic resin to perform their functions. ''Engineering grade" thermoplastics can offer improved performance characteristics, such as increased heat distortion temperatures, but usually at higher cost than general-purpose plastic resins. When additional strength is needed, many types of plastics can be reinforced with structural materials- usually reinforcing fibers to meet the demands for higher performance. Any thermoplastic or thermoset plastic resin that is reinforced is considered as a composite. Table 2.1 shows the classification of composites in brief. FRPs are one type of polymer which is not shown in Table 2.1. It can be classified as fiber and matrix type. Classification by fiber type includes wood (cellulose fibers in lignin and hemicellulose matrix), carbon fiber reinforced plastic or CFRP, Glass-fiber reinforced plastic or GFRP.

	Matrix	Dispersed Phase
Purpose	Transfer to other phases	Enhance Matrix Properties
	Protect phases form the environment	MMC: increase E, δy, Ts and creep
		CMC increase Kc
		PMC increase E, δy, Ts and creep
Classification	MMC, CMC, PMC	Particle reinforced and Fiber-reinforced lamellar

Table 2.1: The classification of composite

Another type is the MCC composite made up of two parts and one part of the constituents is made up of metal the other part can be either ceramic or organic compound For application Cobalt and cobalt-nickel alloy can be used for very high temperatures Also for structural support the metal part of the composite normally made up of lighter material such as Aluminium, Titanium or Magnesium which provides stronger support for reinforcement.

The RCC composite material made up of carbon fiber reinforced with matrix graphite and is used for nose cones of ballistic missiles, and also space shuttle because of its properties that can withstand high heat and shock resistance.

Another composite which exhibits similar physical properties on MMC is called Bone (hydroxyaphite) reinforced with collagen fibres) cement (ceramic and metal) which are examples of ceramic matrix composites. The only difference is that ceramic is added to form the composite instead of metal. These are some of the Organic matrix/ceramics which they have a common physical properties and that is its strength and toughness but there are used in different industries

- Asphalt concrete
- Mastic Asphalt
- Dental Composite
- Syntactic foam

Now composites has been recognised and recommended by most designers, engineers and industries for the unique and combination performance it can offer. Composite features translate into multiple benefits; designers, engineers, and others associated with turning design concepts into product realities can make their jobs easier and more effective.

In considering the formulation of a composite material for a particular type of application, it is important to consider the properties exhibit by the potential constituents. The properties of interest are the stiffness (Young's modulus), strength and toughness. Density is of great significance. Thermal properties such as expansivity and conductivity must also be taken into account. In particular, composite materials are subject to temperature changes (during manufacture and/ or in service), a mismatch between the thermal expansivities of the constituents leads to internal residual stresses. These can have a strong effect on the mechanical behaviour. Some representative property data are shown in the Table 2.2 for various types of matrix and reinforcement, as well as for some typical engineering materials and a few representative composites. Inspection of these data shows that some attractive property combination (for example, high stiffness/strength and low density) can be obtained with composites.

Type of Material	Density ρ ($Mg.m^3$)	Young's Modulus E (GPa)	Tensile Strength σ (MPa)	Fracture Toughness Kc ($MPam^{-1/2}$)	Thermal Conductivity K ($Wm^{-1}K^{-1}$)	Thermal expansivity α ($10^{-6}K^{-1}$)
Thermosetting resin (exposy)	1.25	3.5	50	0.5	0.3	60
Engineering thermosetting (nylon)	1.1	2.5	80	4	0.2	80
Rubber (polyurethane)	1.2	0.01	20	0.1	0.2	200
Construction Ceramic (concrete)	7.8	208	400	140	60	17
Engineering Ceremic (alumina)	3.9	380	500	4	25	8
General PMC (in plane)	1.8	20	300	40	8	20
Adv,PMC (load //fibers	1.6	200	1500	40	200	0

Table 2.2 Overview of properties exhibited different classes of material

2.4 The advantages and disadvantages of using composites

Within the ranges of composite material most are distinguished from each other by the magnitude of its strength and the magnitude of its stiffness of the fibers for example comparing boron and graphite with some of the low fibres such as glass. The advantages of these high strength and high stiffness over the low strength and low stiffness composites are the weight. Also the strength and the stiffness of some of these composites is much more higher than some of high strength steel and also have light in weight. Other advanced composite materials are as much as three times as strong as aluminium, yet only weight 60% as much.

These are some of the advantages of composites [16]:

- **Dimensional Stability**- Under severe mechanical and environmental stresses, thermoset composites maintain their shape and functionality. Typically, composites do not exhibit the viscoelastic or "cold-creep" characteristics of unreinforced thermoplastics. The coefficient of thermal expansion is reduced. Generally speaking, the yield point of a composite is its break point.

- **Corrosion Resistance** – Composites do not rust or corrode. Even though many polymeric matrix composites are capable of absorbing moisture from the surrounding environment, which creates dimensional changes as well as adverse internal stresses within the material. There are a number of resin systems available, which provide long-term resistance to nearly every chemical and temperature environment. Properly designed composite have longer service life and requires minimum maintenance.

- **Inherent damping**- This has better vibrational energy absorption within the material and results in reduced transmission of noise and vibrations to neighbouring structures.

- **Finishing**- In many composites applications color can be moulded into the product for long lasting, minimum maintenance appearance. Low profile and low-shrink resin systems are compatible with most metallic painting operations.

- **Light weight** –Composites deliver more strength per unit of weight than plastics without reinforcement, as well as most metals. This combination of high strength/light weight is powerful incentive for the effective use composites.

- **Increased (or decreased) thermal or electric conductivity**- This depends on the type of composites use. Normally, metal reinforced composite has better conductivity than polymer type polymer. This also depends on the environment it is being placed, in a microwave environment for example.

- **High strength** – Composites are among the most effective materials in delivering high strength. These materials can be designed to provide a wide range of mechanical properties including tensile, flexural, impact compressive strength. Unlike traditional materials, composites can have their strengths oriented or tailored to meet specific design requirements of an application.

Disadvantages:

- **Environmental degradation of matrix**- Climatic conditions such as wind, temperature, moisture will inevitably causes contraction and expansion in a microscopic level of the matrix. Over a period of time, crack starts to appear from the point where it has the higher stress concentration value.

- **Difficulty with analysis**- Composite materials has been used greatly for the past 50 years, thus it is still consider new to the society. Therefore, high number to testing and experiment need to be conducted to test its behaviour under different conditions.

- **Cost of raw materials and fabrication**- Materials such as carbon and graphite for metal and Vinyl Ester and Phenolic for resin. These materials are costly to obtain. In process such as fabrication and sample preparations, many of the unused materials will turn into waste and eventually ended up in a dump truck.

It was found that there are more advantages than disadvantages of using composite materials in industry. This makes the research and development of composite materials vital for the use in next generation.

2.5 Materials

It is essential to exactly know the characteristics and the performance of the material that will be used in the experiment, also how to handle it especially safety. A thorough knowledge will also helps in predicting or making assumptions on the outcome of the experiment.

2.5.1 Pehnol Formaldeyde. [2]

Phenolic resins are typically opaque and range from pale amber and dark brown to black in colour. Of course, some resoles are light in colour prior to the processing. The dark colour of phenolic resins limits their application to a narrower market niche. Phenolic resins are available in flakes, films and liquid powder forms.

Phenol is primarily obtained for the fractional distillation of coal tar and various synthetic processes. Prior to Baekeland's invention [1] of the phenol-formaldehyde resins, earlier processing methods use low-temperature to suppress the evolution of steam and gases to cause bubble formation which is a very long and expensive process.

Formaldehyde is produced by the controlled catalytic oxidation of methyl alcohol (methanol). The result is the dehydration of methanol to formaldehyde. The process is described in [2]. A disadvantage of phenolic resins is that they are characterised by a complex

Properties of Phenolic Resins

- Good electrical resistance – are good electrical insulation materials [1].
- Good chemical resistance – Phenolic moulding resins are resistant to common solvents, weal alkalis, weak acids, hydrocarbons and detergents, but are attacked by alkalis and concentrated oxidizing agent [1].
- Low water absorption – Water absorption moulding compounds is only about 0.03 to 17% described by [1]

This is the acid catalyst used to crosslink the resin was Hexicon Phenecat [3]. The molecular weight of the commercial resin used is approximately 600 and its functionality 2, one on each end of the molecule. The ratio by weight of the resin to hardener for all samples in this work was chosen to be 49:1.

The polymer based on Phenolic resin is Phenol-fromaldehyde (PF). The Pf resins formed by the reaction of phenol with formaldehyde. By varying the reaction time, reaction temperature, catalyst type, and the ratio of formaldehyde to phenol, a number of adhesive systems with different characteristics can be produced.

A disadvantage of phenolic resins is that they are characterized by a complex process of polymerization (cure) with generation of water and formaldehyde, with consequent formation of voids. Therefore, the processing of phenolic materials requires careful temperature control and gradual heating to allow continuous elimination of volatiles

to reduce the number of defects in the final components. Normally the time required for these operations is incompatible with common industrial process schedules.

Initially formaldehyde reacts with phenol to form hydroxymethyl derivatives preferentially at the aromatic ring carbon para to the phenolic hydroxyl as depicted in figure 2.1. As the reaction proceeds, substitutions also take place between the hydroxymethyl groups and the aromatic ring carbons of phenol or another hydroxymethyl group to form methylene linkages. In this manner, the polymeric structure of the resin shown in figure 2 is produced.

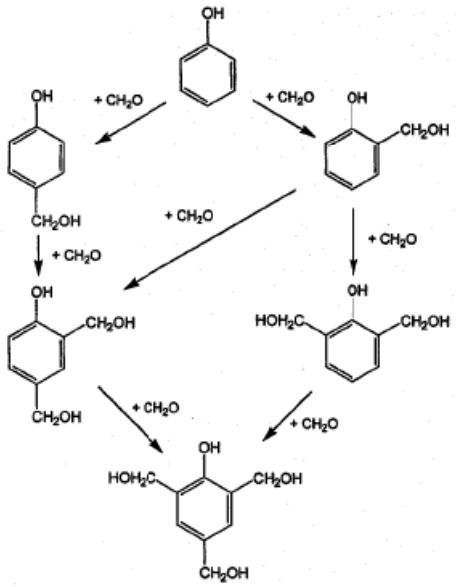


Figure 2.1 Formation of the hydroxymethyl derivates phenol

With reference to phenolic molecule of figure 2.2, here are five 5 hydrogen atoms in the benzene ring but because of limited space, there are only three possible site for reaction and the phenolic molecule is said to have a functionality of three and this is shown in figure 2.3 [5, 13]. As the functionality of the phenolic molecules is greater than two, the molecules can react with formaldehyde molecules to form 3-D network polymer [14].

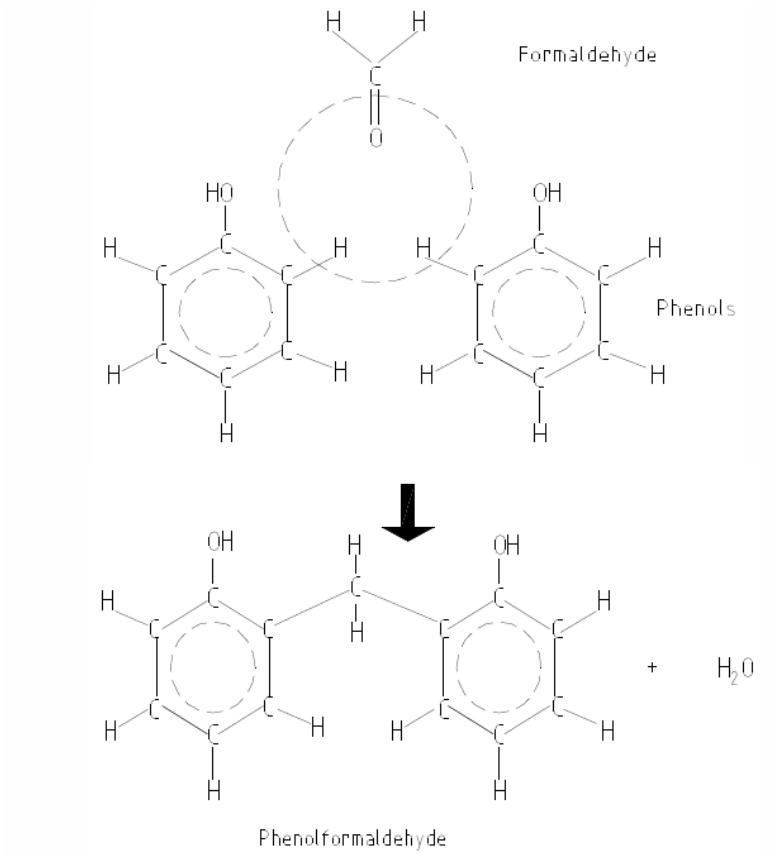


Figure 2.2 Formation of Phenol formaldehyde

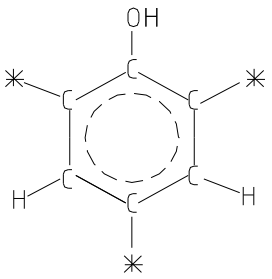


Figure 2.3 Phenol with active sites marked

2.5.2 Hexicon Phencat [3]

In general, there are three catalysts for phenolic resin: Phencat 15, Phencat 382 and *UH*. Phencat 15 is a fast action acid catalyst. The reaction with phenolic resins is strongly exothermic. It is toxic and causes burns with body contact. Its composition consists of xylenesulfonic acid, 70–90%, phosphoric acid, 10–20% and water, 1–10%. Phencat 382 is a slow action acid catalyst. The reaction with phenolic resin is exothermic. It is toxic and dangerous to body contact. Its composition consists of phosphoric acid, 40–80% and water 20–60%. Phencat 382 is similar to Phencat 15 but

with slower reaction rate. *UH* is a urea hydrochloride solution based on a 1:1 mole ratio of urea: hydrochloric acid 32%. The reaction with phenolic resins is strongly exothermic. It has a high toxicity and burns the skin.

In the earlier study, it was found that Phencat 15 reacted very fast with the phenolic resin and provoked moss due to the presence of polysulfone; even with Phencat 382, moss was sometimes found for composites with more than 70% by weight of Hyrez 202 [17] In order to understand the reactions of the latter better, Hyrez 202 with different proportions of parts A and B were mixed with phenolic resin and Phencat 382; the mixture were post-cured at 80 °C for 4 hr.

Composite 80/20 was then mixed with different percentages of epoxidised linseed oil (58%) and then *post-cured* differently: one was heated up to 80 °C and soaked at that temperature for 4 hr and the other was soaked at 80 °C for 4 h followed by gradually increasing its temperature to 150 °C.

For this project the ratio used for resin and catalyst was 40 (parts of resin) and 1 (part of Catalyst).

2.5.3 Saw Dust

Saw dusts are composed of particles of wood. The material is produced from cutting with a saw, hence its name, a by-product of manufacturing timber. It has a variety of practical users, including fuel, manufacturing of the particle board, until the advent of refrigeration, it was often used in icehouses to keep ice frozen during the summer. In terms of hazards it is flammable when in contact with fire.

For the purpose of this project saw dust is being used to determine whether its characteristics will have an impact on the fracture toughness of the phenolic resins. Since the resins have a very high brittleness property thus having certain magnitude of fracture toughness. The issue of saw dust having impact on the brittleness of resin will be explained in the result. The sizes of saw dust grain sizes used in this project were 300 μm , 425 μm and 1.18mm,

2.6 Testing Equipments

The aim for the project focus around testing, therefore there are testing equipments that will be used for this research. For better results there is a need to understand the operation of these various testing equipments including some background knowledge of it. With this knowledge it can stimulate ideas on ways the testing process can be improved by more proactive and innovative ideas, ways of improvement could be the speeding up of certain stages for example replacing manual operation with an automatic system and these can only happen if there is a clear understanding of what are the current performance and accuracy of the available testing equipments.

Calibration of testing equipments is vital as it will determine the accuracy of testing results; as wear and tear takes its toll to various parts of the equipment as the equipment perform testing after testing . Calibration will also keep in tab with the new technology.

2.6.1 Universal Testing Machine (MTS 810 Material Testing System)

The 810 Testing Machine System delivers a broad array of testing capabilities for both high and low force static and dynamic testing [18]. The system has variety of force capacities, servovalve flow ratings, pump capacities, software, and accessories, refer to diagram 2.4 it illustrates an overall typical system of the testing machine.

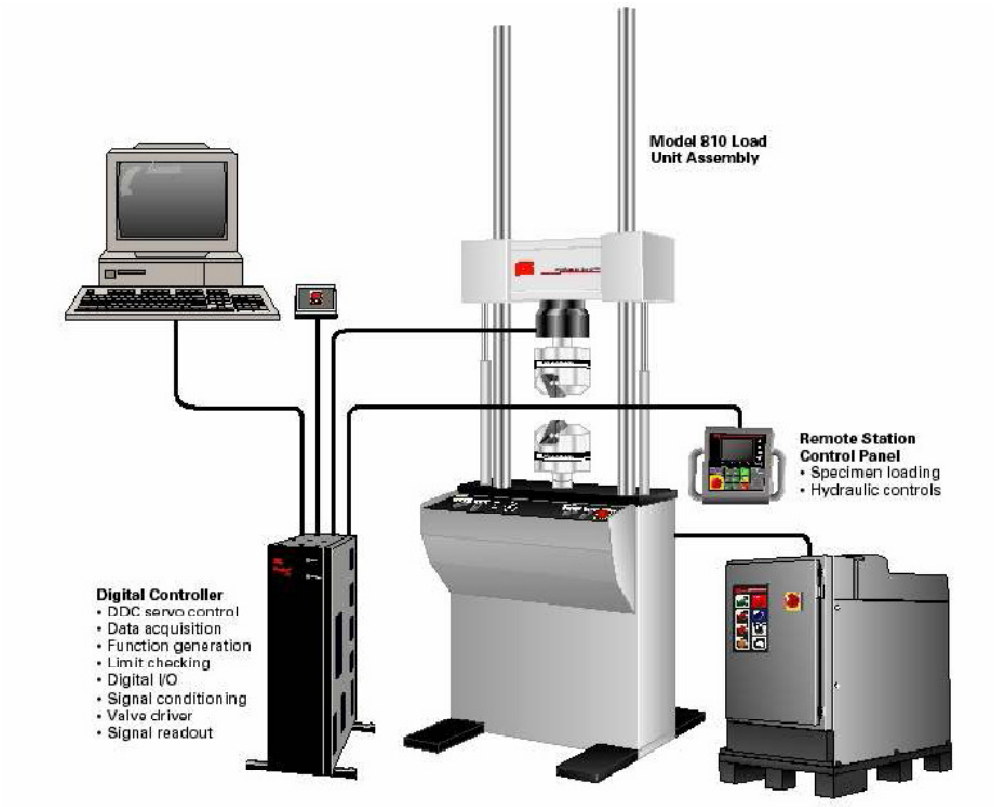


Figure 2.4, Overall components of the UTM (MTS 810 Material Testing System).

The system provides a broad range of test enhancing features including:

- Forces range from 25kN – 500kN.
- The ability to test lower strength materials ranging from plastic to aluminium composites and steel.
- Accommodation of sub size to standard specimen.
- A large test space to accommodate standard, medium and large size specimens, grips, fixtures and environmental subsystem, refer to figure 2.5.

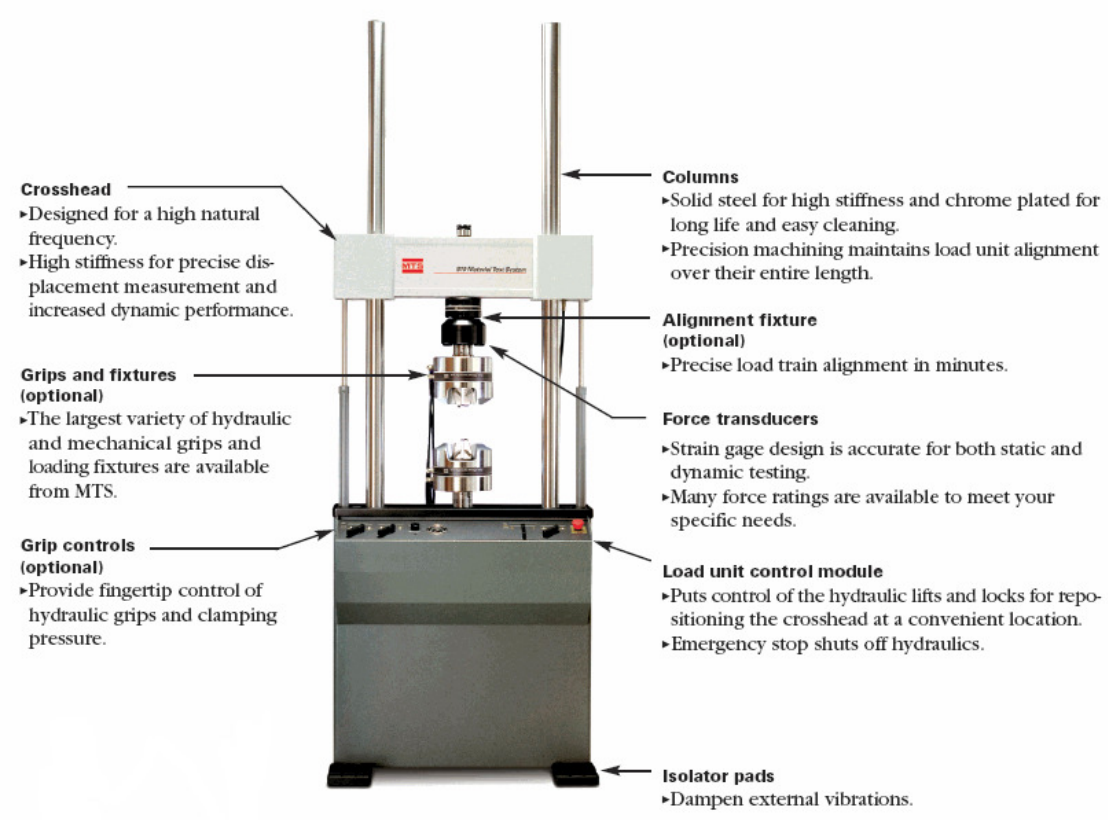


Figure 2.5 Testing panel for the Universal Testing Machine (MTS 810 Material Testing System)

- The capability to perform a wide variety of test types from tensile to high cycle fatigue, fracture mechanics, and durability of components

For fracture testing the MTS system provides the following:

Most complete Linear Elastic and Elastic-Plastic Fracture Toughness solutions. In addition to KIc, J-Integral, and CTOD fracture criteria software, MTS provides Fatigue Crack Propagation solutions. MTS Fracture Mechanics Application software improves the accuracy of your testing while still being easy and flexible to use. Predefined test templates provide the capability of testing to various ASTM, ISO and British test standards. Run-time graphical displays allow for monitoring the testsnin progress and in order to react to events as they occur.

Safety Precautions

Using of PPE like pair of closed or safety footwear at all times, making sure that long sleeve shirts do not stuck in any of the movable part on the testing machine, also it is essential to wear eye protecting glasses.

2.6.2 Conventional Oven

There are ranges sizes and shape of Conventional oven that are available with their specific users. This is the equipment that was used in this study for the post curing process, most past research on phenolic resins conventional oven are used to post cure specimen. Using of conventional oven seems to be found effective in the past, it improves the cross linking process of the resins, and decrease in the negative effect of the polymerisation shrinkage and increase in the hardness and wear resistance of the material [19] and it has been adopted for several years now. An advantage of using convention oven is that heating will be constant and even throughout the entire space. As it heat increase over number of hours less damage is likely afflicted upon the specimen. The conventional oven used in the study is shown in figure 2.6.

Figure 2.6. Conventional oven used for the study

The conventional oven used for the study was designed and manufactured by Watson Victor LTD (Australia) and the temperature capacity ranges from 100^0C – 300^0C and the thermostat readings from 0^0C – 100^0C. The inside walls are made of stainless steel and has compartment for shelves, which can be adjusted according to which sizes required. Figure 2.7 shows the inside view of the conventional oven used for this study.

Figure 2.7 the inside compartment of the conventional oven

The temperatures reading are taken from the thermometer depicted in figure2.8 the orientation of the thermometer inside the oven and in figure 2.9 the orientation of the thermometer outside the oven.

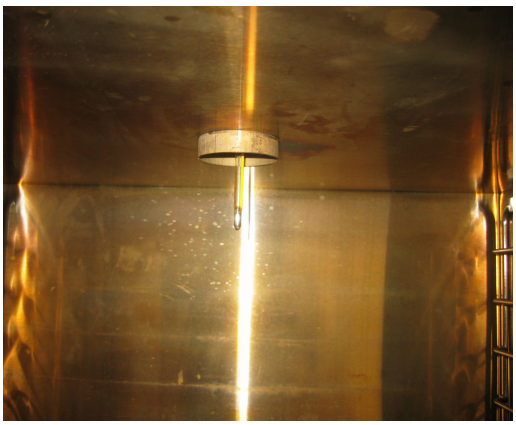


Figure 2.8 Thermometer inside the Oven

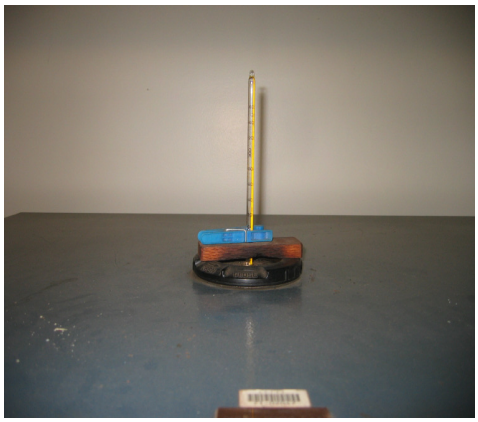


Figure 2.9 Thermometer outside the oven

The temperature readings are adjusted to the required temperature by using the controls located at the bottom frame of the oven's door, figure 2.10.

Figure 2.10 Conventional Oven controls

2.6.3 Brookfield RDVD-II+ Viscosity Testing Machine

The resistance to flow in the fluid can be characterised in terms of the viscosity of the fluid. In this study the constituents are made resin catalyst and saw dust by varying ht e percentages of saw dust, as the percentage of saw dust increase it will tend to dominate the percentage of the mixtures thus creating a more viscosity in the mixtures. To determine as to what percentage this will occur the Brookfield RDVD-II+ Viscosity Testing Machine will be used. Figure2.11 depicts the viscosity machine used in this study.

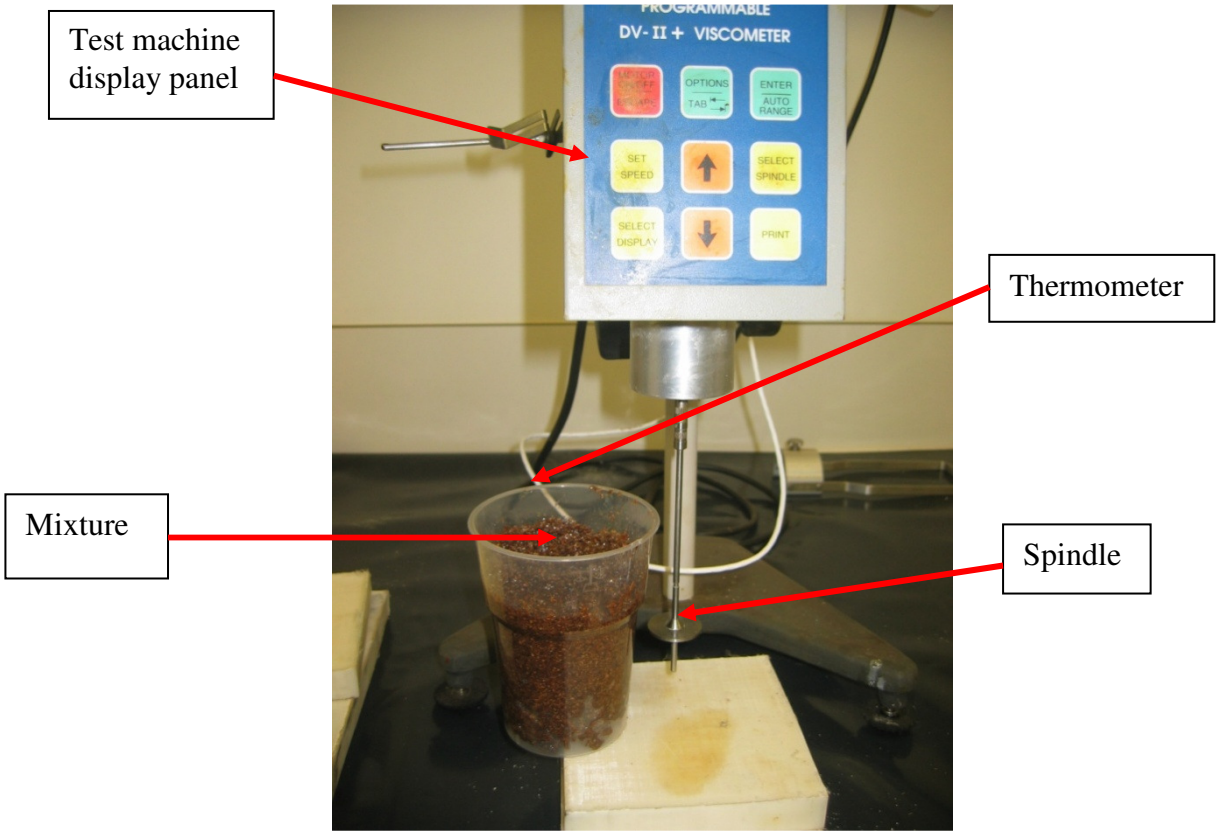


Figure 2.11 Brookfield RDVD-II+ Viscosity Testing Machine

Different machine spindles are used at certain percentages of the mixture. Large spindles used for non-viscous liquids while the smaller spindles used for very viscous liquids figure 2.12

Figure 2.12 Spindles

The effect of the viscosity of the mixtures can have effect on the fractural strength of the composite but the study is not included in this research. The objective for this part of the study was to obtain the percentage at the mixtures has the highest viscosity.

2.6.4 Mechanical Shiver

This equipment is used mainly for extracting required grain sizes of material from a mixture of different sizes. In this study this piece of equipment will b used to extract the different grain sizes of saw dust

Figure 2.13 Mechanical Shiver used in this study

The three different sizes of grains that will be sorted form this equipment are 300 μm, 425 μm and 1.18mm and how to operate just simply filling the sieve with saw dust and slowly shake it to allow the requires grain sizes to fall into a clean container underneath the sieve.

Chapter 3

Fracture Mechanics

3.1 Introduction to Fracture Mechanics

Fracture mechanics is a phenomenon the mostly deals with a behaviour at which a material exhibits crack or small flaws. These small cracks or flaws are believed to be resulted in the characteristics of the material such as small pores or micro cracks. The area of investigation is to find out the maximum stress a material can withstand while it poses this flaws [5].

It is very important to know the ability of the materials we used especially in engineering. The awareness of understanding of material started back in the 1900's since the world war two. Also it has established that lack of understanding the material used has caused death on occasions where building and bridges structures collapsed, also it brings about economic losses, fig 3.1 shows a major failure in bridge structure, may be initiated by flaw and it propagates causing drastic failure as such.

Figure 3.1 Motor Way Bridge in America collapsed (source BBC News)

However such incident have forced engineers and scientists into further research and analysis in order to come up with solutions that will do away with the problem. One of the area they study on is the mechanics of fracture as this is also one of the mode of failure that happens can possibly happen on structures, beams, shafts etc.

3.2 Fracture Toughness

When a material is able to withstand an applied load and on the same time the material posses some sorts of flaws. A typical toughness test can be conducted by applying tensile stress to a specimen with known size and geometry figure 3.2 . The stress applied to the specimen is intensified at the flaw, which acts as a stress raiser, figure 3.2 (b).

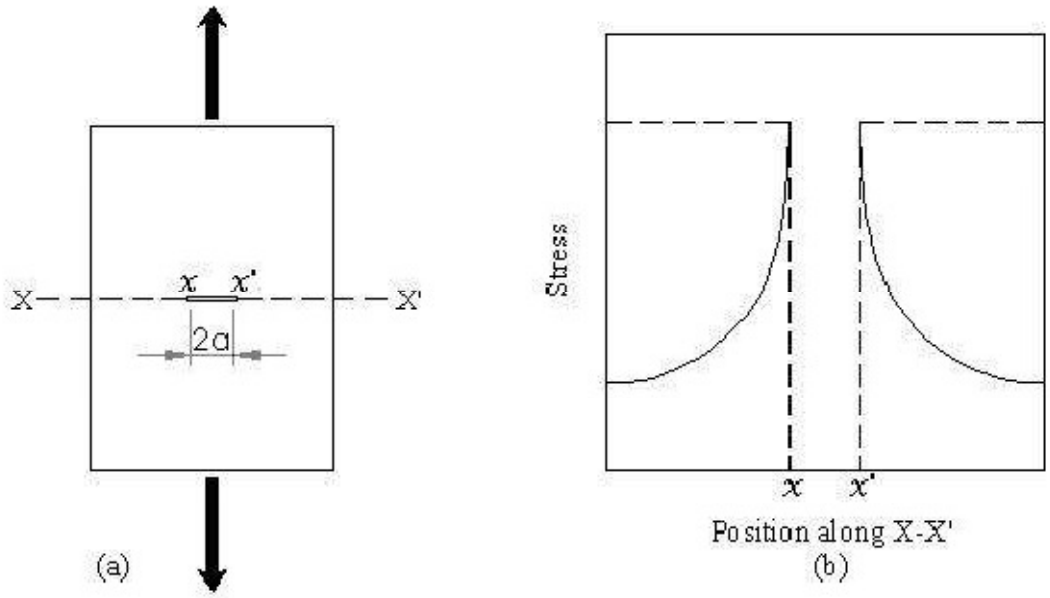


Figure 3.2 The geometry of a typical fracture toughness test with an internal crack. (b) Schematic stress profile along the line X-X' in (a), demonstrating stress amplification at crack or flaw tips. [8] 2003, page 188

[8] 2003.equation 6.18 determines that the equation for the *intensity factor, K,*

$$K = f\sigma\sqrt{\pi a} \qquad (3.2)$$

Where:

f - Geometry factor for the specimen and flaw (see figure 3.3).

σ - The applied stress

a - The flaw size

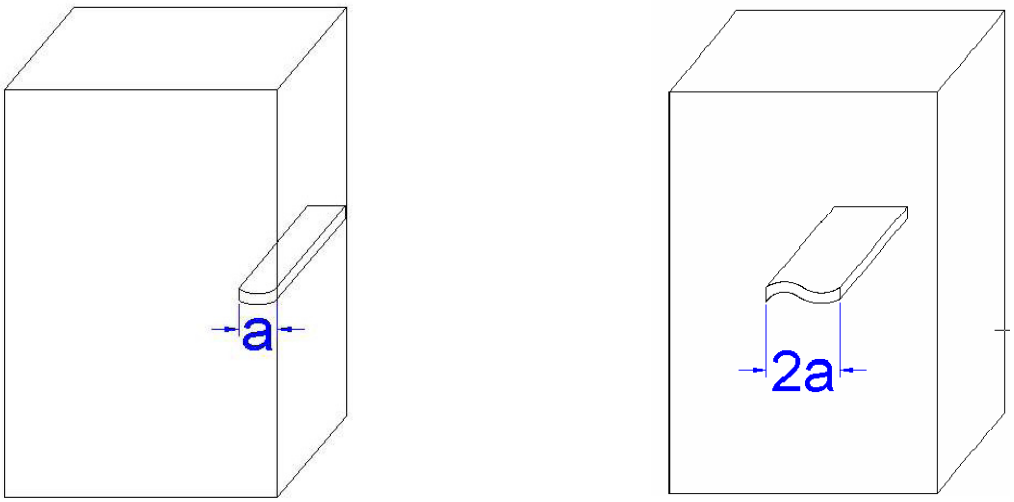
If the specimen is assumed to have 'infinite' width then:

$f \cong 1.0$

For 'semi-infinite' width,

$f \cong 1.1$ [7, 8]

The critical stress intensity factor is defined as fracture toughness, K_C is the K required for a crack to propagate. K_C is a property that measures a material's resistance to brittle fracture when crack is present and its unit is MPa$\sqrt{m}$. The value K_C for this thick specimen situation is known as the plane strain fracture toughness K_{IC}, furthermore, it is define by Munz, D. [6]



(a) (b)

Figure3.3 Schematic drawing of fracture toughness specimens with (a) edge (b) internal flaws [20].

Fracture toughness is dependent on the thickness of the sample. As thickness increases, fracture toughness K_c decreases to a constant value where only a condition of plain strain exists, figure 3.4 This constant is called the plane strain fracture toughness, K_C because K_C does not depend upon the thickness of the sample it is therefore the most commonly reported fracture property of the material

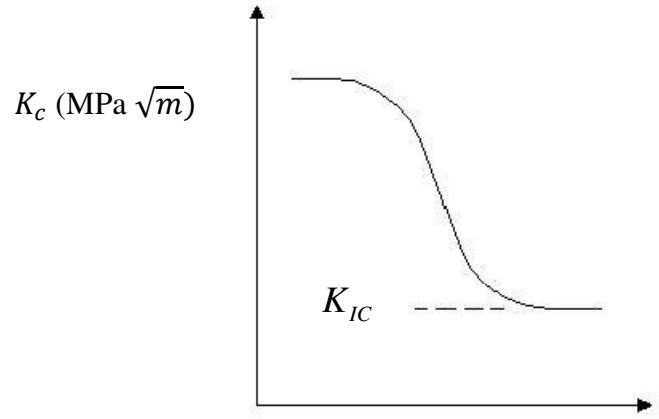


Figure 3.4 The fracture toughnessK_C, decreases with increasing thickness, eventually levelling off the plane strain fracture toughness K_{IC}

To explain this further let us look at some of the common engineering material and compare their respective fracture toughness and the units are in $MPa\sqrt{m}$

Material	**Yield Strength (MPa)**	$\boldsymbol{K_{IC}}$ $\boldsymbol{(MPa\sqrt{m})}$
	Metals	
Aluminium Alloy		36 - 50
Alloy Steel		50 - 90
Titanium Alloy		44 - 66
	Ceramics	
Aluminium Oxide		3.0 – 5.3
Soda-lime Glass		0.7 – 0.8
Concrete		0.2 – 1.4
	Polymers	
Polymethyl methacrylate		1.0
Polystyrene		0.8 – 1.1

Table3.1 The plane strain fracture toughness K_{IC} of common engineering materials

From table 3.3 we can see that ductile material such as Aluminium alloy has high value of K_{IC} while the Ceramics and the Polymers have lower K_{IC} values and also we can say that they are brittle materials. So these sorts of material can have catastrophic failure.

These are some factors that a material can be able to resist the growth of a crack [20]:

- The ability of a material to deform is critical. In ductile materials, the material near the tip of the flaw can deform, causing the tip of any crack to become blunt, reducing the stress intensity factor, and preventing growth of the crack.

Increasing the strength of a given metal usually decreases the ductility and gives lower fracture toughness. Brittle materials such as ceramics and many polymers have much lower fracture toughness than metals.

- In certain ceramic materials we can also take advantage of stress-induced transformations that lead to compressive stresses that cause increased fracture toughness.
- A small grain size normally improves fracture toughness, whereas more point defects and dislocations reduce fracture toughness. Thus, a fine-grained ceramic material may provide improved resistance to crack growth.
- Increasing the temperature normally increases the fracture toughness, just as in the impact test.
- Increasing the rate of application of the load, such as in an impact test, typically reduces the fracture toughness of the material.
- Thicker, more rigid pieces of a given material have a lower fracture toughness than thin materials.
- Larger flaws reduce the permitted stress. Therefore a reduced flaw size will mean improved fracture toughness.

3.3 Importance of Fracture Mechanics

In selecting what material for design there is an essential criterion to include the fracture mechanics approach, as it will enable the designer to incorporate aspects such as flaws that can be present in the material. As a designer these three important variables that must be considered, the K_{IC} or K_C and σ apart from the others like the moment of inertia when selecting which material to use. Askeland [5] stated that if any two of these factors (K_{IC} , K_C , σ) are known the third factor can be determined.

3.3.1 Selection of Material

In order to select the material requires for a task during preliminary stages of designing firstly the maximum size of flaws, a, in the material and the magnitude of the applied stress σ must be known, corresponding values of K_C or K_{CI} can be selected from tables to prevent flaws form propagating, equation 3.2 can be used to calculate the fracture toughness of the material Askeland [5].

3.3.2 Design of a component

In order to design a component, given the material and its fracture toughness and the flaw size, the maximum or critical stress that the component can withstand can be calculated by rearranging equation (3.2) to give:

$$\sigma_c \leq \frac{K_{IC}}{f\sqrt{\pi a}} \qquad (3.3.1)$$

[5] suggest that with equation (3.3) the appropriate size design of a component can be possible by ensuring that the maximum stress not to be exceeded.

3.3.3 Design of a Testing Method

Materials needed for testing must be manufactured according to the standards size of specimen that particular testing required wether it is tensile testing, fracture testing Brinell hardness testing or whatever tests. Including the magnitude of force that particular specimen will be subjected to.

For fracture toughness testing there is a standard size of the specimen and from this the geometrical orientation should be known including the magnitude of the applied stress that will be applied once this information are known by rearranging equation (3.2) the flaw size will be obtained

$$a_c = \frac{1}{\pi}\left(\frac{K_{IC}}{\sigma f}\right)^2 \qquad (3.3.2)$$

Flaws can also be detected in a material by using non-destructive testing. When any flaw size detected by this technique which is greater than the critical size appropriate fractural tests needed to be performed. Askeland [5] Suggests that a suitable manufacturing process can assist in ensuring flaw sizes are below this critical sizes.

3.4 Theories of Fracture

Griffith [21] Conducted the first successful brittle fracture analysis on glass, in which he concluded that an existing crack would propagate if the systems total energy was lowered, assuming a simple energy balance was present. The energy was

balanced by a decrease in elastic strain energy within the stressed component as the crack propagated and the increase in energy required to create a new crack. [21] Theory estimated the theoretical strength of brittle materials and offered a relationship between fracture strength and defect size.

Fracture mechanics today has two major theories which tend to give similar results.

1. Assumes that materials lose plasticity at lowered temperature.
2. Analytical approach derived from the stresses and plastic zones at the tip of the crack.

The two different approaches are outline in the following sections.

3.5 Transitional Temperature Approach

The assumption of this approach claimed that all materials will become brittle below a certain temperature. This happens when at lower temperatures the plastic deformation of the material is being restricted; simultaneously the material cannot hold stresses which supposed to be contained during plastic deformation resulting in cracks begin to propagate within the material at lower stresses.

Figure 3.5 shows this transitional temperature theory which shows materials need less fracture energy for failure at lower temperatures which indicate that the material is brittle. The ductility of the material shows high fracture energy

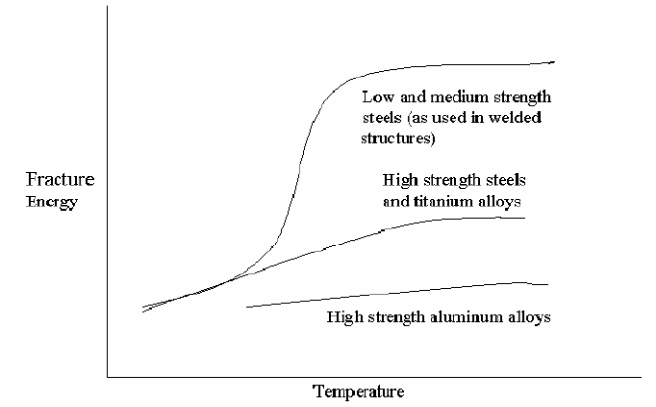


Figure 3.5 Materials exhibiting both ductile and brittle behaviour at different temperatures

3.6 Analytical Approach

This approach focuses mainly on the stresses that occur near the crack tip. The relationship between the change in potential and surface energy of the material and the stresses gives rise to an analytical method of calculating the stress present; assuming the stress distribution around the crack tip is constant.

Linear Elastic Fracture Mechanics (LEFM) was developed as a result of this approach. LEMF can, however, only predict material behaviour if the crack tip remains mostly elastic. For brittle materials, it accurately establishes the criteria for catastrophic failure.

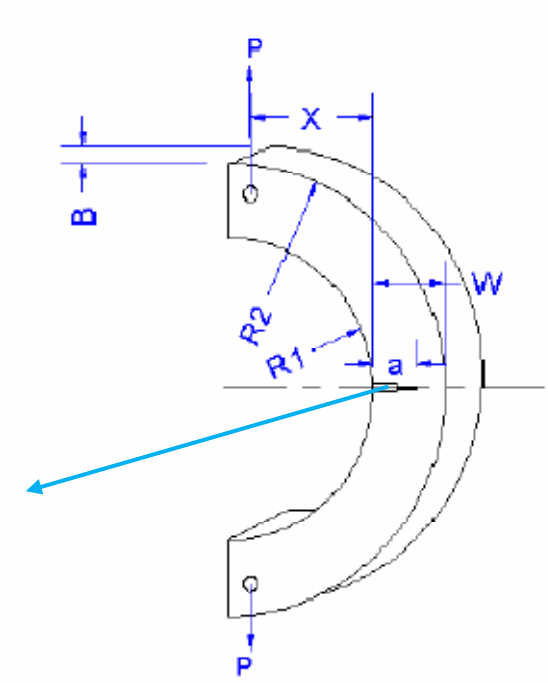
The disadvantage of this approach is when large regions of the material are subject to plastic deformation before a crack propagates. Elastic Plastic Fracture Mechanics (EPFM) is another approach can analyse mixed mode behaviour and large plastic zones. The equations involved are past the scope required in this discussion, only an understanding of the various methods is necessary.

3.7 Standard Tests

There are various types and tests developed to evaluate the fracture toughness of various materials, various organisations have establish procedures and they have set standards internationally so that recent or past research and studies can be easily further researched. Groups like the American Standards (ASTM E399) and British Standards (BS: 5447) are some of the well known standard organisations that deals mostly with this particular testings (fracture toughness tests). Further in the subsections of this report standard test are outlined. Also there are some tests that are regarded as non standard.

3.7.1 C-Shape Section test specimen

This testing practically applies to test the fracture toughness of a cylindrical pipe where a small notch is at the centre as shown in fig 3.7 (a)



WHERE

P – Force

B – Breadth of the specimen

X – dist from the point of load to the notch

a – length of the notch

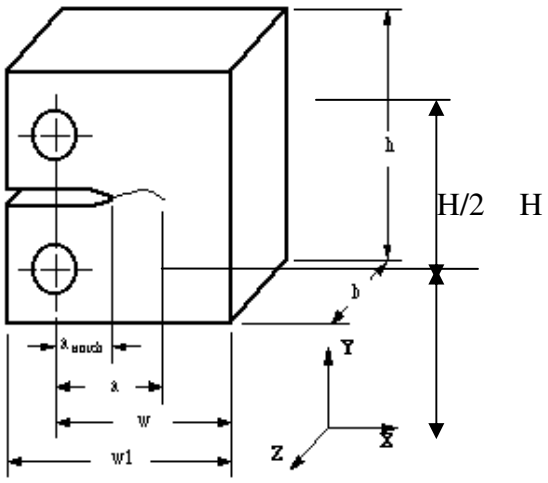
W – Thickness of the specimen

Figure 3.6 C- shape specimen fracture toughness test specimen

The fatigue loads are applied on the ends (point P) by means of two point bend testing.

3.7.2 Compact Tensile Specimen

Compact tensile Test specimen fracture toughness a thin plate figure 3.7 with the notch at the middle of the thin plate.



WHERE

W1 = 1.25W

H/2 = 0.6W

b = 0.5W

λ = 0.45 – 0.55W

D = 0.25W

Figure 3.7 Compact Tensile Specimen fracture toughness geometry

3.7.3 Single Edge Notch Bend (SENB)

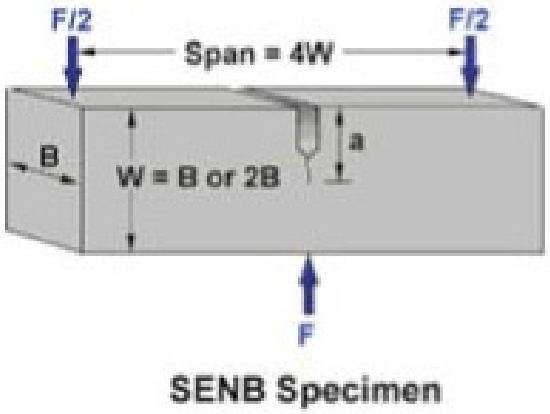


Figure 3.8 Single edge notch bend test geometry

The single edge notch bend specimen geometry figure 3.8, the specimen normally tested using the three point bending test the specimen is machined to the standard size including a notch at the centre of the specimen. Crack start to propagate as the cyclic load is being applied at each end of the specimen.

3.8 Non – Standard Test

Comparing the standard testing and the non standard testing in terms of costs the standard testing is expensive and the specimen preparation is very difficult to manufacture due to its complicated geometry. Therefore non standard testing are

normally used due to the cost and it is simple to manufacture, Mechanical properties of the materials are normally analysed and fracture toughness value can be obtained through mathematical models.

3.8.1 Charpy V-notched Impact Test

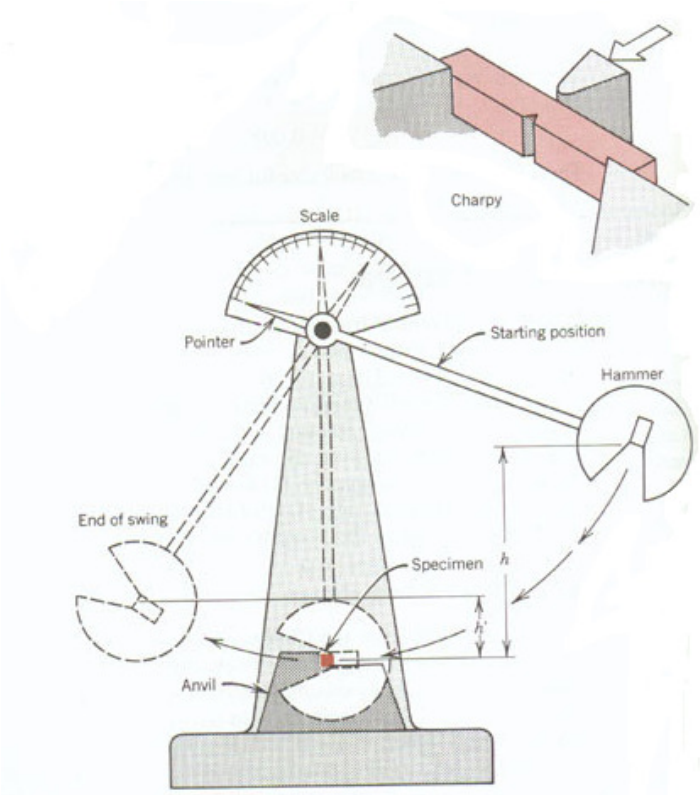


Figure 3.9 Charpy V-notch impact test (source: www.sv.vt.edu/.../anal/yue/img00007.jpg)

The Charpy V-notch specimen and the test equipment is shown in figure 3. 9 the specimen size is a square bar of 10mm x10mm 55mm in length with a small notch to initiate crack at the middle of the specimen. The hammer is elevated to a certain height and recorded by the scale and is released with the hammer's momentum hits strike and break the specimen swing further up to where it stops and the reading taken from the scale at the position it stops. For fracture toughness value equation (3.7) is used.

$$K_{CI^2} = 2 \times E \times CVN^{3/2} \qquad (3.7)$$

Where: E = is the Modulus of Elasticity of the material in Pascals, (Pa).

CVN = is the Charpy V- Notch test result in Joules (J

3.8.2 Short Rod/Short Bar Test

A simple method to obtain the fracture toughness of the material was created by Baker [4] which is applicable to wide range of materials. The method uses rod a bar specimens, figure 3.7.

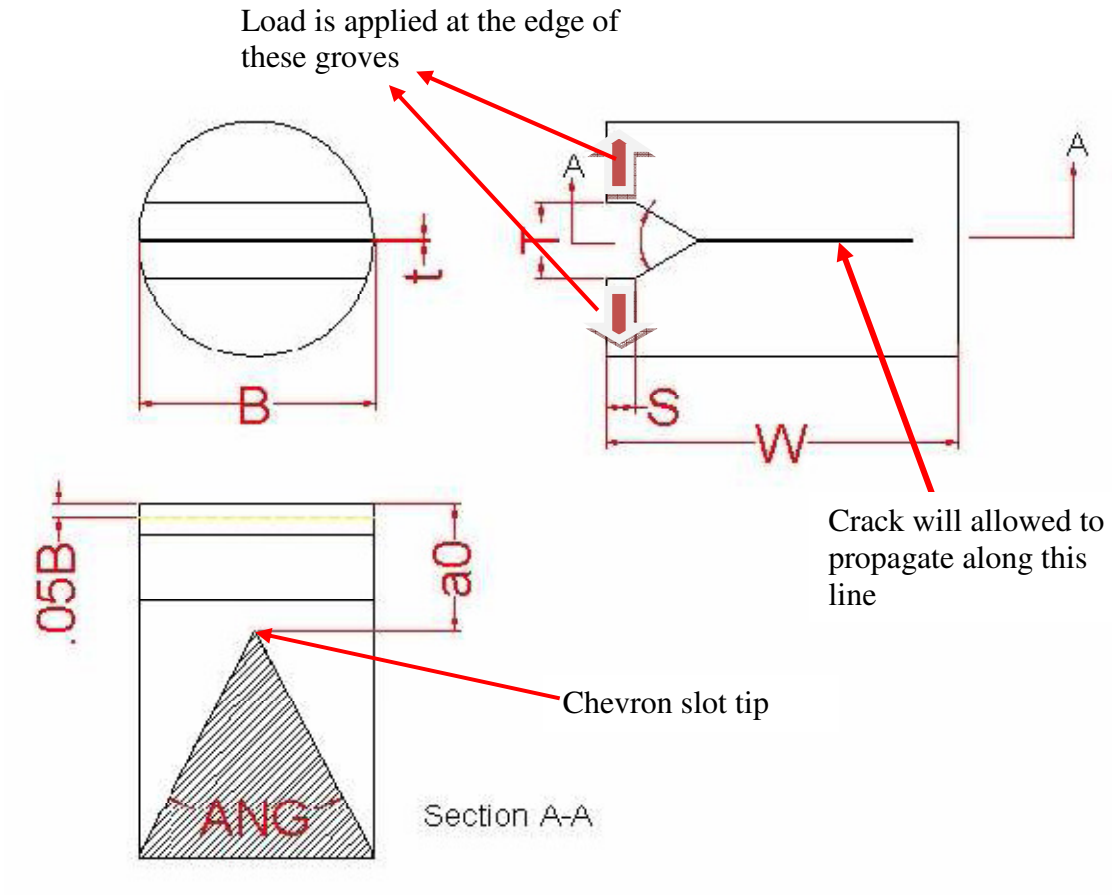


Figure 3.10 Short Rod Fracture Toughness Specimen

As indicated by the arrows in figure 3.10 the position at which the load is being applied to the specimen. The load will cause fracture which it will initiate at a point called the chevron slot tip. The fracture or crack will be allowed to propagate through the specimen and fracture toughness analysis will be taken using the measured load to calculate the strain fracture toughness as measured by the chevron – notched chart short rod method K_{ICSR}.

Here are some of the advantages of short bar methods

- It is applicable to a wide variety of materials.
- Cheaper to test
- Cheaper to create
- Smaller specimen sizes can be created, and

- Reduced sample size

Also this type of fracture toughness test procedures is simple compared to the other fracture toughness method because it does not have to undergo fatigue pre-cracking stages due to the chevron slot.

Chapter 4

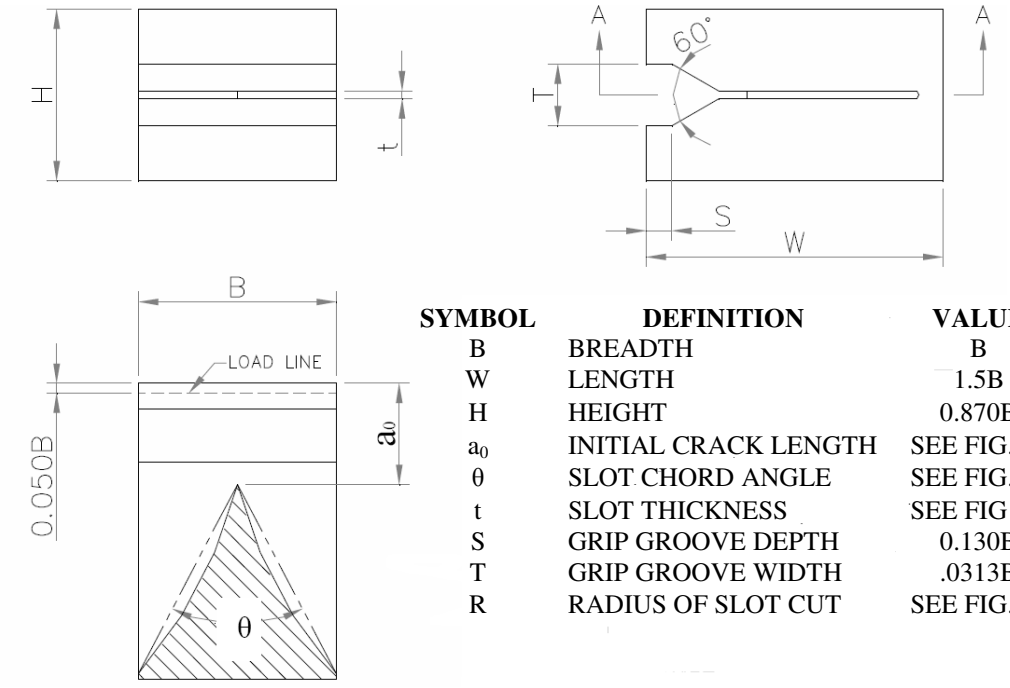
Short Rod and Short Bar Testing Methods

The short rod and short bar are test specimens that have circular and rectangular cross-section respectively initially it was discovered by Baker [4], as it was cheaper way to measure fracture toughness of metallic materials in terms of their plain –strain stress intensity factor. Earlier and recent experiments in calculating fracture toughness have found out the short rod/bar specimens have been applicable in most wide ranges of materials such as ceramics, metals , polymers and rocks Baker [4]. The short bar and short rod testing specimens have also proven that it produces valid and accurate measurement on smaller specimen than other tests for plain-strain fracture toughness of metallic materials. Thus increase usage and created a considerable interest in the short bar geometry to evaluate the impact properties of range of materials.

The different geometry in the short bar specimens have proven by experiments that they produce a similar results despite of the different geometrical orientation .Which means that statements about short bar specimen are generally applicable to short rod and vice versa ,Barker[4] .

The short bar and rod geometry developed by Barker [4] can be seen in figure 4.1 below

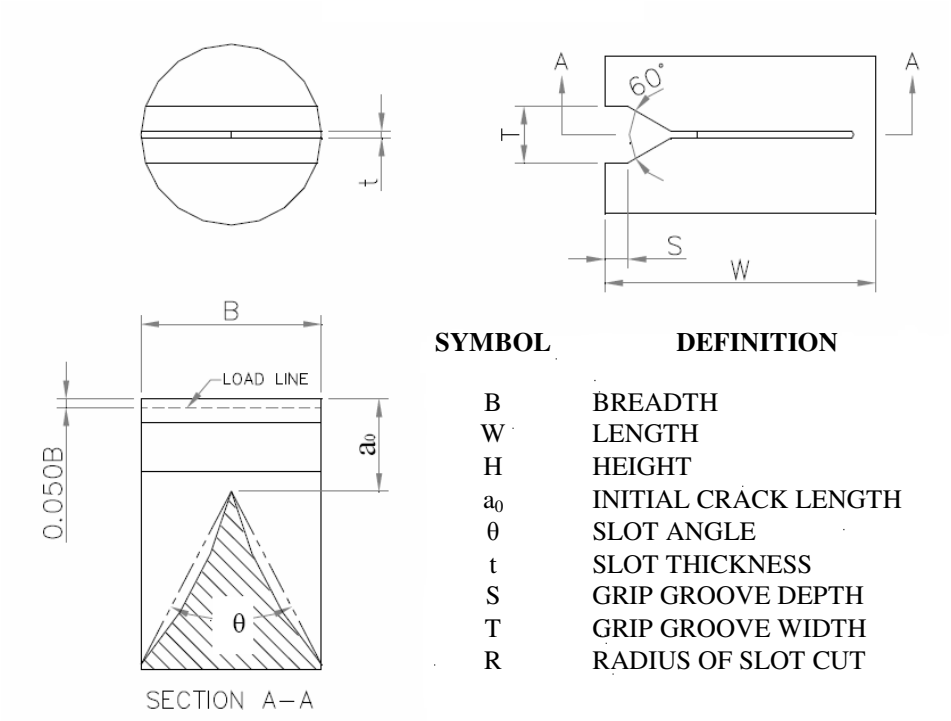
SHORT BAR (a)



SYMBOL	DEFINITION	VALUE	TOLERANCE
B	BREADTH	B	
W	LENGTH	1.5B	±0.010B
H	HEIGHT	0.870B	±0.005B
a_0	INITIAL CRACK LENGTH	SEE FIG.4.3	±0.005B
θ	SLOT CHORD ANGLE	SEE FIG.4.3	$\pm 1/2^0$
t	SLOT THICKNESS	SEE FIG 4.4	-
S	GRIP GROOVE DEPTH	0.130B	±
T	GRIP GROOVE WIDTH	.0313B	±
R	RADIUS OF SLOT CUT	SEE FIG.4.3	$\pm 2.5B$

SECTION A - A

Short Bar (b)



SYMBOL	DEFINITION	VALUE	TOLERANCE
B	BREADTH	B	
W	LENGTH	1.5B	±0.010B
H	HEIGHT	0.870B	±0.005B
a_0	INITIAL CRACK LENGTH	SEE FIG.4.3	±0.005B
θ	SLOT ANGLE	SEE FIG.4.3	$\pm 1/2^0$
t	SLOT THICKNESS	SEE FIG.4.4	-
S	GRIP GROOVE DEPTH	0.130B	±0.010B
T	GRIP GROOVE WIDTH	.0313B	±0.005B
R	RADIUS OF SLOT CUT	SEE FIG.4.3	$\pm 2.5B$

Figure 4.1: Short bar (a) and short rod (b) specimens with curved chevron slots the LOAD line is the line along which the opening load is applied in the mouth of the specimens Barker [4].

4.1 Short Rod / Short Bar Geometry

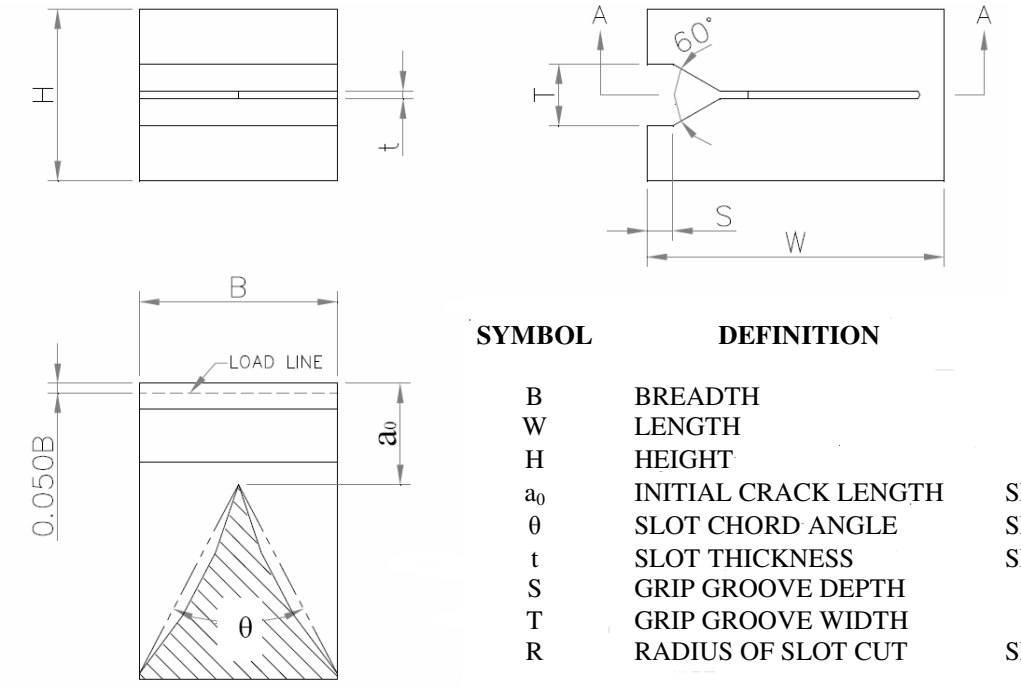
4.1.1 Development of Short Bar Geometry

The dimensional relationships were selected on the basis of a large number of tests of specimens with different length-to-diameter ratios and various chevron slot geometries. From these tests the short bar specimen geometry configurations were selected as a reasonable compromise in an attempt for an optimum geometry (Barker [4]).The optimum geometries are pictured in Figures 4.1 and 4.2. The criteria on which this geometry was created is as follows (Barker [4]);

- The tendency for the crack to "pop in" at initiation should be reduced; the crack initiation should be as smooth as possible.
- The crack should be well guided by the chevron slot.
- The width of the crack front should be an appreciable proportion of the specimen diameter at the time of the fracture toughness measurement.
- The crack should be near the centre of the specimen at the time of the fracture toughness measurement.
- The load should be at or near its peak value at the time of the toughness measurement.
- The specimen geometry should be as simple as possible for ease of specimen fabrication.
- The specimen should be economical in its use of sample material.

The short rod/short bar geometry for curved chevron slots is shown in Figure 4.2.

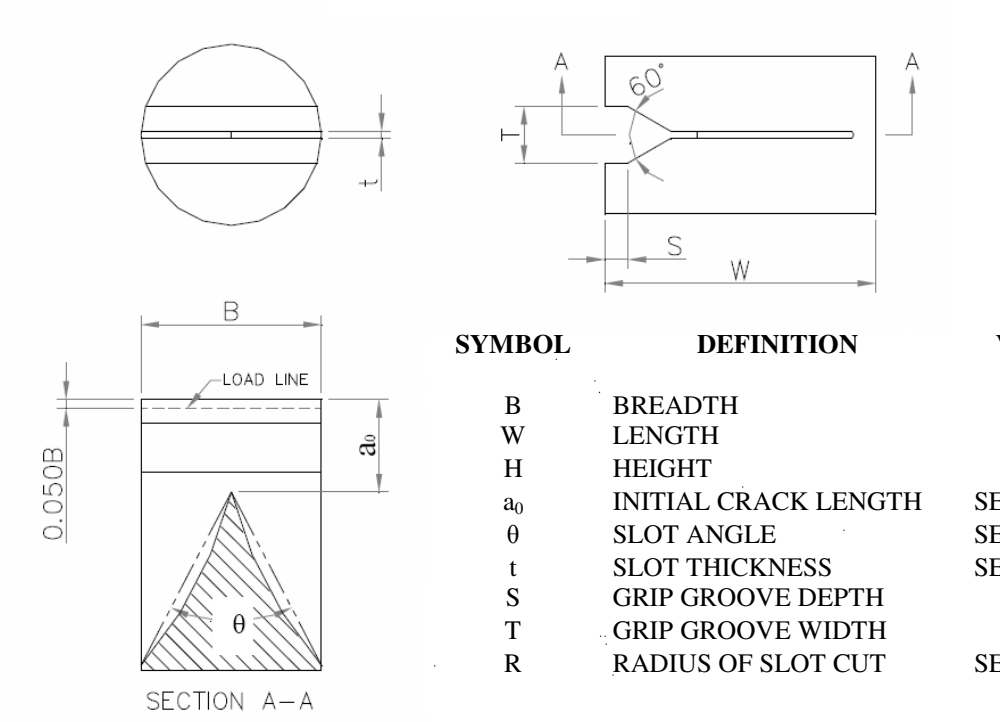
SHORT BAR (a)



SECTION A - A

SYMBOL	DEFINITION	VALUE	TOLERANCE
B	BREADTH	B	
W	LENGTH	1.5B	±0.010B
H	HEIGHT	0.870B	±0.005B
a_0	INITIAL CRACK LENGTH	SEE FIG.4.3	±0.005B
θ	SLOT CHORD ANGLE	SEE FIG.4.3	$\pm 1/2^0$
t	SLOT THICKNESS	SEE FIG 4.4	-
S	GRIP GROOVE DEPTH	0.130B	±
T	GRIP GROOVE WIDTH	.0313B	±
R	RADIUS OF SLOT CUT	SEE FIG.4.3	$\pm 2.5B$

SHORT ROD (b)



SECTION A–A

SYMBOL	DEFINITION	VALUE	TOLERANCE
B	BREADTH	B	
W	LENGTH	1.5B	±0.010B
H	HEIGHT	0.870B	±0.005B
a_0	INITIAL CRACK LENGTH	SEE FIG.4.3	±0.005B
θ	SLOT ANGLE	SEE FIG.4.3	$\pm 1/2^0$
t	SLOT THICKNESS	SEE FIG.4.4	-
S	GRIP GROOVE DEPTH	0.130B	±0.010B
T	GRIP GROOVE WIDTH	.0313B	±0.005B
R	RADIUS OF SLOT CUT	SEE FIG.4.3	$\pm 2.5B$

Figure 4.2: Short bar (a) and short rod (b) specimens with curved chevron slots the LOAD line is the line along which the opening load is applied in the mouth of the specimens Barker [4].

4.1.2 Specimen Geometry option

Four basic geometries are revealed in Figure 4.1 and 4.2, all of which give accurate results of fracture toughness. The specimen size parameter, B, is the specimen diameter (short rod) or the specimen breadth (short bar) shown in the respective tables of Figures 4.1 and 4.2. These Figures show two different chevron slot geometries, straight or curved, as a result of the different methods of machining or creating the chevron slot. Figure 4.1 (a) and (b) show the short bar and short rod geometries, respectively, for straight chevron slots. Straight chevron slots are created by feeding a saw or cutter through the specimen or by placing a thin piece of material cut to size n into the mould before pouring. Figure 4.2 (a) and (b) show the short bar and short rod geometries, respectively, for curved chevron slots. Curved chevron slots are created from a plunge-type feed of a saw blade into the specimen. In Figures 4.1 and 4.2 it is noticeable that the section views (section A-A) of the rectangular short bars are identical with those of the circular short rods Barker [4]. By making the height of the short bar specimen 0.870B the short rod and bar geometries therefore have the same calibrations, this has been proven in experimental studies Barker [4].

Another desirable calibration is that between straight-slotted specimens, Figure 5.1, and curved-slotted specimens, Figure 4.2. This is done by superimposing the section views of the two different slot geometries, and then adjusting the slot configurations until the straight and curved slot bottoms are tangent to one another at the critical crack length, a_c , where the peak load occurs in an LEFM test, that is, where the fracture toughness measurement is made. Figure 4.3 shows the superimposed slot geometries tangent at a_c. This means that when the crack is near the position where the toughness measurement is taken, both slot geometries have essentially the same crackfront width, rate of change of crack-front width with crack length, and compliance derivative, which causes their calibrations to be effectively equivalent Barker [4].

Barker [4] has discovered that when machining the chevron slots in a curved slotted specimen, it is easier to measure the distance to the point of the chevron slot, a_o , and the slot chord angle, θ , than to measure the slots passing through the desired tangency point at the required angle. The values of a_o, and θ which produce the desired

tangency have been calculated as a function of saw blade diameter. This is plotted in Figure 4.4.Figure 4.3: Superimposed curved and straight chevron slots tangent at C a . Figure 4.4:

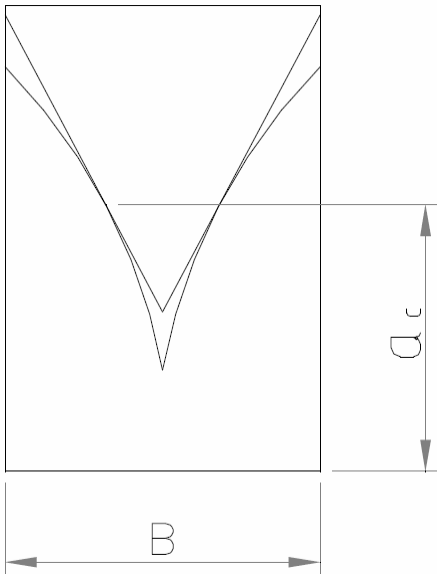


Figure 4.3 Superimposed curved and straight chevron slots tangent at a_c

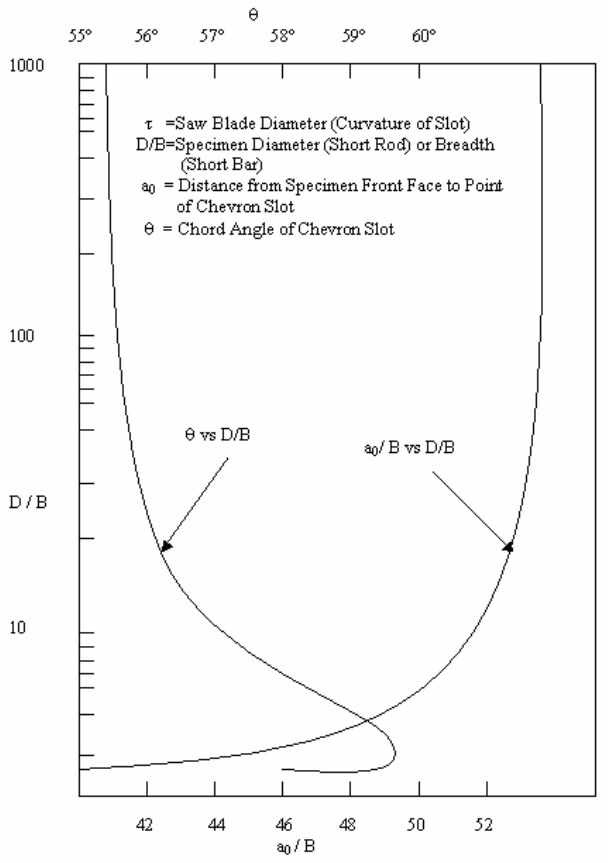


Figure 4.4 Chevron slot angle, θ, and initial crack length, a_o for curved chevron slots

Using a_o and, $\boldsymbol{\theta}$, derived from Figure 4.4 for the saw blade diameter, an effectively constant specimen calibration can be obtained, regardless of specimen size, when the crack is in the vicinity of the critical crack length, C, a_c ,Barker [4].

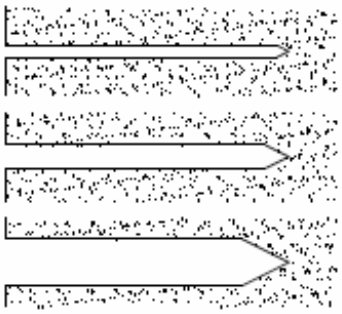
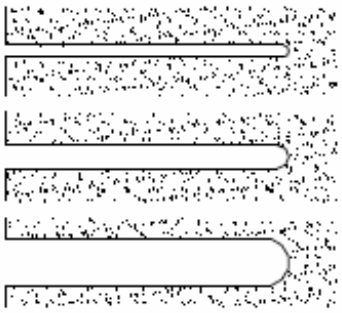
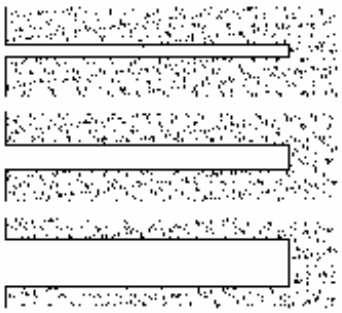
4.1.3 Specimen tolerance and Correction

The variation in a specimens calibration is a related to the parameters,a_o, $\boldsymbol{\theta}$, and W , when B is assumed to be constant. This variation should be measured to determine the allowable dimensional tolerances on the parameters in manufacturing specimens Barker [4]. Barker [4] conducted a sensitivity study on these parameters and it was found that the dimensional tolerances listed in the tables in Figure 4.1 and 4.2 were selected to ensure the effect of within-tolerance variations of any one parameter is within about ± 0.5 percent of the calculated fracture toughness Barker [4].

When the parameters,a_o, θ , and W , are out of tolerance the sensitivities of the test results to variations in parameters are well enough known to permit the application of a correction factor. Barker (1981, p. 463), Table 1, contains the equations used in the calculation of the configuration correction factor, C_c. This factor is multiplied by test results to correct inaccurate specimen geometries. By using the C_c factor, test results for specimens which are out of tolerance by up to three times the tolerances of the tables in Figures 4.1 and 4.2 can be corrected to within ±0.5 percent toughness uncertainty of nominal specimens Barker [4].

4.1.4 Chevron Slot Thickness and Sharpness

The thickness and sharpness of the bottom of the chevron slot can have a major effect on the fracture toughness result. Properly designed slots can greatly enhance the degree of plain-strain along the crack front. Better slot geometries lead to a smaller plain-stress or plastic zone in comparison to the size of the specimen and therefore an enhanced plain-strain region Barker [4]. Controlling the plain-strain constrain with the slot geometries means that a range of materials can be tested accurately from very tough, brittle low yield materials, to high yield ductile materials. Figure 4.5 is the result of a study into the chevron slot geometries and depicts the best slot configurations.

SLOT CONFIGURATION	SLOT THICKNESS (mm)	EFFECT ON SLOT CALIBRATION	PLAIN –STRAIN CONSTRAINT*
	0.38	0	Excellent
	0.8	−1%	Excellent
	1.6	−3%	Excellent
	0.38	0	Excellent
	0.8	−1%	Good
	1.6	−3%	Poor
	0.38	0	Good
	0.8	−1%	Poor
	1.6	−3%	Poor

* Excellent = less than +2% effect on the measurement
Good = less than +5% effect on the measurement
Poor = more than +5% effect on the measurement

Figure 4.5 Effects of chevron slot geometry (Barker [4])

4.2 Short Bar Fracture Toughness Test

Specimen geometry and preparation are important to obtain accurate fracture toughness results, but the testing procedure must also be controlled in order to obtain accurate testing data Barker [4]

In fracture toughness testing of short bar specimens a load is applied to the mouth of the specimen to initiate crack growth at the point of the chevron slot. In an ideal test the load to initiate crack growth is smaller than the load that is needed to further advance the crack. The test therefore requires an increasing load to be applied to the specimen until the crack length reaches its critical length, a_c . Figure 4.6 shows the load variation with crack length of an ideal test.

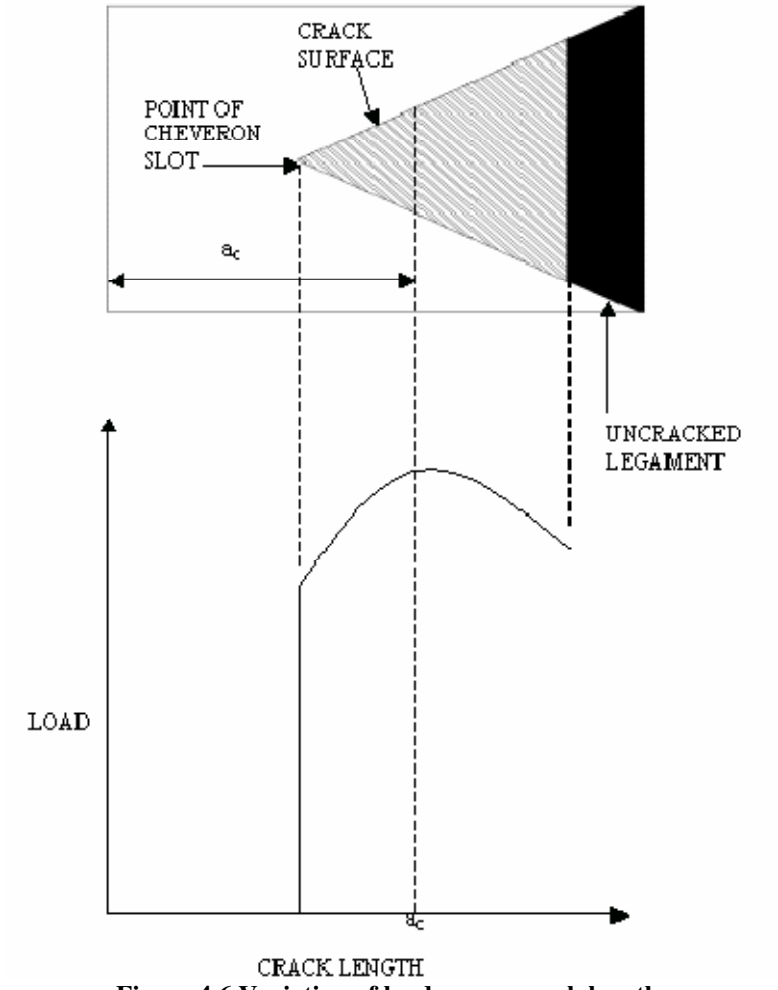


Figure 4.6 Variation of load versus crack length

Using linear elastic fracture mechanics principles (LEMF) the equation for fracture toughness in a short bar test specimen can be derived. The material plane strain critical stress intensity factor, F_{ICSB}, is given by the equation Munz [6]

$$K_{ICSB} = \frac{(F_{\max} Y_m^{\ *})}{B\sqrt{W}} \qquad (4.1)$$

Where $F_{\max}$ = Peak Load.

$Y_m^{\ *}$ = is the compliance calibration according to ASMT E – 399 – 78.

The compliance calibration, Y^*_m for the short bar test method from ASTM E-399-78 is given by:

$$Y_m^* = \{-0.36 + 5.48\omega + 0.08\omega^2 + (30.56 - 27.49\omega + 7.46\omega)\alpha_o)\} + (65.90 + 18.44\omega - 9.7\omega)\alpha_o^2\}\left\{\frac{a_1 - a_0}{1 - a_1}\right\}^{1/2} \qquad (4.2)$$

Where:

$$\omega = \frac{W}{H} \qquad (4.3)$$

$$\alpha_o = \frac{a_o}{W} \qquad (4.4)$$

$$\alpha_1 = \frac{a_1}{W} \qquad (4.5)$$

In the equations, above, *W, H*, a_o and a1 are the measured specimen dimensions in millimetres, shown in Figure 4.7.

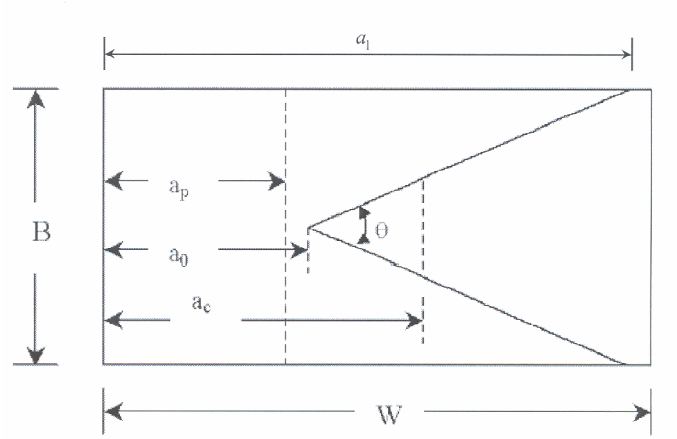


Figure 4.7 Cross-sectional dimension of short bar specimen showing a_1

After testing the specimens the measurements in Figure 4.7 need to be recorded for use with equations (4.3), (4.4) and (4.5). In this project these measurements can be seen tabulated in Appendix F, Table F.1

Chapter 5

Experiment Methodology

5.1 Saw Dust Preparation

Saw dust is composed of particles of wood. The material is produced from cutting with a saw, hence its name, a by-product of manufacturing timber. It has a variety of practical users, including fuel, manufacturing of the particle board, until the advent of refrigeration, it was often used in icehouses to keep ice frozen during the summer. In terms of hazards it is flammable when in contact with fire.

For the purpose of this project saw dust is being used to determine whether its characteristics will have an impact on the fracture toughness of the phenolic resins. Since the resins have a very high brittleness property thus having certain magnitude of fracture toughness. The issue of saw dust having impact on the brittleness of resin will be explained in the result. The sizes of saw dust grain sizes used in this project were 300 μm , 425 μm and 1.18mm,

A thorough preparation of saw dust is vital for this project, the saw dust collected from the mill were exposed to the atmosphere as there were no proper system of storing them, since it was exposed into the atmosphere, rain and other debris would have been mixed together with the saw dust.

Firstly it has to be dried thoroughly presence of moisture within the saw dust particle would cause a deteriorating results on the mechanical properties of the composites. After the saw dust is thoroughly dried then it has to be sieved into the required grain sizes using a mechanical shiver. Careful attention should also be taken while carrying

out this as there are possibilities of unwanted grain size mixed with the required size due to the method of extracting or sieving. A proper container should be used to keep the prepare saw dust and tightly closed and clearly labelled

5.2 Mould Preparation

Having selected the short bar test as the method of fracture toughness measurement the size of the specimen had to be determined as this would have a major effect on the mould material and construction properties. From the standard ISRM short bar geometry, Figure 4.1(a), a size of B = 50mm was selected**.** This size gives a practical specimen for testing because is easy to handle and also it reduces the cost of the testing as mould and composite materials are reduced. This step of the selection of geometry size was done in conjunction with the design and construction of the mould step that is described in section 5.2 because size, cost and material selection are all interconnected

5.2.1 Mould Cleaning

In this experiment the mould was made up of poly vinyl chloride (PVC) material with a thickness of 3mm. The mould was designed by previous researchers depicted in fig 5.1 which shows the main parts of the mould excluding the mould cover. The mould has to be thorough cleaned before use. Foreign material presence on the mould during casting will have an impact either on extracting the specimen from the mould or the mechanical properties of the specimen will be altered.

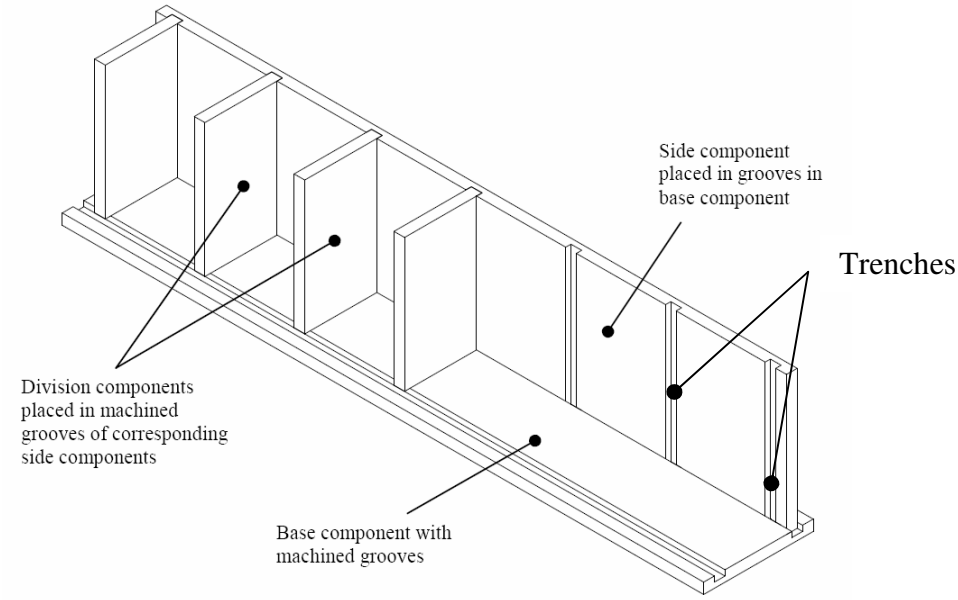


Figure 5.1 AutoCAD 2006 Isometric view of half assembled mould

The mould as can be seen on figure 5.1 has couple of trenches and this has to be cleaned thoroughly so that the component of the mould has to be fitted well into the trench before pouring of the composite mixture.

5.2.2 Mould cover Preparation

The mould cover consist of the chevron slot and the plastic notches that creates the grip for the groove as demonstrated in fig 5.2

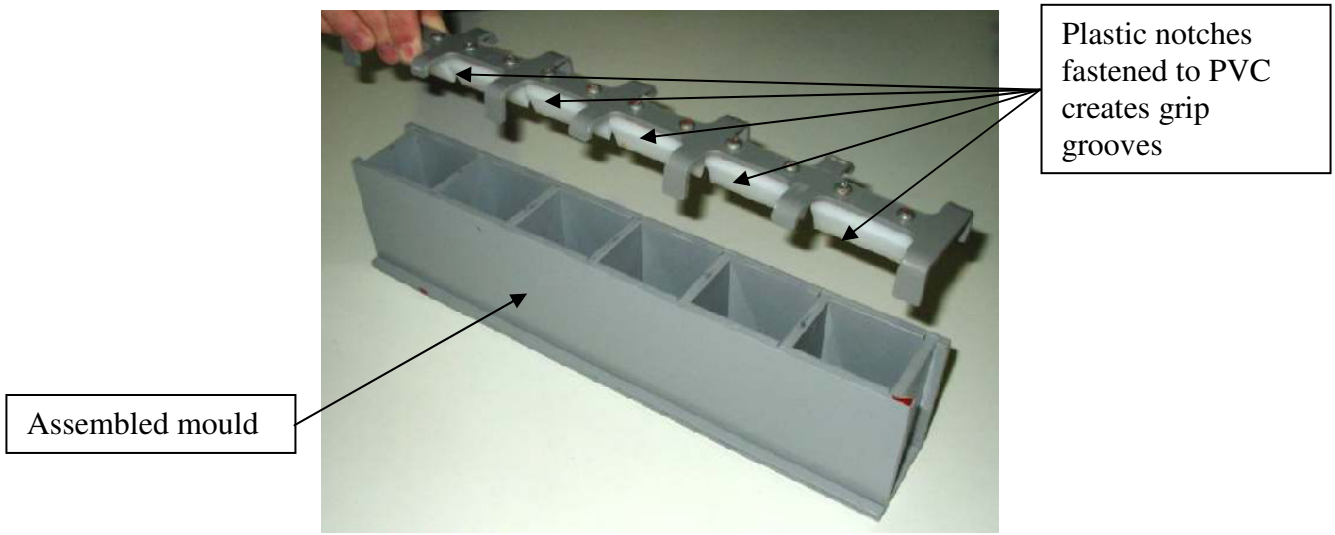


Figure 5.2 Assembled mould and notch components

The plastic notches are securely fixed on to the mould cover via screws on to the mould cover. The notch component has been machined and shaped to allow for pouring of the composite and to clamp the mould together. The notch component guarantees that accurate grip grooves will be created repeatedly and with ease, thus each sample set will be almost exactly the same

5.2.3 Chevron Slots Preparation

In this experiment the chevron slots were made from some sort of card board paper (Manila Folder) manufactured into the dimension shown in figure 4.7 after the chevron slots are manufactured into the necessary size and shape than it is glued on to the plastic notches as shown in figure 5.3

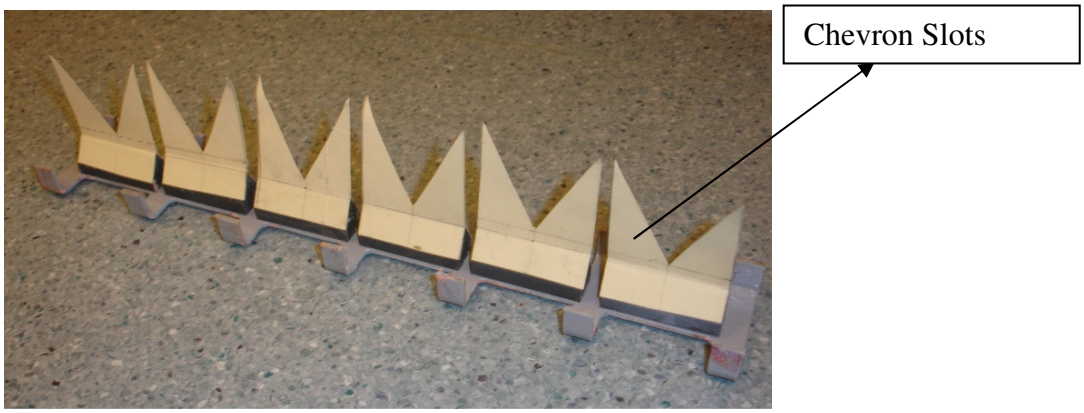


Figure 5.3 The chevron slots are fixed on to the plastic notches

5.2.4 Final Mould Preparation

Finally the mould was built up from the designed components and the notch component was placed into the assembled mould. Rubber bands were placed at each division to make certain the mould would stay together during pouring and curing operations. The finished ready to pour mould can be seen in 5.4 below.

Figure 5.4 The final assembly of the mould ready for pouring

Also at this stage oil or wax has already applied on to the inside surface of the mould to ease the extraction of the specimen from the mould.

5.3 Resin and Catalyst Preparation

The ratio of the resin Phenol Formaldehyde (PF) weight was calculated in this ratio of 39:40 of the combine weight with catalyst and the catalyst Hexicon Phencat (HP) weight was calculated in a ratio of 1:40 of the combined weight with (PF). Table 5.1 shows the calculated weight of the resin and catalyst with the respective ratios

There were altogether 12 castings that were made; the percentage weights were calculated as follows:

Parameters	**MATERIALS**		
	Resin	**Catalyst**	**R + C**
Weight each material using 5% of Saw dust and 95% of Resin and Catalyst	$\frac{39}{40}\times 1140g$ = 1111.5g	$\frac{1}{40}\times 1140g$ =28.5g	1140g
Ratio of Resin and Catalyst	39:40	1:40	-

Table 5.1 The calculated weight of the resins and Catalyst according to the ratio.

Once the weights are known it is ready for mixing.

5.4 Measuring Components

In the previous section it shows the calculation of the respective weights of the resin and the catalyst as for the filler the table below depict the calculation of the percentage of filler with respective to the total weight of the composite.

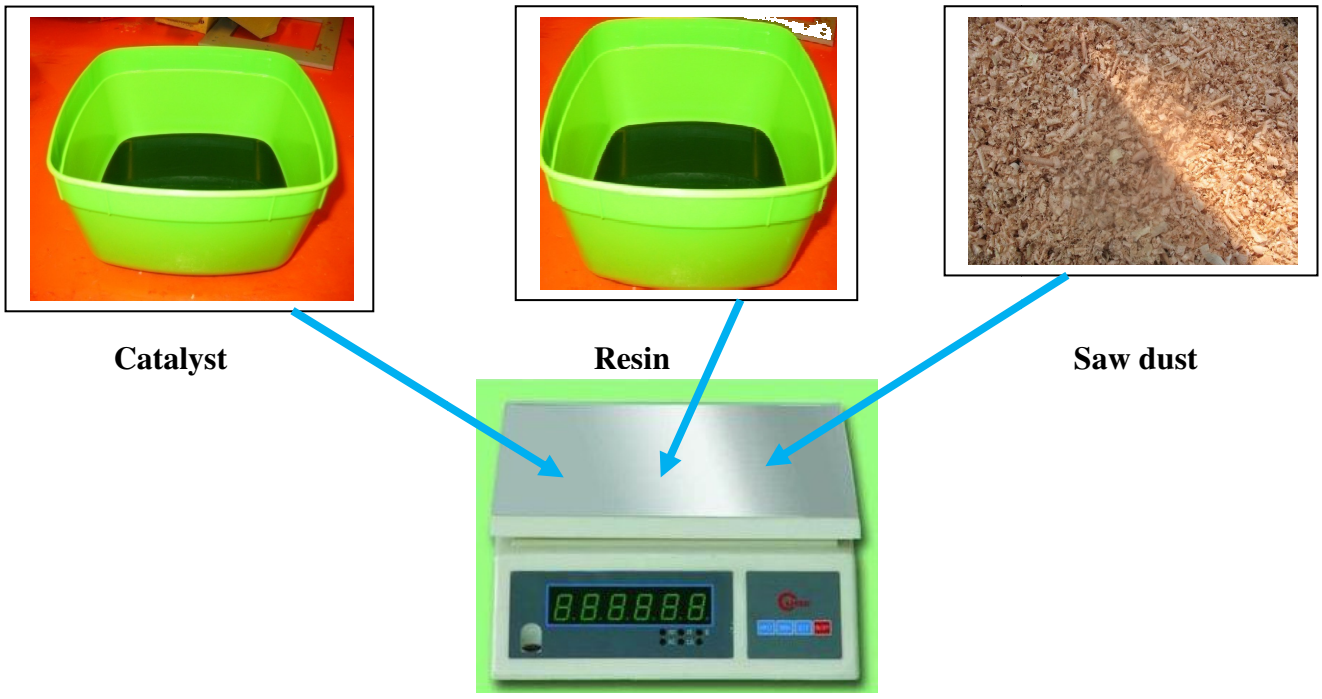
Total Mass of the Composite (grams)	Calculation taking 5% of the Saw Dust	Calculated weight of the Saw Dust (g)
1200	$\frac{5}{100} \times 1200$	60

Table 5.2. The calculated weight of the filler at 5% of the total weight.

Other weight calculation on the remaining percentages of the saw dust can be found at the Appendix D. Once the weights of the components are obtained then the mixing process now proceed.

5.6 Mixing of Components

The three main components of the mixtures figure 5.5 are now ready for mixing



Scales for measuring constituents

Figure 5.5 The constituents ready for mixing

Steps followed during mixing

1. A clean container is place on the measuring scale and the scale was adjusted to zero.
2. Resin is then poured into the empty container on the measuring scale until the required weight reached. Pouring should be done in a slow rate so that air bubbles do not form in the mixture.
3. Followed by the catalyst until the required weight is also reached.
4. Lastly the filler (saw dust) is now then added.
5. Once the constituents are all weighed then the mixing process starts. The mixing has to be done in the ventilator.
6. Mixing also should be done at a rate that air bubbles are not formed ion the mixture as this will create pores after the specimens are cured.
7. The mixing may be done for about 3 - 4 mins or when the mixture, also at this stage it must be aware that the curing process will start to occur.

Once the mixture is ready then the pouring process proceed

5.7 Pouring of Mixtures into the mould

Pouring of the mixture has to be done in this manner as shown in figure 5.6

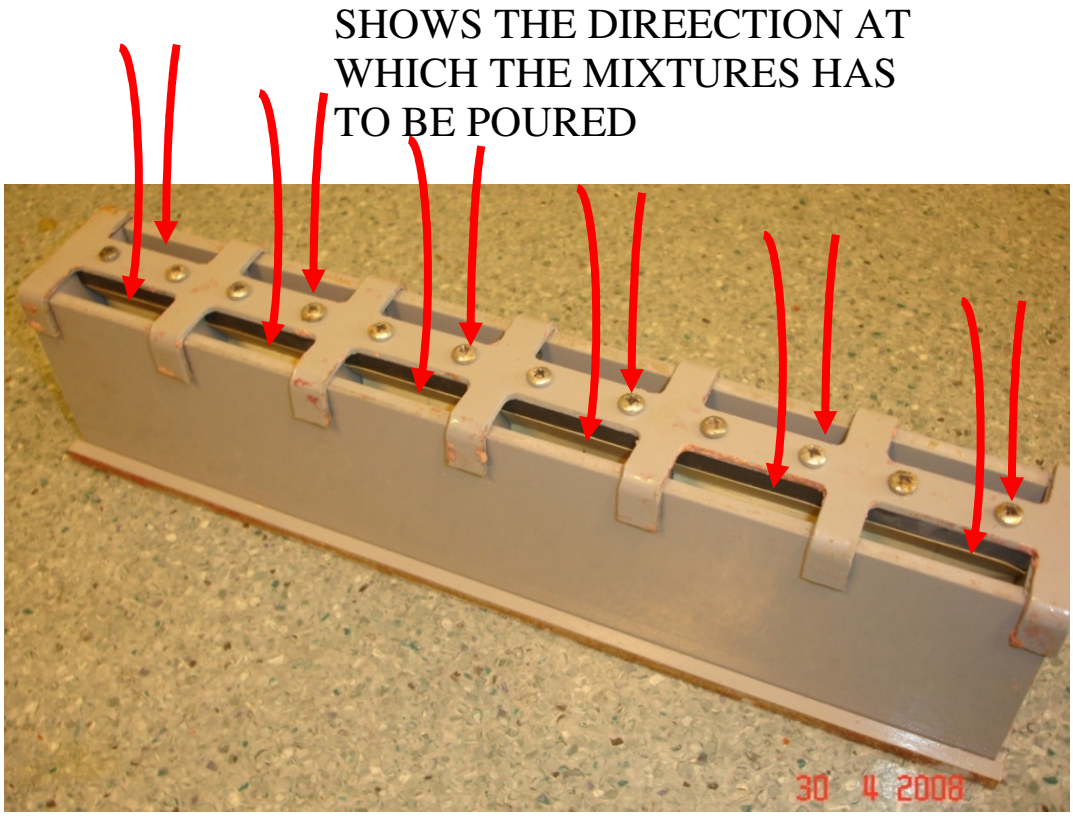


Figure 5.6 Manner at which the mixture has to be poured into the mould

One of the reasons why the mixtures have to be poured in this manner is to minimise the chance of the chevron slot one sided can be seen in figure 5.7 also the pouring process must be done in a slow rate to minimise air bubble in the mixture.

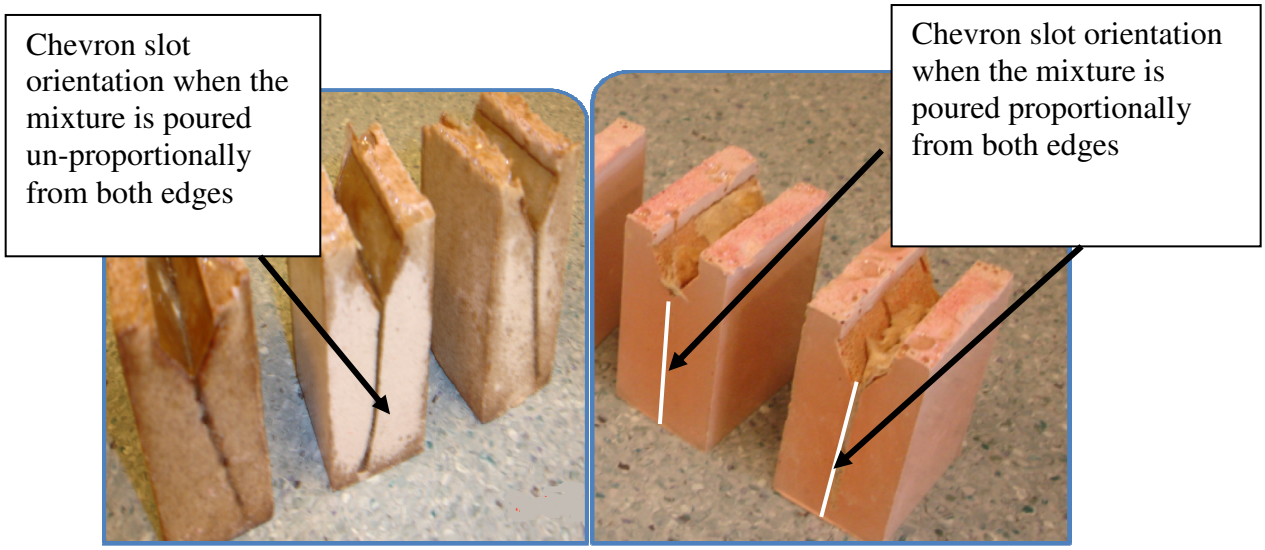


Fig 5.7 The different orientation of the chevron slot when mixtures are poured.

Excess material on the mould to be wiped off this will ease the cleaning of the mould for the next casting process.

5.8 Curing Process

There are two stages involved in this stage the curing and the post curing process. It is the process at which the resin performs the cross linking process as been explained in the earlier chapter of this study and this process is boosted by the catalyst and also process in the post curing process.

5.7.1 Natural Curing Process

This process occurs after the mixtures have been poured into the mould and the mixtures are left in the mould for 24 hrs for it to cure, the process is just leaving the specimen to expose in normal room temperature for the 1st stage of curing.

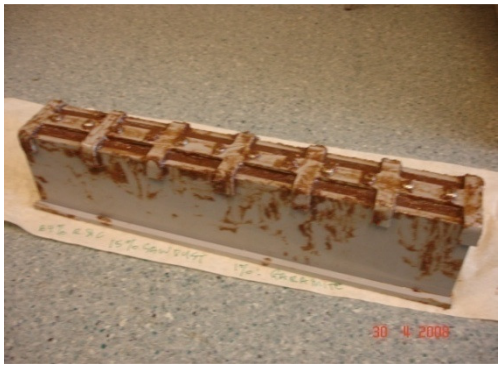


Figure 5.8 The casting is left at the room temperature for curing process

5.7.2 Post Curing Process

This process happens after the specimens have undergone the natural cooling process, the specimens are exposed under certain temperatures for certain duration of time. This is done just to speed up the curing process and it has been done in previous study of phenolic composites as been explained in the earlier chapters of this study.

Figure 5.9 Conventional oven used for the study

The specimens are extracted from its mould and are placed inside the conventional oven in figure 5.5 for the following duration of time at the following respective temperatures:

Number of Hours (duration)	Temperatures the specimen is exposed to
4	50^0C
4	80^0C
2	100^0C

Table: 5.3The duration and the temperature the specimen is exposed to.

After the post curing process the testing process now proceeds.

Chapter 6

Specimen Testing Process

Fracture Toughness Testing

In this study the specimen were tested in the MTS 810 testing system, located at the Faculty of Engineering and Surveying at the University of Southern Queensland (USQ). A tensile force is applied to the load line of the specimen using grippers and a high tensile bolt mechanism that has been specifically designed by Phelan (1990) for this purpose.

6.1 Equipment Familiarisation

During this process I was introduced into the basic operation of the various parts of the MTS 810 system despite conducting a literature review on the system in the earlier chapter of this study. The basic process such as:

- Mounting the test specimen on to the gripper as shown in figure 6.1

Figure 6.1: Grippers used in MTS 810 Material Testing System

- Mounting of the grippers on to the chucks of the tensile testing machine.
- Running of the system

- Obtaining results
- Printing and saving of results

Also some housekeeping after conducting the experiment.

6.2 Testing Procedures

In order to obtain an accurate and organised results there are certain procedures to follow, incorporated in these procedures are the safety awareness and precautions that needed to be taken.

1. **Checks**

Visual inspect the system from the hydraulic controls to the unit assembly and the digital controller before starting up the system.

2. **Start the system**

The system is initiated by switching the hydraulic controls, from the hydraulic controls to the load unit assembly and the digital controller

3. **Insert Gripper**

The specimen grip is then inserted on to the load unit chucks and height between the two grips are adjusted to fit the specimen and the distance between the upper grip and the lower grip will be around 15mm to 20mm figure 6.2 shows the distance between the grips.

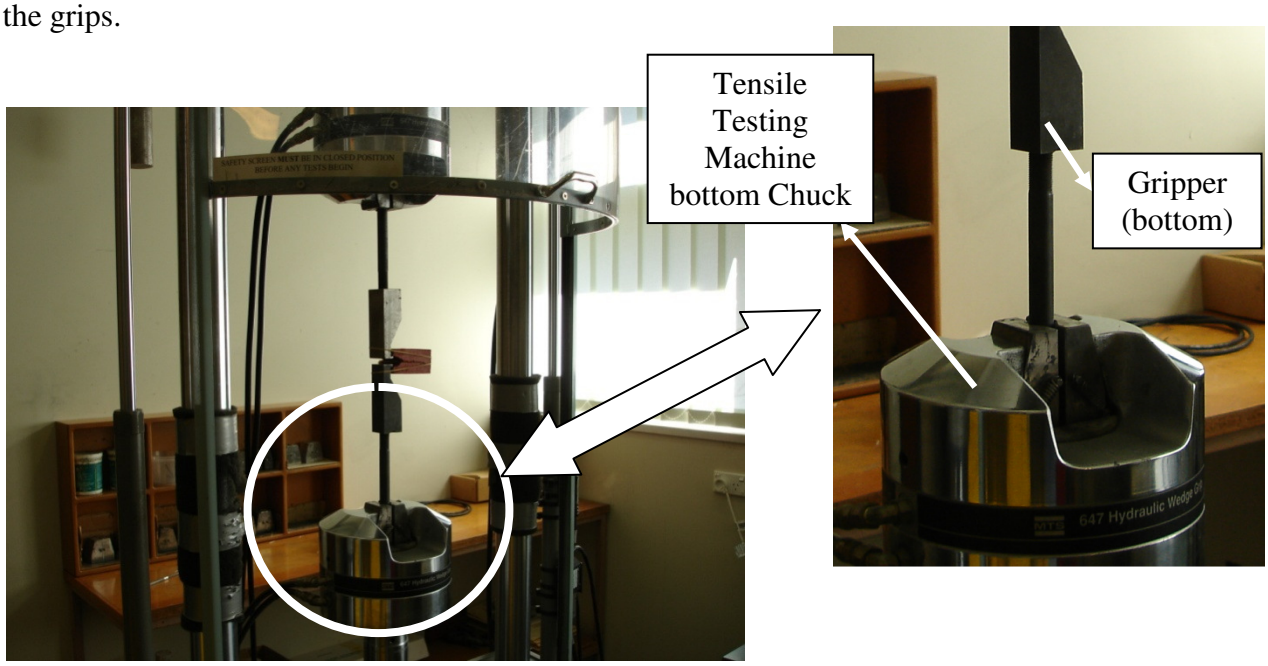


Figure 6.2 Exploded view of the gripper inserted on to the tensile testing machine bottom chuck

The tensile chucks normally opened and closed by adjusting controls shown in figure 6.3

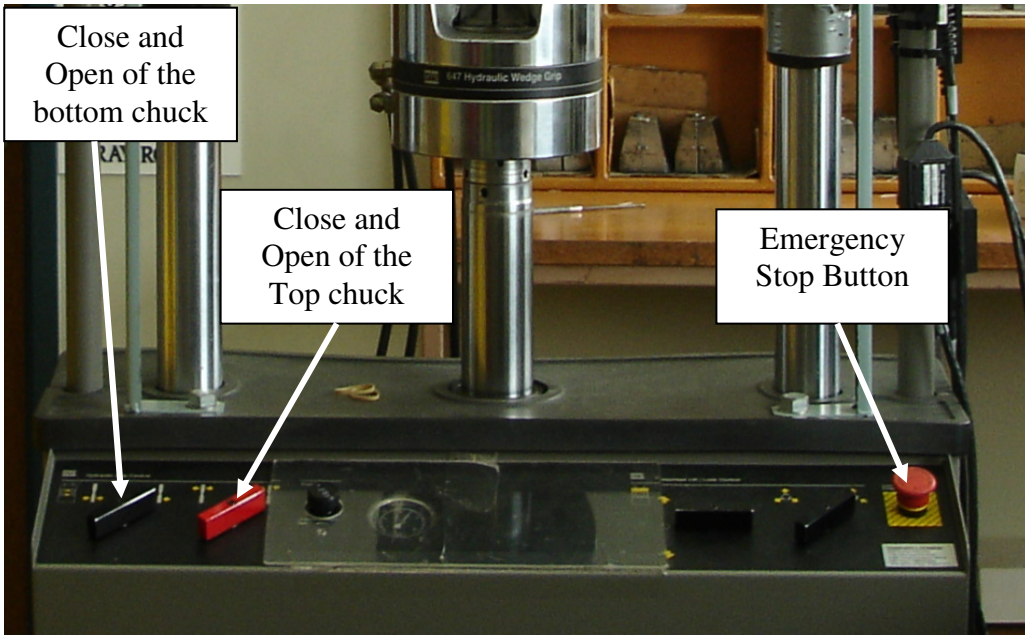


Figure 6.3 Control panel of the tensile testing machine

4. Insert Specimen

The specimen is then inserted on to the gripper (bottom and top) shown in fig 6.4

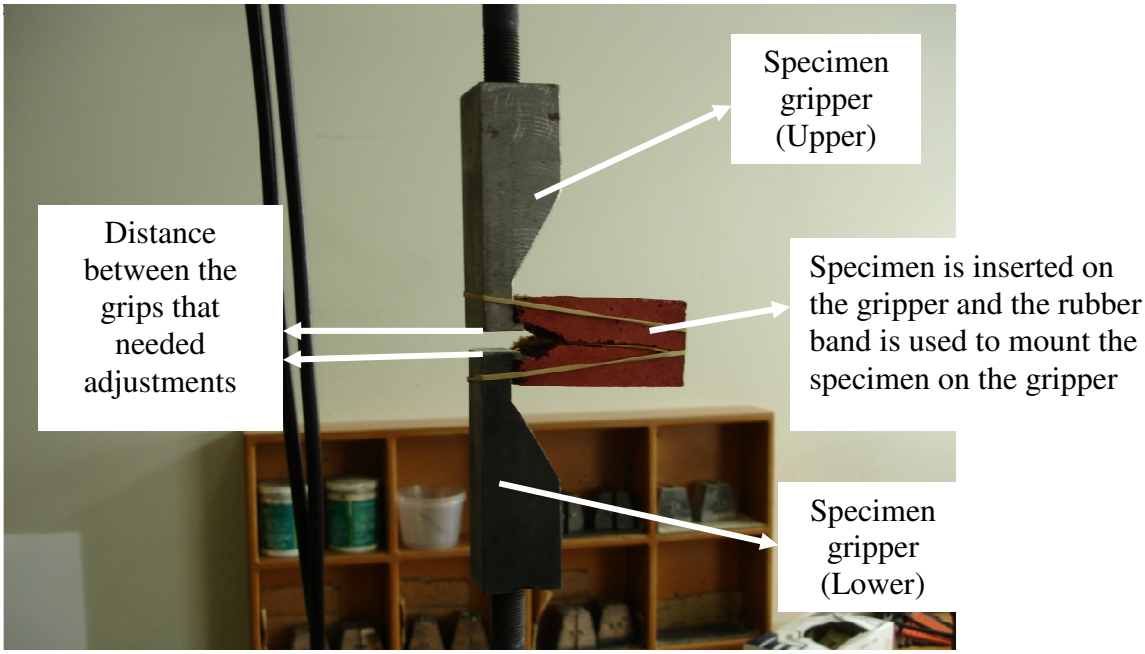


Figure 6.4 The distance between that must be adjusted before inserting the specimen.

The specimen is attached to the gripper via rubber band shown in figure 6.4 just to hold the specimen on to the gripper once the load applied then the rubber band is

useless as the gripper will automatically hold the specimen, due to the elasticity properties of the rubber band it will not have any effect on the loading, it may have but very minimal.

5. **Apply Load**

Load is applied on the system when all the necessary information are input into the digital controller refer to figure 2.11From the digital controller inputs signal into the load cell of the tensile testing machine which automatically activated and load is applied. The load cell is located on the top chuck.

6. **Observe Operation**

After load is being applied a close observation must be taken and the following things that must be taken into consideration:

- The plot taken by the system which can be seen on the control unit screen, is the plot performing the required or assumed plot?
- Is there any slippage on the gripper?

7. **Systematically Record and save data**

The results and plot needed to be saved and recorded systematically. There are individual test plots, each individual specimen information and recorded and also there are batch records where it records the batch of specimen according to the category selected. For example a batch record will include all the 5 % specimens, which are altogether 6 specimens.

6.3 Testing Analysis

Table 6.3 shows the various reading produce by the tensile testing machine

Figure 6.5 Specimen after testing

Analysis is mostly concerned with the reading under the column of Peak load in table 6.1 By using equation (4.1) in order to calculate for the fracture toughness (K_{ICSB}) the(F_{max}) will be the mean value of the peak load according to table 6.1 the cells highlighted. Also from the table below there is a minimum difference between the Peak load and the breaking load.

Calculating the fracture toughness of

0% Saw Dust, 100% Phenol Formaldehyde and Catalyst

Test Date : 14-Jun-07 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	**218**	0.17	218	0.17
2	50.000	26.175	1309	**137**	0.10	136	0.10
3	50.000	26.175	1309	**102**	0.08	98	0.08
4	50.000	26.175	1309	**228**	0.17	228	0.17
5	50.000	26.175	1309	**195**	0.15	195	0.15
6	50.000	26.175	1309	**210**	0.16	210	0.16
Mean	**50.000**	**26.175**	**1309**	**182**	**0.14**	**181**	**0.14**
Std Dev	**0.000**	**0.000**	**0**	**51**	**0.04**	**52**	**0.04**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.992	0.147	193.030
2	0.554	0.069	90.640
3	0.267	0.043	56.902
4	0.618	0.115	151.067
5	0.761	0.059	77.212
6	0.870	0.105	137.638
Mean	**0.677**	**0.090**	**117.748**
Std Dev	**0.257**	**0.039**	**51.485**

Table 6.1 Results of test supplied by the tensile testing machine

More of this table can be seen in Appendix E. The plot taken from the tensile testing machine fig. 6.6 the nature of the graph seems. The graph or the plot shows the assumption that was made earlier that see figure 4.6 a similar plot obtain from the tensile testing machine.

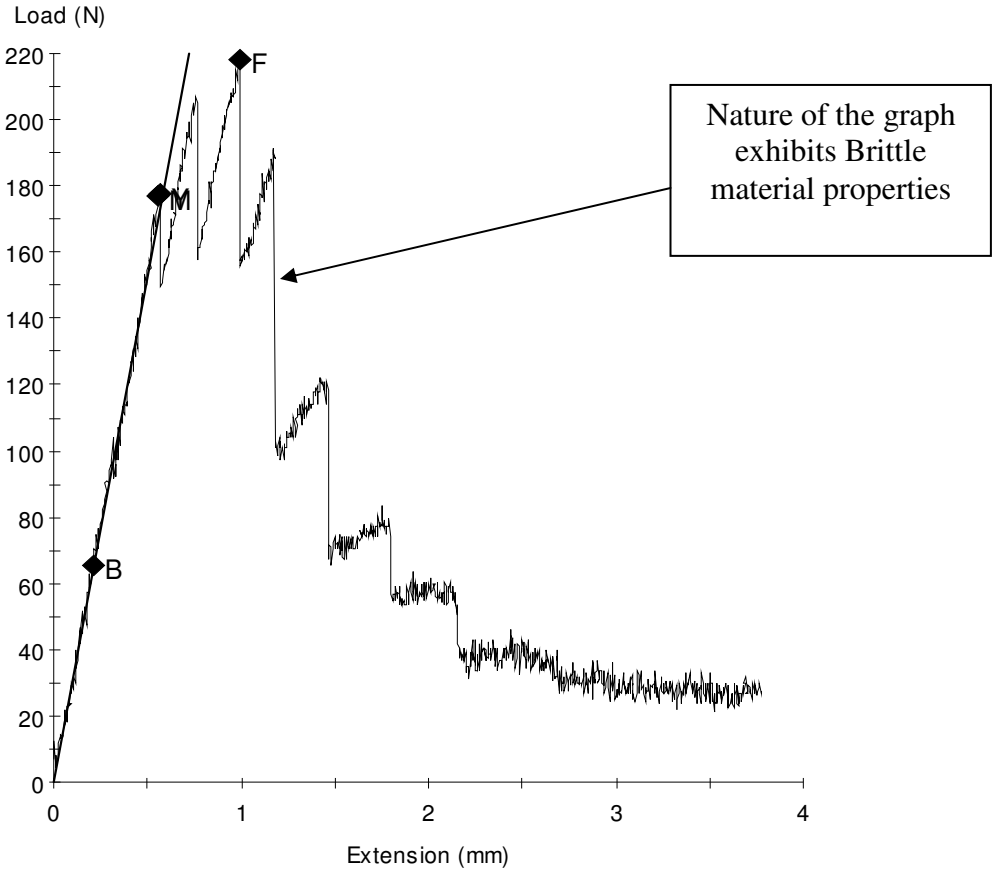


Figure 6.6 Plot produce by the tensile testing machine

More of these plots can be seen in Appendix E

Viscosity Testing

6.4 Testing Procedures

The viscosity testing was conducted at the FCDD Fibre Composite Design and Development Centre, the main purpose was to determine the maximum percentages of saw dust that can be mixed from the ratio used. Refer to figure 2.11 the viscosity meter that was used in this study.

These were the following procedures that were taken during the viscosity testing:

1. Turn on the viscometer head and allow it to warm up for 10 minutes
2. Move the thermocouple out of the bath to temporarily get it out of the way
3. Auto zero the viscometer following the DV-II+ operating instructions.
    a. Remove the spindle.

The spindle has a **left-handed** thread, so it tightens and loosens in the opposite direction than the more often used right-handed thread. Also it is important to both lift the upper half of the drive and keep it from rotating with the thumb and forefinger of one hand while unscrewing the spindle with the other hand. You may need to raise the viscometer head out of the beaker to remove the spindle.

b. Press any key on the viscometer keypad
c. Wait until the display asks for the spindle to be replaced
d. Replace the spindle paying careful attention to the items mentioned in a. above. Also make sure that when the spindle is submerged into the beaker, that the fluid to be measured reaches the groove on the spindle. Also make sure that the viscometer head is level (see the bubble level on the very top of the viscometer head). Level the head using the thumbwheels at the base of the stand.
e. Press any key on the viscometer keypad

4. Put the thermocouple back in the oil. Put the tip of the thermocouple at about half of the disk radius away from the spindle centerline. Make sure that it is not touching the spindle!
5. Check that the correct Spindle Entry Code is being used. It must correspond with the spindle being used, so that the unit will display the correct Viscosity, Shear Rate and Shear Stress values. The simple disk-type spindles do not allow the software to calculate the shear stress and shear rate values. Why? Verify the correct spindle to use with your instructor.
6. Display the currently selected speed by pressing either the UP-arrow or DOWN-arrow
8. Set the speed to 180 RPM (or the highest RPM that will keep the torque below 100%) by pressing and holding one of the arrow keys until the number '180' comes up.
9. Press the SET SPEED to accept 180 RPM as the spindle speed.
10. Turn on the spindle motor
11. Make sure that the temperature reading is in degrees F.
13. Enter a new speed, and take at least one reading. Then, take data over as many speeds as you can where the % Torque reading stays at 10% or above.

6.5 Testing Analysis

The aim of the test was to define at which percentage that has the viscous mixtures however it is assumed that there could be impact on the properties as the viscosity level increases, the assumption were made by visual observing the physical appearance of the specimen as there were numbers of pores occurs see figure 6.5 and the assumption were based on this.

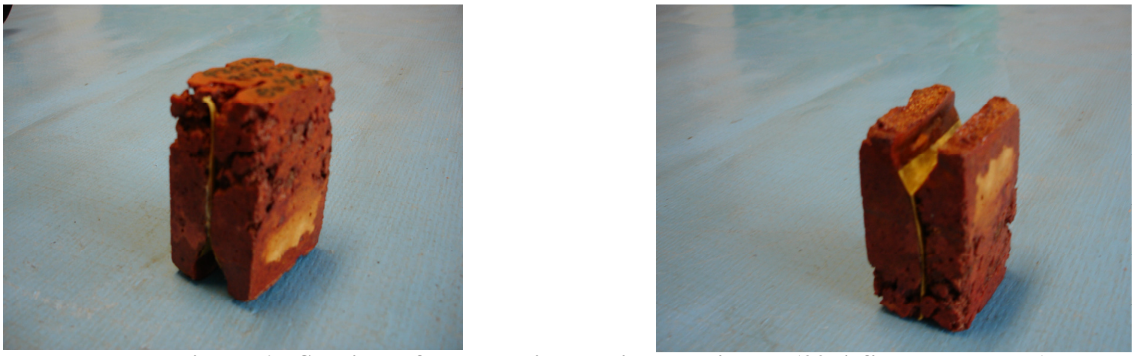


Figure 6.7 Specimen from the highest viscous mixture (20% filler – saw dust)

The table below shows the results obtain from the viscosity testing

% of Saw dust	Spindle speed (rpm)	Viscosity meter Reading (cp)	Temperature (^{0}C)	Spindle number
0	10	4400	24	SO 6
5	10	10800	24.9	SO 6
10	10	23300	24.1	SO 6
15	10	98500	23.2	SO 6
20	Error	200000	-	-
25	Error	-	-	-

Table 6.3: Viscosity reading taken using Brookfield Programmable DV-II + Viscometer, these were the percentages of the 1.18mm grain.

The maximum viscosity reading taken was 98500 (cp) and the mixture was 15% filler (saw dust)

Chapter 7

Results and Discussion

7.1 Fracture Toughness

Using equations 4.2 to 4.5 from Chapter 4, the fracture toughness was calculated by the following procedure.

$$K_{ICSB} = \frac{(F_{\max} Y_m^{*})}{B\sqrt{W}}$$

Where:

$F_{max} = 182N$ (Load refer to figure 6.1 under the column of the Man Peak Load)

$Y_m^* = 17.1645$

$B = the\ breadth\ of\ the\ specimen$

$W = Width\ of\ the\ specimen$

So by calculating the fracture toughness of the specimen at 5% filler

$$K_{ICSB} = \frac{(182 \times 17.1645)}{50\sqrt{75}} = 7.20\sqrt{m}$$

Saw Dust Grain Size	**300 μm**				
Ratio of percentage by weight of filler (Saw Dust)	0%	5%	10%	15%	20%
Fracture toughness MPa $\sqrt{m}$	7.20	11.26	10.82	18.71	18.19
Standard deviation	2.00	0.805	2.038	1.630	5.276

Table 7.1 : (300 μm) Fracture toughness of different percentage by weight of Saw dust reinforces phenolic resins

The other specimens fracture toughness are calculated following the procedure above and are arranged as shown in table 7.1, other fracture toughness values can be seen in appendix C

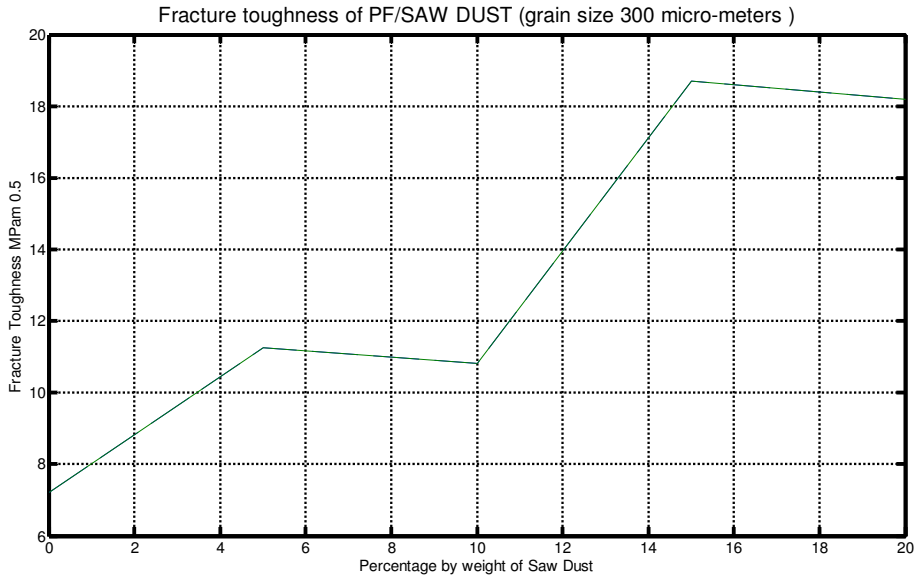


Figure 7.1: Fracture toughness of PF- Saw Dust grain size of 300 μm with vary percentages by weight.

From the data above a trend can be derived regarding the fracture toughness of the composite as the filler (saw dust grains) increase and the percentage increases the magnitude of the fracture toughness also increases.

In the other results see appendix C the trend seems to be in the same nature. However the readings that were taken for the 20% seems to be inconsistent. Figure 6.7 depict the nature of the specimen where more pores are present and with these defects present in a specimen it is unlikely to produce such results.

7.2 Viscosity

Below is the plot of the viscosity readings taken by the viscosity meter which shows around 15% -20% are mixtures that would be possible necessary for this study , data were extracted from table 6.7

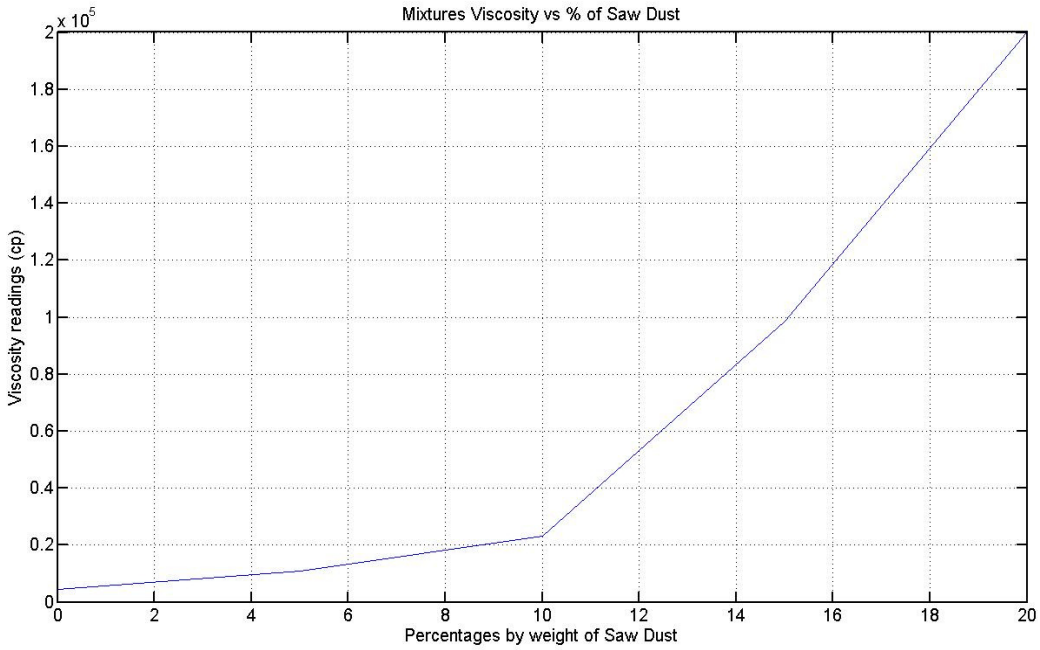


Figure 7.2 Viscosity of various composites mixtures at approximately 20%

Chapter 8

Conclusion and Recommendations

8.1 Conclusion

The project has proved that by adding 5%, 10 % , 15% and 20% by weight of Saw dusts as filler to phenolic resin, the fracture toughness of the composite is 8.28 times of that of the pure
resin. It has also proved that 20 % by weight of E-Spheres is the most suitable amount of filler to add to achieve maximum fracture toughness.

At 20% of filler the mixtures are too viscous to be mixed.

8.2 Recommendation

There are few recommendations regarding this study which could initiate further research into this area especially using saw dust as filler in phenolic resin.

In this study, 20 % was the maximum percentage of filler that can be used in the mixture and was proven by the viscosity test. However further research can be done in investigating other chemicals that can be mixed together with the filler and the resin that will minimise the viscosity of the mixtures, and also investigate as to what effect the properties of the composite will be effected by the inclusion of such chemicals.

Also in this study there were 3 different grain sizes of saw dust were used investigation can also be conducted on the performance of other different grain sizes,

making comparison with this study by evaluating the results of test on the new sets of grain sizes.

In the analysis of this study the fracture toughness of the specimens are plotted against percentage of filler used and the trend were analysed by investigating these plots, most metals and non metal materials properties are obtained by further investigate on the various plots obtained for example for mild steel under tensile testing from 0 to the yield point this region of the plot shows the elasticity region and from the yield point to the breaking point shows the plasticity region, so further study can be made in order to obtain such relationship of the composite.

One of the factors that contribute to the poor physical properties of the specimen are the cavitations or pores which are formed in the specimen due to the presence of air during the mixing process, it seems that eliminating air from the mixtures are inevitable due the assumption that the filler by itself produce air because of its dryness, further studies can be carried out to prove the assumption made and ways to minimise air in the mixtures.

References

1. Sidney H. Goodman (1999). Hand Book of Thermostat Plastics 2nd Edition, William Andrew Inc, (5 – 22): (23 – 27): (32 – 34): (38 – 40).

2. Chemwatch (2005). Material safety data sheet for Hexion Cellobond J2027L, 1 – 14

3. Chemwatch (2005). Material safety data sheet for Hexion Phenecat 15, 1 – 14

4. Barker, L. M. (1979). Fracture mechanics applied to brittle materials, ASTM, STP 678, American Society for Testing and Materials, 73 – 82.

5. Askeland, D.R. (1998 - 2003). The science and engineering of materials. Third Edition, Stanley Thornes, 163 – 164.

6. Munz, D. (1981). Determination of Fracture Toughness of High Strength Aluminium Alloys with Chevron Notched Short Rod and Short Bar Specimens, Engineering Fracture Mechanics, 15 (1 – 2): 231 – 236.

7. Wang, H. (2007). Engineering Materials – Study Book 1, University of Southern Queensland, 9.13.

8. Callister, W.D. (2006). Materials science and engineering an introduction, 7th Ed., John Wiley and Sons, Inc, 217 – 219.

9. Lampman, S. (2003) Characterisation and failure Analysis of Plastics, ASM International, 27.

10. Smith, W.F. and Hashemir, J. (2006). Foundations of material science and engineering, 4th edition, McGraw – Hill, 523 – 525.

11. Ku, H. Cardona, F, Pattarachaiyakoop, N, Trada, M and Rogers, D, Fracture Toughness of Phenol Formaldehyde Composites Reinforced with E-spheres of Journal of Reinforced Plastic and Composites, 2009.

12. Strong, A.B. (2006). Plastics: Materials and Processing, 3rd edition, Pearson / Prentice – Hall, 182 – 183, 304 – 309, 333, 620 – 621.

13. Lampman, S, (2003). Characterisation and failure Analysis of Plastics, ASM International, 27

14. Mel M. Schwartz 1997, Composite Materials, Volume 1: Properties, Nondestructive Testing and Repair, PTR Prentice Hall, Upper saddle River, New Jersey.

15. Robert M. Jones 1999, Mechanics of Composite Materials, 2nd edition, Taylor and Francis, Philadelphia.

16. Shackelford, 1992 J.F. Shackelford, Introduction to Materials Science for Engineers, Macmillan (1992) pp. 435–437, 459.

17. MTS System Corporation 14000 Technology (2006), *Material Testing Systems,* [Brochure], United States of America.

18. Marais J. T, Booyse A, Dannheimer M. F, Oosthuizen M. P, 1999, *The effects of post-curing on Vickers Hardness of four light-cure resin composite materials.* www.pubmed.gov, vol 54, no. 3, p. 123-5, viewed 20 August 2008.

19. Askeland, D.R. (2003). The science and engineering of materials. Third Edition, Stanley Thornes, 266 – 267

20. Griffith (1920). The phenomenon of rupture and flow in solids. Philosophical Transactions of the Royal Society of London, A221, 163.

Appendix A - Project Specification

University of Southern Queensland

FACULITY OF ENGINEERING AND SURVEING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

Project Title: Fracture toughness of sawdust reinforced phenolic composites.

Student: Isei Ledua Yavu – (0050071082)

Supervisor: Dr. Harry Ku
Co- Supervisor:

Sponsorship:

Project Synopsis:

The project involves the production of range sawdust as fillers reinforced phenolic specimen. Fracture Toughness test will be conducted on this specimen to evaluate its fractural properties. The findings will have to be analysed in detail in order to establish behaviour trends and formulas that can be used for theoretical prediction of filled polymer behaviour.

Timelines:

1. Familiarisation of equipment and literature reviews.

   Commence : 10th March 2008.
   Completion : 24th March 2008.
   Approx.Hours : 30 hours.

2. Preparation of fillers Sawdust.

   Commence : 25th March 2008.
   Completion : 8th April 2008.
   Approx.Hours : 30 hours.

3. Casting Components.

   Commence : 9th April 2008.
   Completion : 12th April 2008.
   Approx.Hours : 20 hours.

4. Perform fracture toughness and examination of specimens.
   Commence : 21st April 2008.

Completion : 17th May 2008.
Approx.Hours : 40 hours.

5. Analysis of results.

   Commence : 18th May 2008.
   Completion : 31st May 2008.
   Approx.Hours : 50 hours.

6. Draw up conclusion.

   Commence : 1st June 2008.
   Completion : 24th June 2008.
   Approx.Hours : 50 hours.

7. Software package analysis.

   Commence : 25th June 2008.
   Completion : 12th July 2008
   Approx.Hours : 20 hours.

8. Discuss for the thesis outline with supervisors.

   Commence : 22nd July 2008.
   Completion : 2nd August 2008.
   Approx.Hours : 20 hours

9. Thesis initial drafting – discussion with the supervisor on each draft chapter.

   Commence : 3rd August 2008.
   Completion : 22nd August 2008
   Approx.Hours : 60 hrs

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

    Commence : 23rd August
    Completion : 20th September
    Approx.Hours : 60 hours

11. Complete thesis in requested format.

    Commence : 21st September
    Completion : 1st November 2008.
    Approx.Hours : 20 hours.

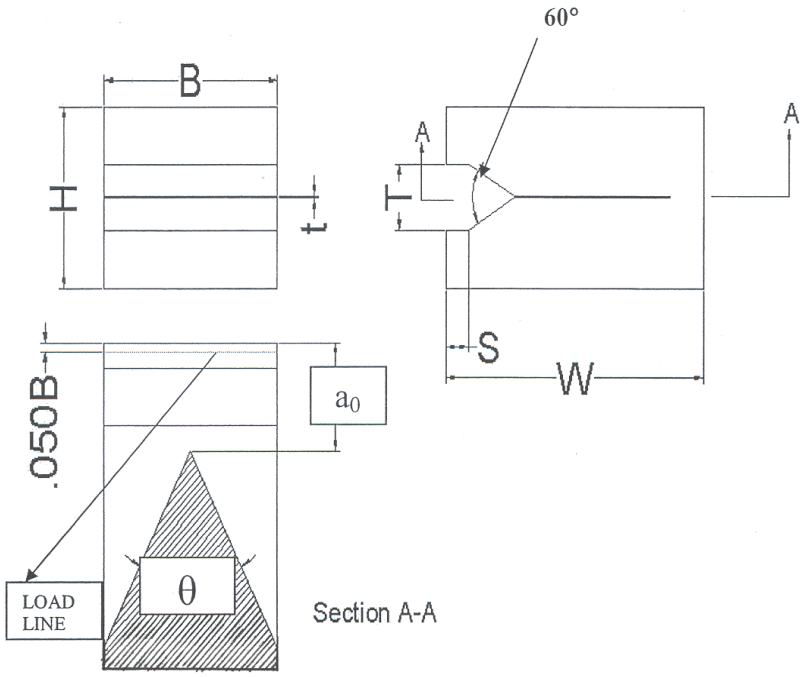
AGREED

(Student)_____ (Supervisor) _____

Date: / / 2008 Date: / / 2008

Co-examiner _____

Appendix B – Specimen Dimension



SYMBOL	DEFINITION	VALUE	TOLERANCE
B	Breadth	B	
W	Length	1.5B	$\pm 0.010B$
H	Height	0.870B	$\pm 0.005B$
a_0	Initial Crack Length	0.513B	$\pm 0.005B$
θ	Slot Angle	55.2^0	$\pm \frac{1}{2}^0$
t	Slot Thickness	See table III (of Baker, 1981)	
S	Grip Groove Depth	0.130B	$\pm 0.005B$
T	Grip Groove Width	0.313B	$\pm 0.005B$
R	Radius of Slot Cut	See fig 4 (of Baker, 1981)	$\pm 2.5B$

Table B: Short Bar specimen with Straight Chevron Slots. The LOAD LINE is the line along which the opening load is applied in the mouth of the specimen.

Appendix C – Calculated Fracture Toughness

Table 1: Weight of materials required to make 1200g of Phenolic Saw Dust composite using 300 μm of saw dust. Using the ratio of 39 : 40 resin and 1 : 40 catalyst with 5 % of Saw Dust.

Saw Dust (%)	**Saw Dust Grain Size**	**Average Peak Load (F_{max}) (N)**
0	-	182
5	300 μm	284
10		273
15		472
20		459
5	425 μm	271
10		294
15		347
20		437
5	1.18mm	357
10		300
15		324
20		376

Table C1: The average Peak Load obtained by the Universal tensile testing machine of the three different grain sizes.

Saw Dust Grain Size	**425 μm**				
Ratio of percentage by weight of filler (Saw Dust)	0%	5%	10%	15%	20%
Fracture toughness MPa $\sqrt{m}$	7.20	805.68	874.08	1031.6	1299.2
Standard deviation	2.00	1.962	1.909	1.560	2.556

TableC2: (425 μm) Fracture toughness of different percentage by weight of Saw dust reinforces phenolic resins

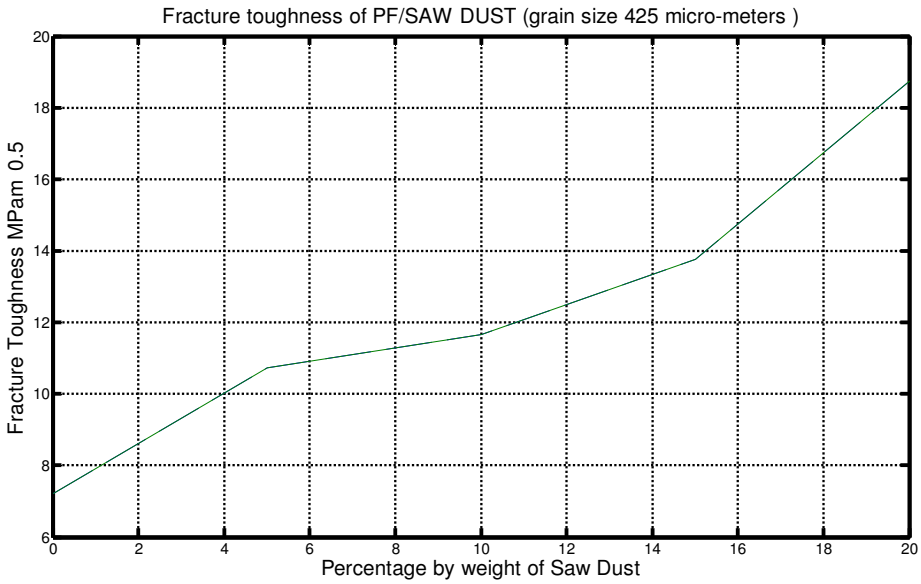


Figure C1: Fracture toughness of PF- Saw Dust grain size of 425 μm with vary percentages by weight.

Saw Dust Grain Size	**1.18mm**				
Ratio of percentage by weight of filler (Saw Dust)	0%	5%	10%	15%	20%
Fracture toughness MPa $\sqrt{m}$	7.20	1061	891.9	963.2	1118
Standard deviation	2.00	1.150	1.487	0.987	2.246

Table C3: (1.18mm) Fracture toughness of different percentage by weight of Saw dust reinforces phenolic resin

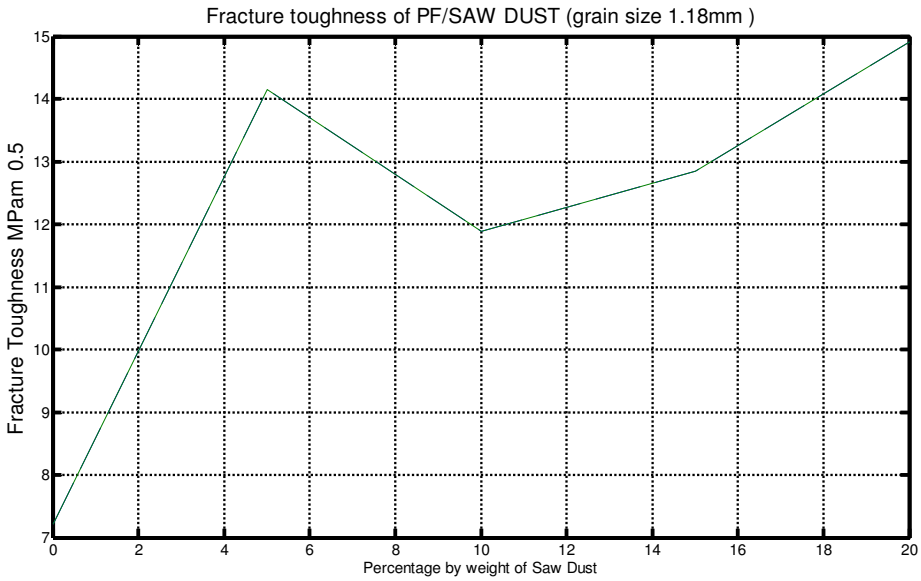


Figure C2: Fracture toughness of PF- Saw Dust grain size of 1.18mm with vary percentages by weight.

Appendix D – MTS 810 Testing Results

0% Saw Dust, 100% Phenol Formaldehyde and Catalyst

Test Date : 14-Jun-07 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	218	0.17	218	0.17
2	50.000	26.175	1309	137	0.10	136	0.10
3	50.000	26.175	1309	102	0.08	98	0.08
4	50.000	26.175	1309	228	0.17	228	0.17
5	50.000	26.175	1309	195	0.15	195	0.15
6	50.000	26.175	1309	210	0.16	210	0.16
Mean	**50.000**	**26.175**	**1309**	**182**	**0.14**	**181**	**0.14**
Std Dev	**0.000**	**0.000**	**0**	**51**	**0.04**	**52**	**0.04**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.992	0.147	193.030
2	0.554	0.069	90.640
3	0.267	0.043	56.902
4	0.618	0.115	151.067
5	0.761	0.059	77.212
6	0.870	0.105	137.638
Mean	**0.677**	**0.090**	**117.748**
Std Dev	**0.257**	**0.039**	**51.485**

Table D 0% Filler

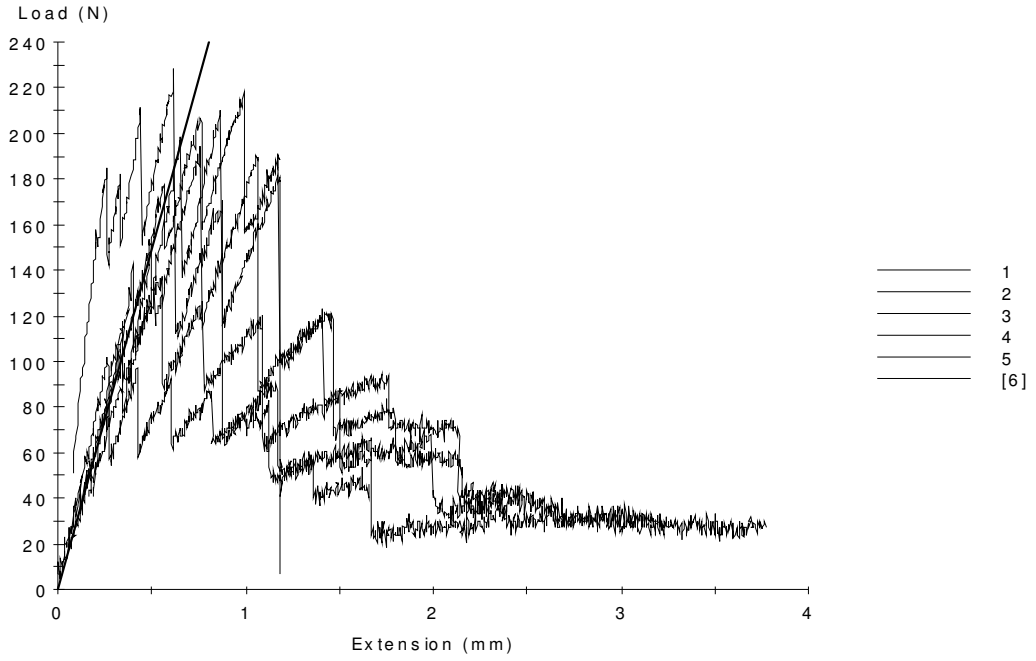


Figure D1: Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 100% of Phenol Formaldehyde and Catalyst

300 μm 5% Saw Dust, 95% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	268	0.20	268	0.20
2	50.000	26.175	1309	295	0.23	295	0.23
3	50.000	26.175	1309	275	0.21	275	0.21
4	50.000	26.175	1309	265	0.20	261	0.20
5	50.000	26.175	1309	280	0.21	280	0.21
6	50.000	26.175	1309	319	0.24	319	0.24
Mean	**50.000**	**26.175**	**1309**	**284**	**0.22**	**283**	**0.22**
Std Dev	**0.000**	**0.000**	**0**	**20**	**0.02**	**21**	**0.02**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	1.028	0.144	189.001
2	1.056	0.151	198.065
3	0.699	0.159	207.465
4	0.776	0.113	147.710
5	0.727	0.146	190.847
6	1.092	0.159	208.136
Mean	**0.896**	**0.145**	**190.204**
Std Dev	**0.181**	**0.017**	**22.311**

Table D1 5% Filler, 300 μm

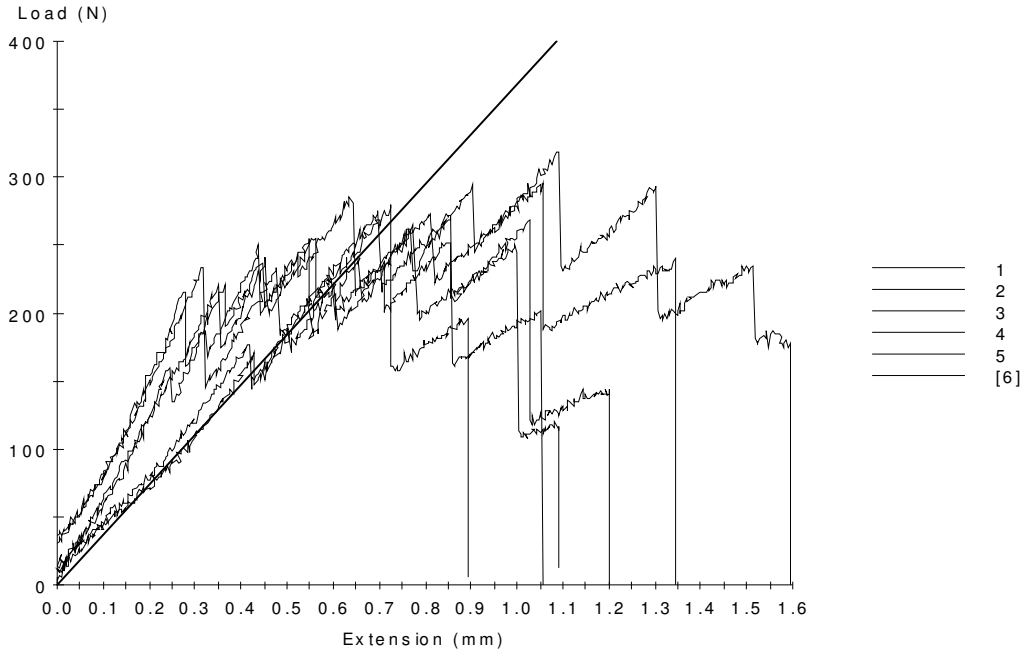


Figure D2: Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 5% saw dust 95% PF

300 μm 10% Saw Dust, 90% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	190	0.14	183	0.14
2	50.000	26.175	1309	259	0.20	256	0.20
3	50.000	26.175	1309	316	0.24	313	0.24
4	50.000	26.175	1309	332	0.25	330	0.25
5	50.000	26.175	1309	252	0.19	252	0.19
6	50.000	26.175	1309	292	0.22	289	0.22
Mean	**50.000**	**26.175**	**1309**	**273**	**0.21**	**270**	**0.21**
Std Dev	**0.000**	**0.000**	**0**	**52**	**0.04**	**53**	**0.04**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	1.100	0.103	134.281
2	0.618	0.118	154.424
3	0.829	0.176	229.957
4	1.051	0.174	227.439
5	1.174	0.139	181.280
6	1.214	0.162	211.997
Mean	**0.998**	**0.145**	**189.896**
Std Dev	**0.230**	**0.030**	**39.820**

Table D2 10% Filler, 300 μm

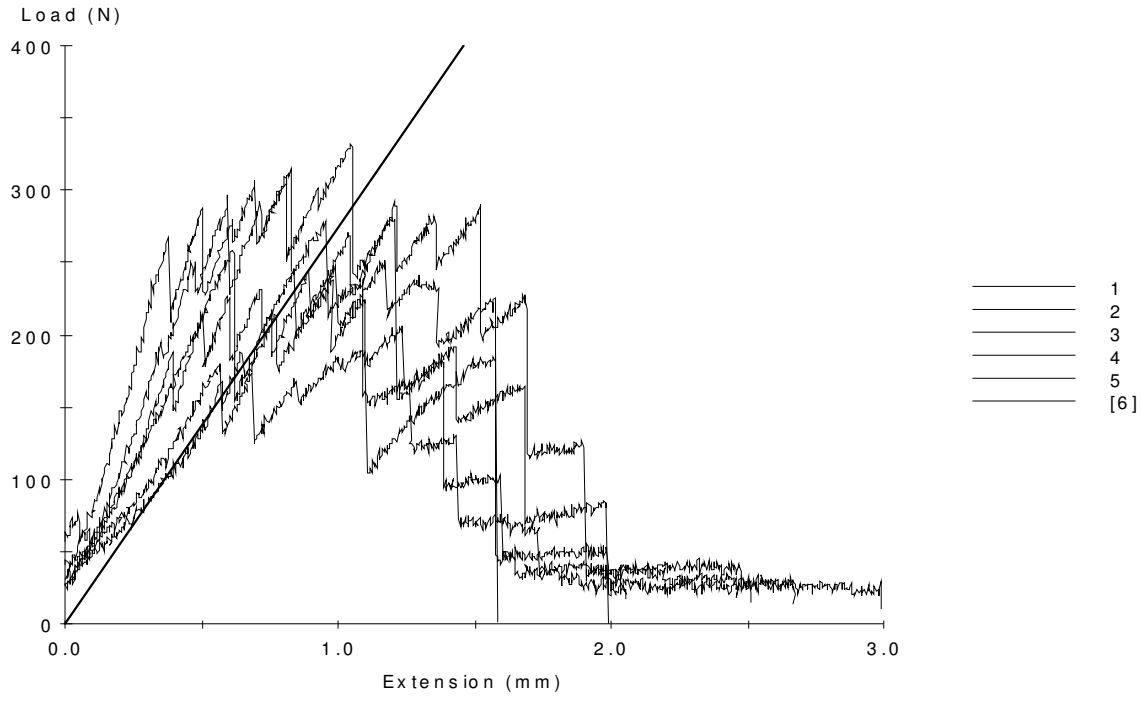


Figure D3 Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 10% saw dust 90% PF

300 μm 15% Saw Dust, 85% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	440	0.34	436	0.33
2	50.000	26.175	1309	500	0.38	500	0.38
3	50.000	26.175	1309	496	0.38	496	0.38
4	50.000	26.175	1309	524	0.40	523	0.40
5	50.000	26.175	1309	457	0.35	457	0.35
6	50.000	26.175	1309	416	0.32	413	0.32
Mean	**50.000**	**26.175**	**1309**	**472**	**0.36**	**471**	**0.36**
Std Dev	**0.000**	**0.000**	**0**	**41**	**0.03**	**42**	**0.03**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	1.336	0.239	312.204
2	1.596	0.277	362.560
3	0.979	0.285	373.638
4	0.974	0.297	389.080
5	1.132	0.281	367.595
6	1.256	0.253	330.500
Mean	**1.212**	**0.272**	**355.930**
Std Dev	**0.237**	**0.022**	**28.814**

Table D4215% Filler, 300 μm

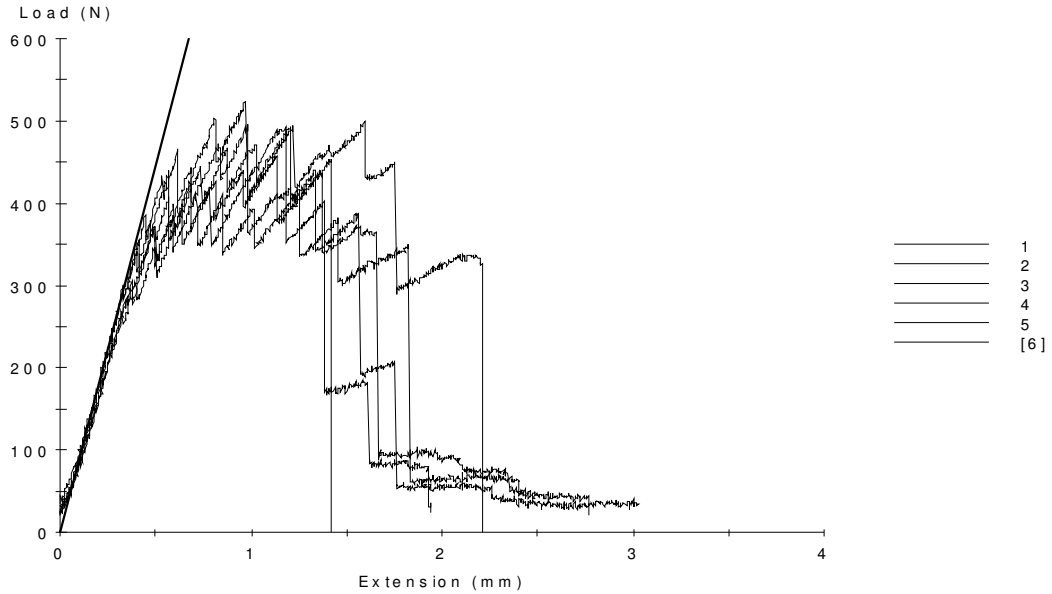


Figure D4 Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 15% saw dust 85% PF

300 μm 20% Saw Dust, 80% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	26.175	50.000	1309	542	0.41	470	0.36
2	26.175	50.000	1309	625	0.48	587	0.45
3	26.175	50.000	1309	417	0.32	411	0.31
4	26.175	50.000	1309	451	0.34	448	0.34
5	26.175	50.000	1309	487	0.37	383	0.29
6	26.175	50.000	1309	232	0.18	224	0.17
Mean	**26.175**	**50.000**	**1309**	**459**	**0.35**	**421**	**0.32**
Std Dev	**0.000**	**0.000**	**0**	**133**	**0.10**	**119**	**0.09**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	1.746	0.191	250.603
2	1.589	0.396	517.823
3	0.735	0.292	382.702
4	1.102	0.235	307.169
5	1.800	0.361	471.831
6	0.613	0.096	125.217
Mean	**1.264**	**0.262**	**342.558**
Std Dev	**0.521**	**0.111**	**145.593**

Table D3 20% Filler , 300 μm

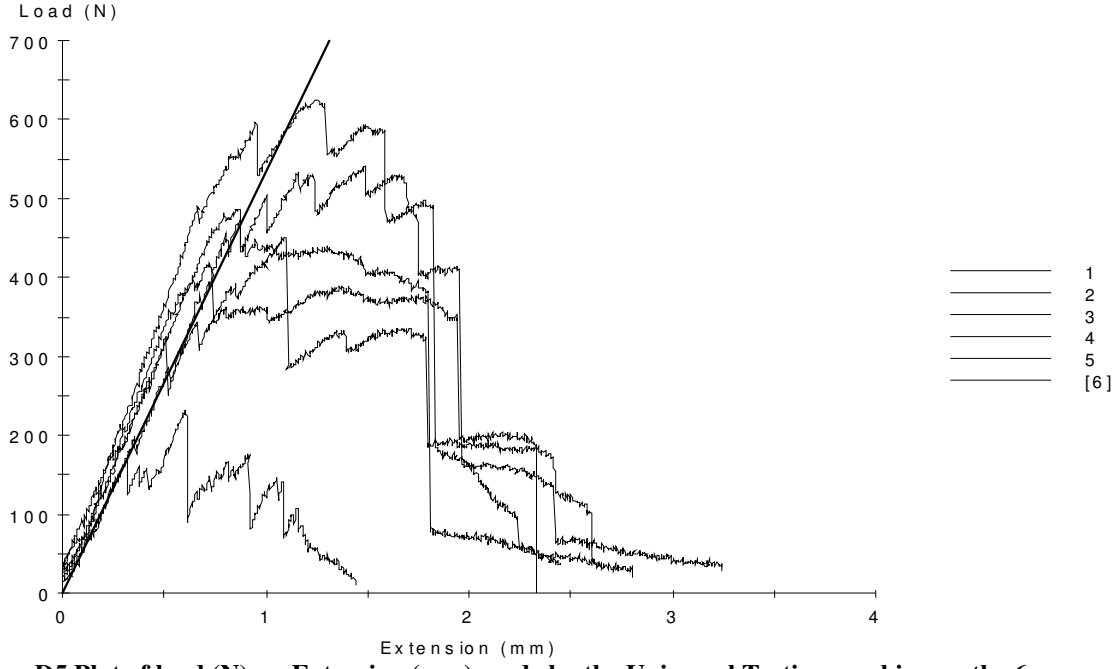


Figure D5 Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 15% saw dust 85% PF

425 μm 5% Saw Dust, 95% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	26.175	50.000	1309	312	0.24	312	0.24
2	26.175	50.000	1309	292	0.22	292	0.22
3	26.175	50.000	1309	222	0.17	222	0.17
4	26.175	50.000	1309	261	0.20	261	0.20
5	26.175	50.000	1309	312	0.24	310	0.24
6	26.175	50.000	1309	367	0.28	367	0.28
Mean	**26.175**	**50.000**	**1309**	**294**	**0.22**	**294**	**0.22**
Std Dev	**0.000**	**0.000**	**0**	**50**	**0.04**	**49**	**0.04**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.415	0.151	197.897
2	0.782	0.140	183.294
3	0.413	0.116	151.402
4	0.451	0.180	235.328
5	0.678	0.186	243.721
6	0.998	0.217	284.173
Mean	**0.623**	**0.165**	**215.969**
Std Dev	**0.239**	**0.036**	**47.665**

Table D4 5% Filler, 425 μm

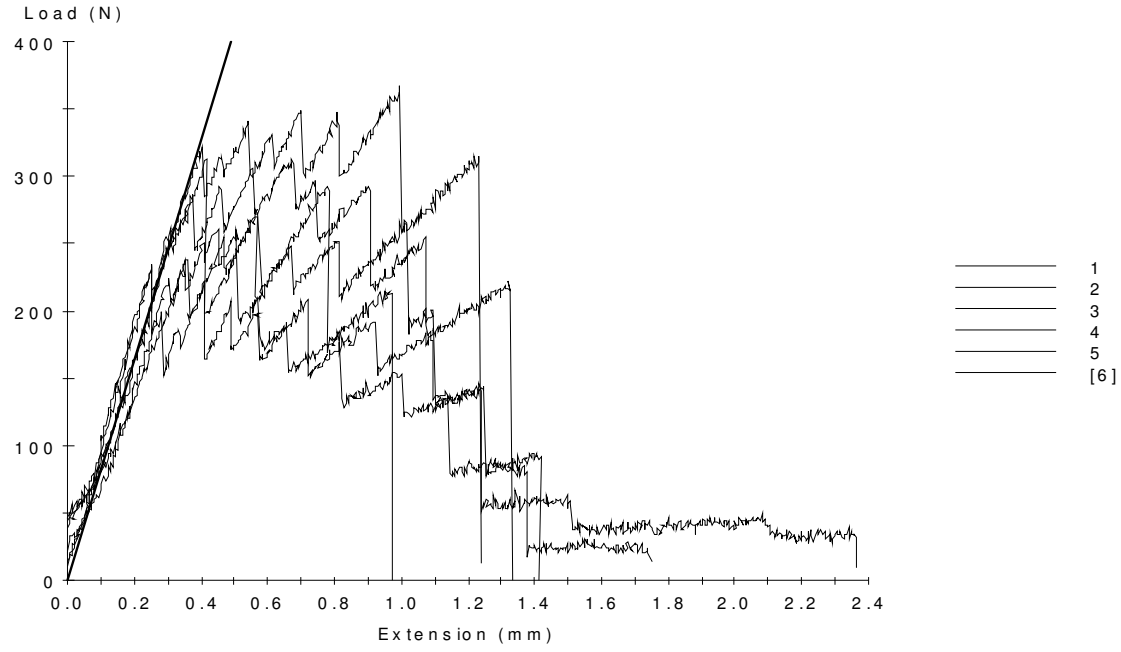


Figure D6 Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 5% saw dust 90% PF

425 μm 10% Saw Dust, 90% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	26.175	50.000	1309	275	0.21	275	0.21
2	26.175	50.000	1309	332	0.25	332	0.25
3	26.175	50.000	1309	349	0.27	349	0.27
4	26.175	50.000	1309	402	0.31	402	0.31
5	26.175	50.000	1309	376	0.29	376	0.29
Mean	**26.175**	**50.000**	**1309**	**347**	**0.27**	**347**	**0.27**
Std Dev	**0.000**	**0.000**	**0**	**48**	**0.04**	**48**	**0.04**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.896	0.171	224.250
2	0.586	0.179	234.657
3	0.543	0.209	272.927
4	0.675	0.243	318.079
5	0.605	0.255	334.025
Mean	**0.661**	**0.211**	**276.788**
Std Dev	**0.140**	**0.037**	**48.814**

Table D5 10% Filler, 425 μm

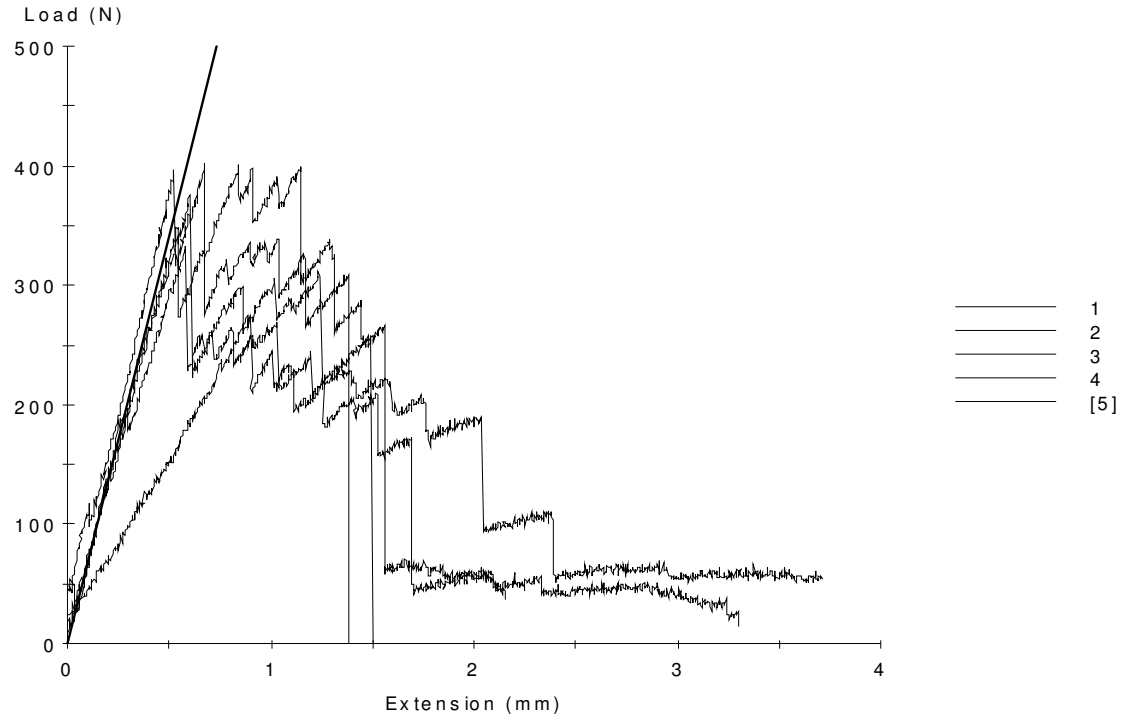


Figure D7 Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 10% saw dust 80% PF

425 μm 15% Saw Dust, 85% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	26.175	50.000	1309	269	0.21	265	0.20
2	26.175	50.000	1309	262	0.20	258	0.20
3	26.175	50.000	1309	348	0.27	348	0.27
4	26.175	50.000	1309	247	0.19	242	0.18
5	26.175	50.000	1309	263	0.20	263	0.20
6	26.175	50.000	1309	238	0.18	235	0.18
Mean	**26.175**	**50.000**	**1309**	**271**	**0.21**	**269**	**0.21**
Std Dev	**0.000**	**0.000**	**0**	**39**	**0.03**	**41**	**0.03**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.542	0.146	191.015
2	1.297	0.173	225.761
3	0.615	0.204	267.556
4	0.679	0.154	201.086
5	0.516	0.161	211.158
6	0.587	0.136	177.923
Mean	**0.706**	**0.162**	**212.416**
Std Dev	**0.295**	**0.024**	**31.611**

Table D6 15% Filler, 425 μm

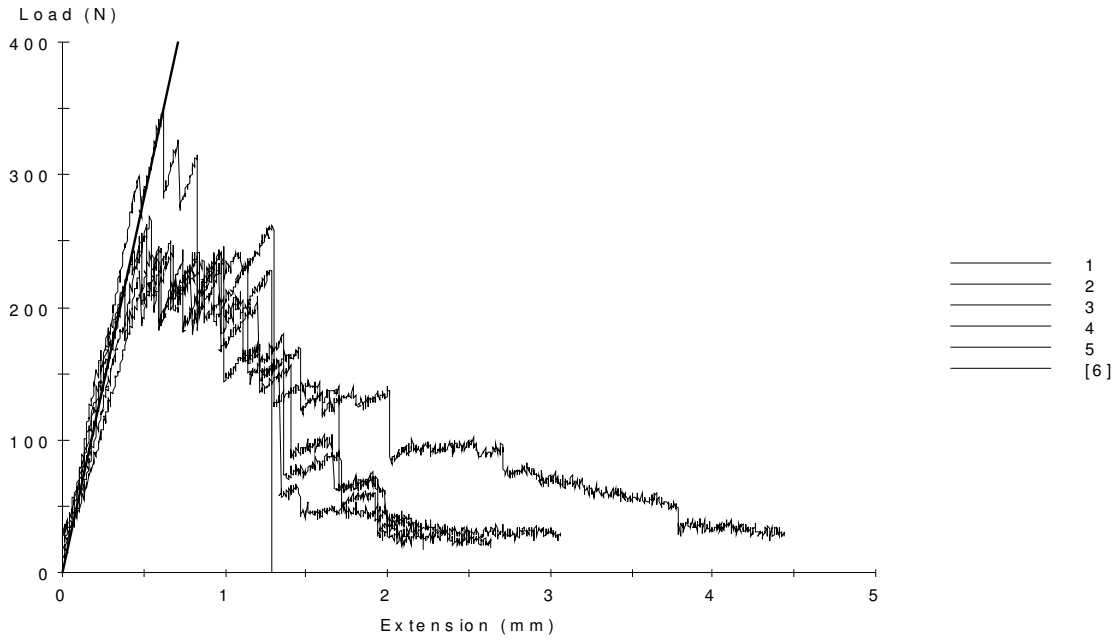


Figure D8 Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 15% saw dust 85% PF

425 μm 20% Saw Dust, 80% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	443	0.34	396	0.30
2	50.000	26.175	1309	567	0.43	564	0.43
3	50.000	26.175	1309	463	0.35	446	0.34
4	50.000	26.175	1309	532	0.41	528	0.40
5	50.000	26.175	1309	443	0.34	437	0.33
6	50.000	26.175	1309	392	0.30	390	0.30
Mean	**50.000**	**26.175**	**1309**	**473**	**0.36**	**460**	**0.35**
Std Dev	**0.000**	**0.000**	**0**	**64**	**0.05**	**71**	**0.05**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	1.375	0.286	374.310
2	1.703	0.378	494.491
3	1.495	0.246	322.275
4	1.703	0.326	426.344
5	1.307	0.239	313.379
6	1.229	0.271	355.174
Mean	**1.469**	**0.291**	**380.996**
Std Dev	**0.201**	**0.053**	**68.803**

Table D7 20% Filler, 425 μm

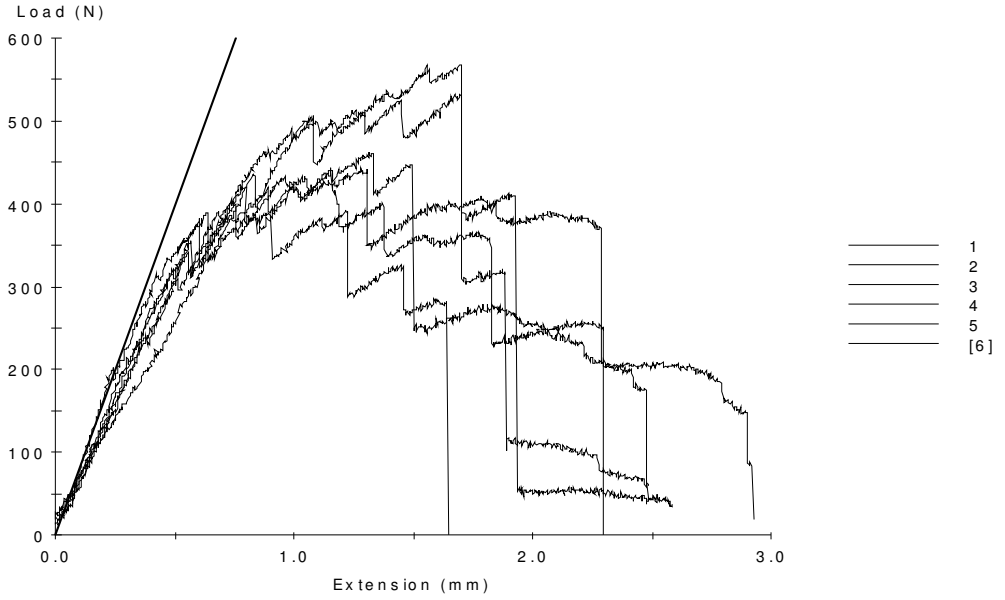


Figure D9: Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 20% saw dust 80% PF

1.18mm 5% Saw Dust, 95% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	349	0.27	349	0.27
2	50.000	26.175	1309	379	0.29	376	0.29
3	50.000	26.175	1309	353	0.27	336	0.26
4	50.000	26.175	1309	339	0.26	339	0.26
5	50.000	26.175	1309	321	0.24	297	0.23
6	50.000	26.175	1309	402	0.31	363	0.28
Mean	**50.000**	**26.175**	**1309**	**357**	**0.27**	**343**	**0.26**
Std Dev	**0.000**	**0.000**	**0**	**29**	**0.02**	**27**	**0.02**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.713	0.249	325.968
2	0.839	0.280	365.917
3	1.169	0.256	335.368
4	0.435	0.213	278.634
5	1.428	0.185	241.874
6	1.124	0.278	363.567
Mean	**0.952**	**0.243**	**318.555**
Std Dev	**0.358**	**0.038**	**49.154**

Table D8 5% Filler, 1.18mm

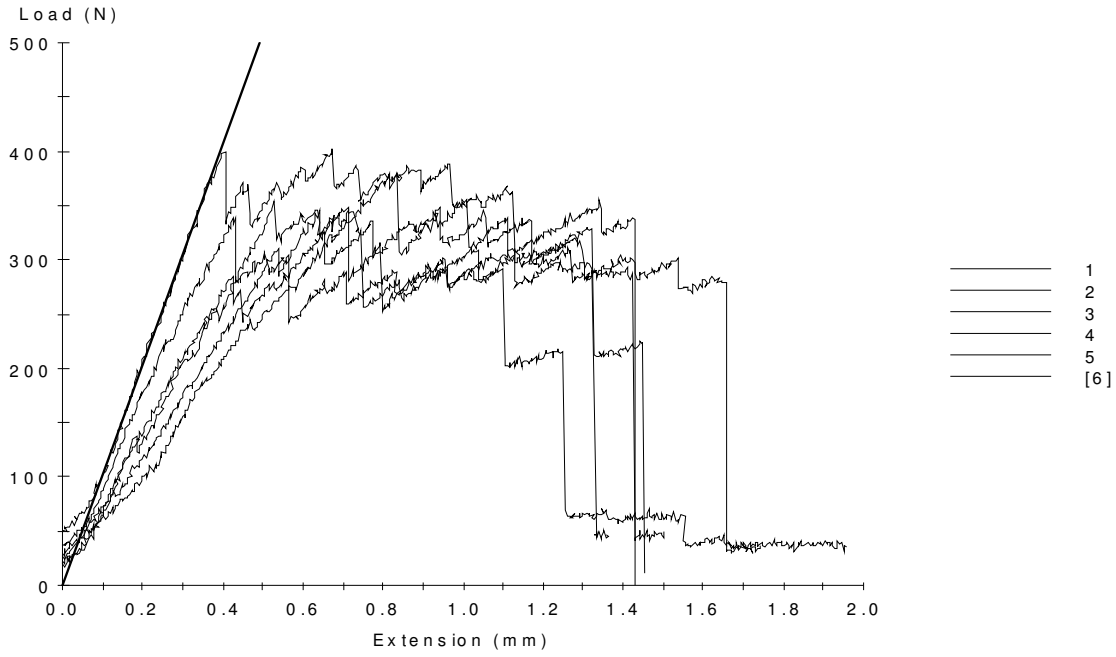


Figure D10: Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 5% saw dust 95% PF

1.18mm 10% Saw Dust, 90% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	279	0.21	279	0.21
2	50.000	26.175	1309	282	0.22	282	0.22
3	50.000	26.175	1309	272	0.21	267	0.20
4	50.000	26.175	1309	335	0.26	291	0.22
5	50.000	26.175	1309	359	0.27	359	0.27
6	50.000	26.175	1309	272	0.21	272	0.21
Mean	**50.000**	**26.175**	**1309**	**300**	**0.23**	**292**	**0.22**
Std Dev	**0.000**	**0.000**	**0**	**38**	**0.03**	**34**	**0.03**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.654	0.142	185.308
2	0.626	0.184	241.035
3	0.652	0.113	148.381
4	1.705	0.217	284.005
5	0.907	0.188	245.903
6	0.839	0.137	178.930
Mean	**0.897**	**0.163**	**213.927**
Std Dev	**0.412**	**0.039**	**51.007**

Table D9 10% Filler, 1.18mm

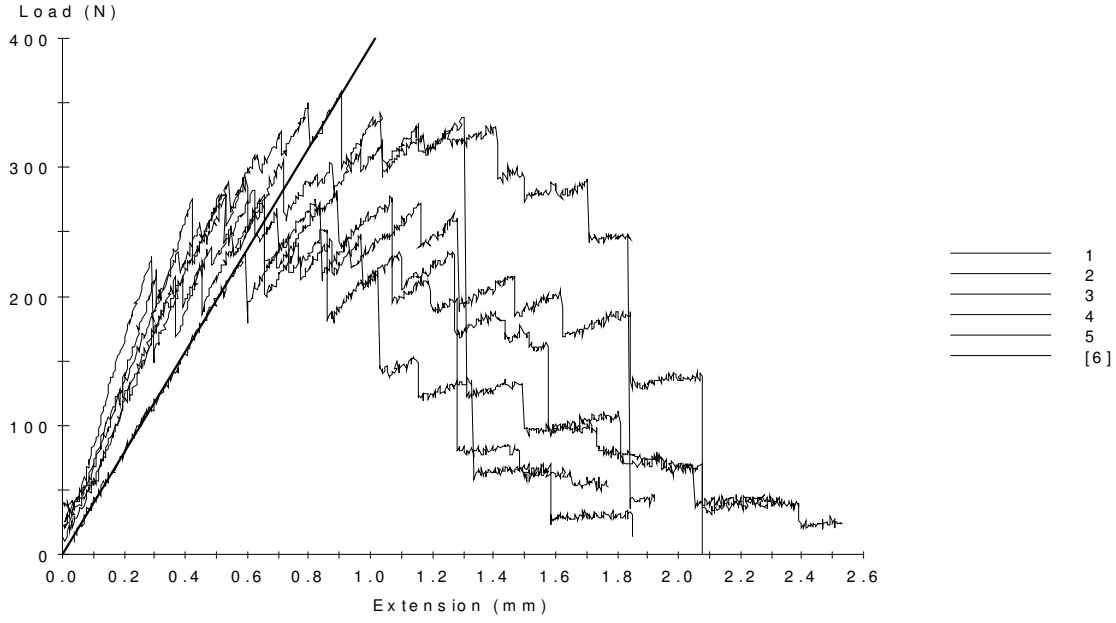


Figure D11: Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 10% saw dust 90% PF

1.18mm 15% Saw Dust, 85% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	326	0.25	321	0.25
2	50.000	26.175	1309	354	0.27	336	0.26
3	50.000	26.175	1309	352	0.27	337	0.26
4	50.000	26.175	1309	290	0.22	290	0.22
5	50.000	26.175	1309	311	0.24	280	0.21
6	50.000	26.175	1309	315	0.24	312	0.24
Mean	**50.000**	**26.175**	**1309**	**324**	**0.25**	**313**	**0.24**
Std Dev	**0.000**	**0.000**	**0**	**25**	**0.02**	**24**	**0.02**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	1.495	0.178	232.810
2	1.338	0.198	259.331
3	1.409	0.190	249.092
4	0.706	0.179	233.818
5	1.414	0.173	226.936
6	0.755	0.195	255.135
Mean	**1.186**	**0.186**	**242.854**
Std Dev	**0.357**	**0.010**	**13.395**

Table D10 15% Filler, 1.18mm

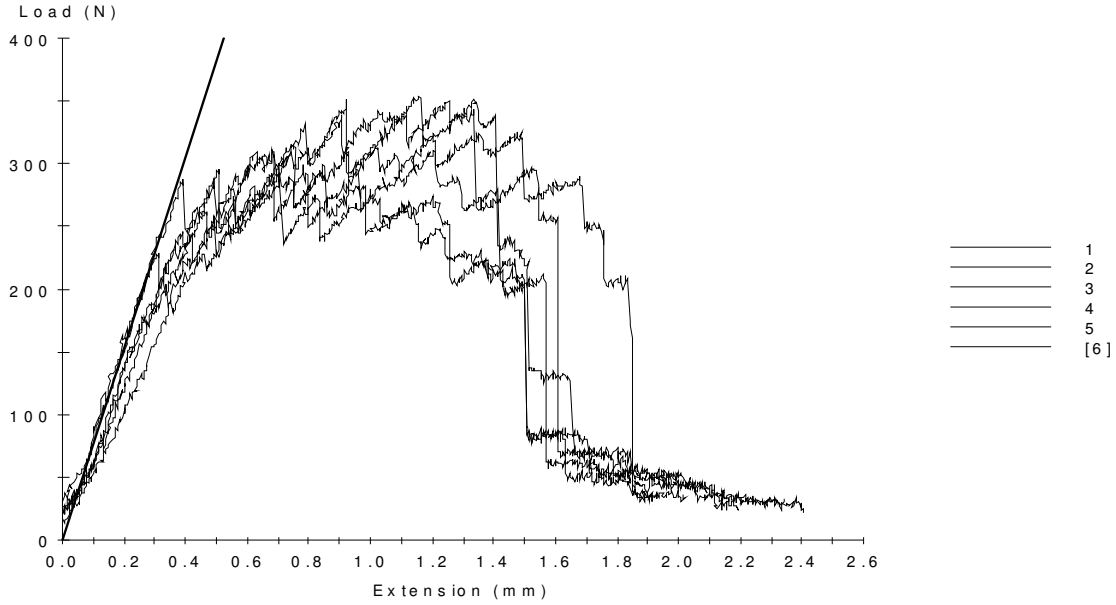


Figure D12: Plot of load (N) vs. Extension (mm) made by the Universal Testing machine on the 6 specimen of 15% saw dust 85% PF

1.18mm 20% Saw Dust, 80% Phenol Formaldehyde and Catalyst

Test Date : 17/07/2008 **Method:** MMT fracture toughness Test

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	50.000	26.175	1309	277	0.21	274	0.21
2	50.000	26.175	1309	374	0.29	359	0.27
3	50.000	26.175	1309	420	0.32	413	0.32
4	50.000	26.175	1309	433	0.33	430	0.33
5	50.000	26.175	1309	352	0.27	352	0.27
6	50.000	26.175	1309	398	0.30	338	0.26
Mean	**50.000**	**26.175**	**1309**	**376**	**0.29**	**361**	**0.28**
Std Dev	**0.000**	**0.000**	**0**	**57**	**0.04**	**56**	**0.04**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N
1	0.693	0.174	228.111
2	1.548	0.236	308.847
3	0.989	0.257	335.704
4	0.676	0.277	362.896
5	0.645	0.203	265.206
6	1.366	0.216	282.662
Mean	**0.986**	**0.227**	**297.238**
Std Dev	**0.389**	**0.037**	**48.872**

Table D11 20% Filler, 1.18mm