University of Southern Queensland

Faculty of Engineering & Surveying

Tensile strength of sawdust reinforced phenolic resin composite materials

A dissertation submitted by

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Abstract

The basic aim of this project is to study the tensile strength properties of sawdust reinforced phenolic resin composites.

The phenolic resin composite materials with sawdust as filler are tested for tensile strength, where sawdust composition is varied from 5% -15% by weight. Also, three different grain sizes of sawdust were used simultaneously: 1.18mm, 300 microns and 425 microns. The composite is made from: Resin- Hexion Cellobond J2027L, Catalyst- Hexion Phencat 15 & Sawdust.

Earlier project works have covered phenolic resin composites with other filler materials such as glass powder, slg, etc. and/or for studying other properties such as flexural strength of sawdust reinforced resin composites. This project comprising the study of the sawdust reinforced composites for tensile strength properties would enable us to further understand detailed behaviour of phenolic composites.

Sawdust helped in increasing the tensile strength of the phenolic resin composites. Also these are commercially cheap to produce and hence, have tremendous potential in various fields such as civil, defence, automobile industry, etc.

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Date

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Shashi Shekhar

University of Southern Queensland

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Nomenclature

FCDD Fibre Composite Design and Development

CEEFC Centre of Excellence in Engineered Fiber Composites

MSDS Material Safety Data Sheet

F = Force (in Newtons)

A = Cross section area

L = Original length

σ = Stress

ε = Strain

E = Young's modulus

MPa = Mega Pascals

Chapter 1 Introduction

1.1 Introduction

In order to improve the properties and performance of various materials, we need to find new materials, new ways of manufacturing or use the existing materials and form new ones with the use already available materials by varying compositions to achieve desired properties. The most desired properties are low cost, ease of manufacture, availability, low weight, mechanical properties such as strength, fire resistance, corrosion resistance, environmental friendly (bio-degradable), etc.

Composite materials are thus finding increasing use today, as they can cater to various desired properties in a material. Composites are engineered material made up of two or more different materials. Some common examples are: concrete, bones, teeth, fibre glass, wood, chobham armour, ceramics, plywood, plastics, mastic asphalt, etc.

The use of natural fibres has been ever increasing in today's composite industry. Sawdust is one of the most commonly used natural fibres in thermoplastic industry. The fibrous nature of the sawdust particles provide enhanced mechanical properties to phenolic resin composite materials. In this research, different percentage by weight of sawdust is added to phenolic resin to find the optimum percentage by weight of sawdust in the composite to achieve best tensile strength. The sawdust used in this research is use in three different particulate sizes (300 microns, 450 microns and 1.18 mm). The sawdust is dry and not subjected to any kind of processing before use.

Phenolic resins are thermosetting polymers with high chemical resistance though with poor mechanical properties and thermal stability. Some of the advantages of phenolic resins are that they are relatively low cost engineering materials; generate low smoke, resistant to ignition, etc. and thus have found favour with various applications.

1.2 Project Aims

The research will try to find the optimum percentage by weight of sawdust as filler in the phenolic resin composite. The tensile strength testing on the produced specimen is done after they are naturally cured at room temperature and later post cured in conventional oven at set temperatures for specified intervals of time.

1.3 Applications of Composite Materials

Some of the applications/ uses of composites in the various industries are also categorized and mentioned below:

- Aerospace (Space crafts, passenger aircrafts, unmanned drones, etc.)
- Mechanical and Automotive Engineering (Tools, bearing materials, engine blocks, piston rods, chassis, brakes, clutch pads, etc.)
- Marine (Catamarans, yachts, canoes, lifeboats, etc.)
- Military (Armoured vehicles, humvees, arms, weaponry, etc.)
- Civil engineering (Interiors, beams, window panels, etc.)
- Electrical (Electrical contacts, fuse plugs body, etc.)
- Medical (Composite teeth, synthetic bones, medical equipments, etc.)
- Fire proofing (Buildings, aircrafts, oil rigs, etc.)
- Sports (Composite cricket bats, helmets, golf clubs, pool and snooker balls, etc.)

1.4 Advantages of Composite Materials

- Phenolic resins have low flammability and low smoke production, as compared to other cheap resins.
- Phenolic resins have good dimensional stability under temperature fluctuations and good adhesive properties.

Due to these special properties phenolics have been found to be attractive for aircraft, mass transit vehicles, and as interior construction materials where out gassing in case of fire should be extremely low.

- Phenolics have found their use in sheet molded compound (SMC), pultrusion, filament winding, etc.
- Processing of phenolic resins is quite different from other thermosets, but successful production has been achieved at good production rates and mechanical properties.
- Cost of phenolic resins is comparative with polyesters and are thus is used in various applications, for its very low cost per unit volume.

1.5 Assessment of Consequential Effects

The data obtained during the experiments will be used for analysis and may form the basis of future research work. Thus we need to assess and be aware of the safety and other ethical issues related to the technical tasks performed/ undertaken.

A detailed risk assessment needs to be carried out before the commencement of any technical tasks, such that the potential dangers and risks could be identified and minimized. There are very severe penalties and fine for negligence in case of injury. We must also keep in mind that some of the equipment and facilities are worth multi-thousand –dollars.

We need to be fully aware of the Workplace Health and Safety Act, 1995. This must be used as a reference only and apart from it the ‘duty of care’ of each individual involved must be emphasized. Codes of practice must be adhered to such that risks can be minimized to humans and machinery.

Other risks are the loss of data from the experiments due to computer failures, etc. It can easily be minimized by keeping multiple data back ups at different locations. Risk assessment basically will comprise an observation such that basic areas of risk assessment are covered as below:

- Risk identification
- Risk evaluation
- Risk control

The reference material can be found by browsing the internet and also from some course books from USQ, e.g. Engineering Management, Technology and Society, etc.

1.6 Risk Assessment

The correct assessment of various risks and safety issues involved in this research project must be analysed. The various processes such as mold preparation, raw material handling, casting of composites, removing of cured composites from casts, heat treatment of specimen in oven, tensile testing in laboratory, etc. all involve risk factors that must be taken into account.

At all times personal protective equipment must be used, workshop and laboratory rules and regulations must be adhered to. The personal protective gear include, eye protection-safety goggles, fully covered shoes, face masks, safety hand gloves for chemical handling, etc. While working in laboratory ventilation must be used at all times to get rid of toxic fumes generated during the composite formation processes.

The material safety data sheet related to the raw materials used are very useful in providing us various important facts about handling, careful use and related hazards.

1.6.1 Risk Assessment for Resin:

Product name: Hexion Cellobond J2027L (aka Phenol formaldehyde resin)

Use: Adhesive resin

Figure 1. 1: Hazard rating for resin

Risk

- Toxic by inhalation, skin contact and if swallowed
- Causes burns
- Carcinogenic effect
- May cause serious damage to eyes

Safety

- Keep locked up
- Keep container in well ventilated place
- Avoid exposure, keep container tightly closed
- Keep away from food, drink and animal feed

Swallowed

- Contact doctor immediately
- Do not vomit if swallowed
- Give patient water to rinse mouth
- Observe the patient carefully

Eye

- Immediately hold eyelids apart and flush the eye continuously with running water
- Continue flushing till 15 min or more till advised to stop by doctor
- Transport patient to doctor without delay

- Removal of contact lenses only to be taken by skilled personnel

Other details enlisted in the MSDS:

- Extinguishing media
- Fire Fighting
- Fire/ Explosion Hazard
- Fire Incompatibility
- Personal Protective Equipment
- Minor Spills
- Major spills
- Handling procedures
- Storage Requirements

1.6.2 Risk Assessment for Catalyst:

Product name: Hexion Phencat 15 (aka Phenolic resin hardener catalyst)

Use: Composite phenolic resin hardener

Figure 1. 2: Hazard rating for catalyst

Risk

- Harmful by inhalation and if swallowed
- Causes burns
- Risk of serious damage to eyes
- Respiratory problems

Safety

- Keep locked up
- Keep container in well ventilated place
- Avoid exposure
- Use water to clean floor or contamination
- Take off immediately contaminated clothing
- Immediately contact doctor in case of emergency

Swallowed

- If swallowed do not induce vomiting
- Observe the patient carefully
- Give water to rinse mouth
- Seek medical advise

Eye

- Immediately flush with running water
- Continue flushing till about 15 min.
- Transport to doctor as soon as possible
- Removal of contact lenses must be done only by an expert

Skin

- Immediately flush body parts
- Quickly remove all contaminated clothing
- Wash skin and hair with running water
- Transport to hospital or doctor immediately
- Burn: Immerse burnt part in cold running water for at least 10 to 15 minutes

Other related safety aspects covered in MSDS:

- Inhalation

- Notes to physician
- Extinguishing media
- Fire fighting
- Fire/ explosion hazards
- Personal protective equipment
- Minor spills
- Major spills
- Procedures for handling
- Storage requirements
- Appearance

Chapter 2 Literature Review

2.1 Fibre Composites

Composites have bee in use since a long time by ancient civilizations such as Romans, Egyptians, Chinese, etc. Many of these composite materials were manufactured by man by mixing two or more different materials to get desired properties. Many composites are naturally occurring as well such as wood, teeth, bones, etc.

The structure of a typical fibre reinforced composite comprises a matrix material and a reinforcing material. Thus basically fibre composite materials are made up of 2 phases: where the 2nd phase reinforces the 1st phase known as matrix. The fibre phase is responsible for bearing loads by their orientation in the matrix of composite.

2.1.1 Matrix

This part of the composite is mostly in larger quantity and homogeneous in the composite. The various matrices in a composite can be ceramic, metallic or polymeric. The matrix properties are enhanced when a composite is formed by addition of other constituent.

2.1.2 Reinforcement

Reinforcement increases the mechanical properties of the matrix. Generally reinforcement material is stronger and harder than the matrix, although it can be ductile as well to reduce the brittleness of the matrix. Thus we cam conclude that the mechanical properties of the composites are a function of this shape and dimensions of the reinforcement inter-phase. (Matthews; 2003)

The composite materials are generally classified as per their matrix materials, thus called as metal matrix composites (MMC), polymer matrix composites (PMC), ceramic matrix composites (CMC), etc. (Mallick 1997)

2.2 Classification of Composite Materials

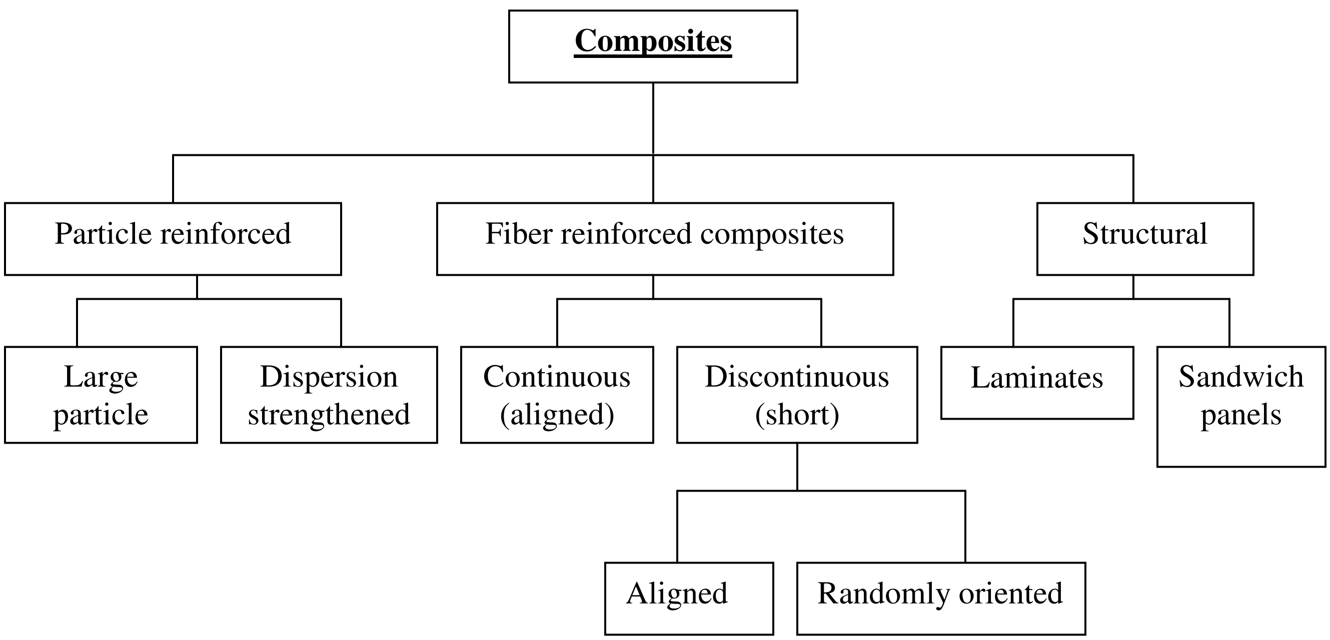

Figure 2. 1: Classification of composite materials (Mukhopadhayay, 2004)

2.3 Polymers

Polymers are materials having very high molecular weight, thus often referred to as macromolecules. Polymers and their derivatives (e.g. Plastics) have various uses today. They are relatively used in many applications these days and are manufactured by various methods accordingly.

Polymers due to their low densities as compared to metals, etc. are easier to shape and molded at relatively lower temperatures. It is due to these properties and ease of manufacturing that polymers have been replacing conventional materials such as metals, wood, glass, etc.

The diagram below show the classification of materials as polymers:

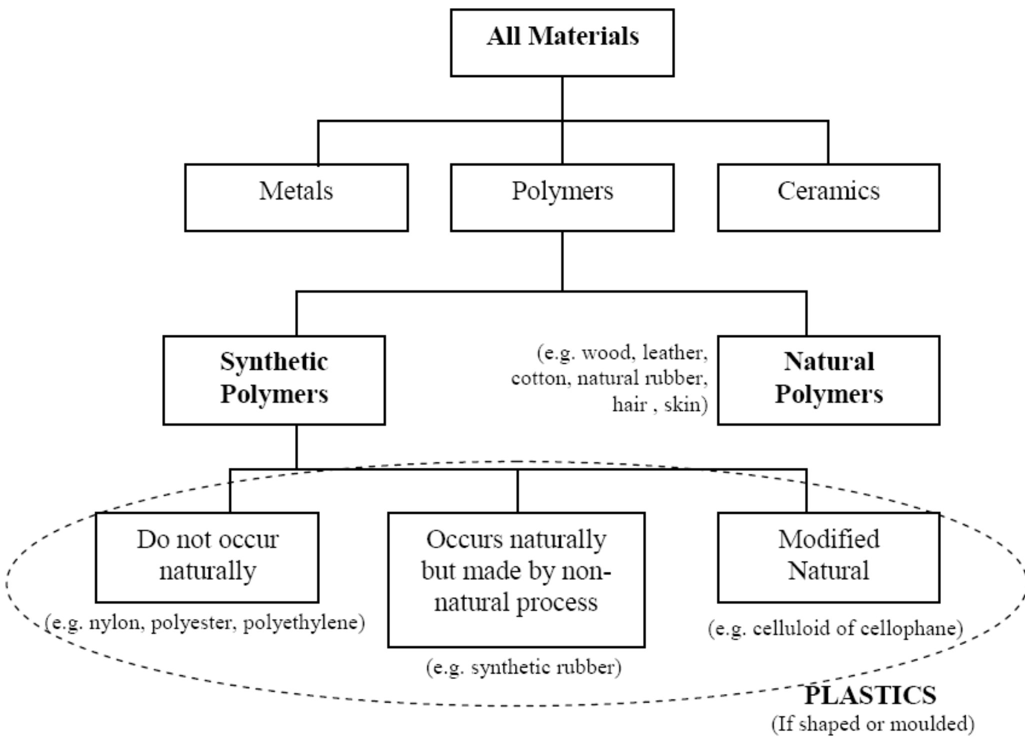

Figure 2. 2: Classification of materials into polymers/ plastics (Source: Strong 2000, p.2)

2.4 Polymer Composites

The various polymers shown below can be used to manufacture various composites by the use of different additives, fillers and various forming processes. The end product's property depends upon the application in which they would be used eventually. The table below shows some of the common polymers and their applications.

Polymer	**Application**
Amorphous	***Thermoplastics***
Polystyrene	Mass-Produced transparent articles, thermoformed packaging, Thermal Insulation (foamed)
Polymethyl methacrylate	Skylights, airplane windows, lenses, bulletproof windows, stop lights.
Polycarbonate	Helmets, hockey masks, bulletproof windows, blinker lights, headlights.
Un-plasticized poly vinyl chloride	Tubes, window frames, bottles, thermoformed packaging, gutters.
Plasticized poly vinyl chloride	Shoes, hoses, rotor-moulded hollow articles such as balls and other toys, calendered films for raincoats and tablecloths.
Semi-crystalline	
High density polyethylene	Milk and soap bottles, mass production of household goods of higher quality, tubes, paper coating.
Low density polyethylene	Mass production of household goods, grocery bags.
Polypropylene	Goods such as suitcases, tubes, engineering application (fibre glass reinforced), housings for electrical appliances.
Polytetrafluoroethylene	Coating of cooking pans, lubricant-free bearings.
Polyamide	Bearings, gears, bolts, skate wheels, pipes, fishing line, textiles, ropes.
	Thermosets
Epoxy	Adhesives, automotive leaf springs (with glass fibre), bicycle frames (with carbon fibre).
Melamine	Decorative heat resistant surfaces for kitchens and furniture, dishes.
Phenolics	Heat resistant handles for pans, irons and toasters, electric outlets.
Unsaturated polyester	Toaster sides, iron handles, satellite dishes, breaker switch housing (with glass fibre), automotive body panels (with glass fibre).

Table 2. 1: Examples of common polymers and their applications. (Source: 'Materials Science of Polymers for Engineering' T.A.Oswald, G.Menges. Hanser published NY, 1996)

2.4.1 Thermoplastics

Thermoplastics are the type of polymers which are able to flow when heated. They are solid when they have cooled but the flow characteristics are regained on heating. The flow can be explained by the ability of the polymer molecules to slide against each other. The thermoplastics are also of two types: amorous and semi-crystalline. Amorous thermoplastics have a random molecular distribution in their structure while the semi-crystalline thermoplastics have a particular order of structure.

2.4.2 Thermosets

Thermosetting resins are fluid at room temperature. This property is used in mixing various desired ingredients/ additives such as fillers, additives, etc. Phenolics, epoxies, polyamides, etc. are the most commonly used thermosetting resins used today. The selection of a particular resin depends upon the application in which it is to be used.

2.5 Materials Used To Manufacture Phenolic Resin Composites

2.5.1 Filler (Sawdust)

Sawdust can be found in abundance and is a natural by-product of sawing and milling process of wood. In this research three different sawdust sizes were used namely: 300 microns, 450 microns and 1.18 mm. In order to achieve these particulate sizes, manual sieves of similar size were used. After procurement of raw sawdust from wood mills, sieves were used to segregate it into three sizes for further use. Different specimen was formed using different percentage by weight of sawdust as filler from 5-15 %. The obtained tensile test results were then compared to obtain the optimum composition in the phenolic composite material.

2.5.2 Resin: Hexion Cellobond J2027L

Hexion Cellobond J2027L is the phenolic resin used in the preparation of composites in this research; it is actually the product name for phenol formaldehyde resin solution. It is a classic resin which is brownish and with a phenolic odour. The viscosity is around 2800 cp at 25 deg. C. Its composition consists of:

Phenol/ formaldehyde resin- 30-60%

Phenol- 1-10%

Formaldehyde- 1-5%

Water- 30-60%

It is worth noting that phenolic resins are thermosetting polymers with high chemical resistance and thermal stability but low toughness and mechanical strength. Also, they have intrinsic resistance to ignition, generate low smoke and relatively cheap.

2.5.3 Choice of Phencat 15 as Catalyst

We have a few choices of catalysts to go with phenolic resins, namely:

- Phencat 15
- Phencat 382
- UH

Phencat 15 is a fast acting catalyst among these. It is acid based and the reaction with phenolic resins is highly exothermic. Its typical composition is:

Xylenesulfonic acid- 70 to 90%

Phosphoric acid- 10 to 20%

Water- 1 to 10%

Phencat 382 is a relatively slow acting acid based catalyst. It combines with phenolic resins resulting in exothermic reaction. Its typical composition is:

Phosphoric acid- 40 to 80%

Water- 20 to 60%

UH is typically urea hydrochloride solution with 1:1 ratio of urea to hydrochloric acid. The reaction is highly exothermic in this case and hence making it even more dangerous to use.

2.6 Phenolics

Phenolics are very hard materials as they are formed when reaction takes place between phenol and formaldehyde. This results in the formation of three-dimensional polymer linkages and crosslinks. Bakelite was one of the first phenolic based thermoset materials used extensively. These became very popular as they are one of the lowest costing engineering materials on a cost per volume basis.

The figure below shows the condensation polymerisation reaction between phenol and formaldehyde, producing Phenolformaldehyde.

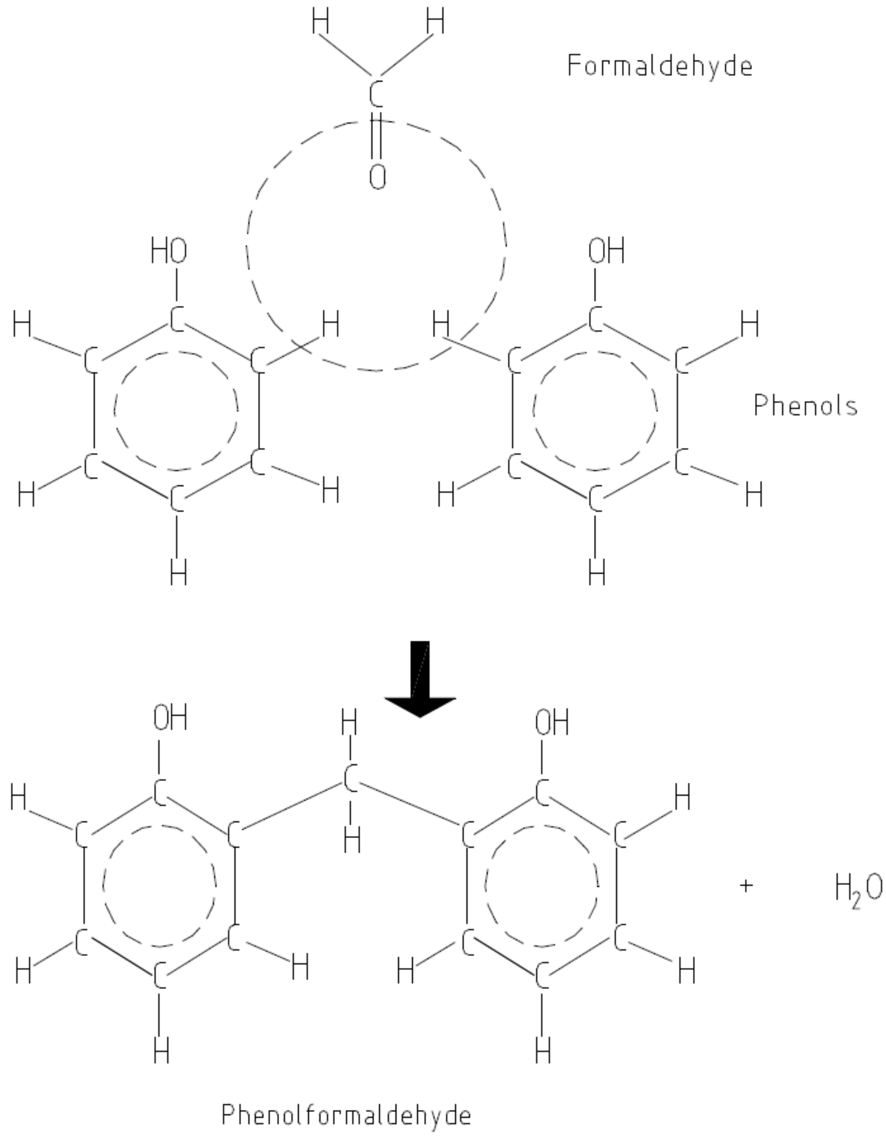

Figure 2. 3: Condensation polymerization of Phenolformaldehyde resins

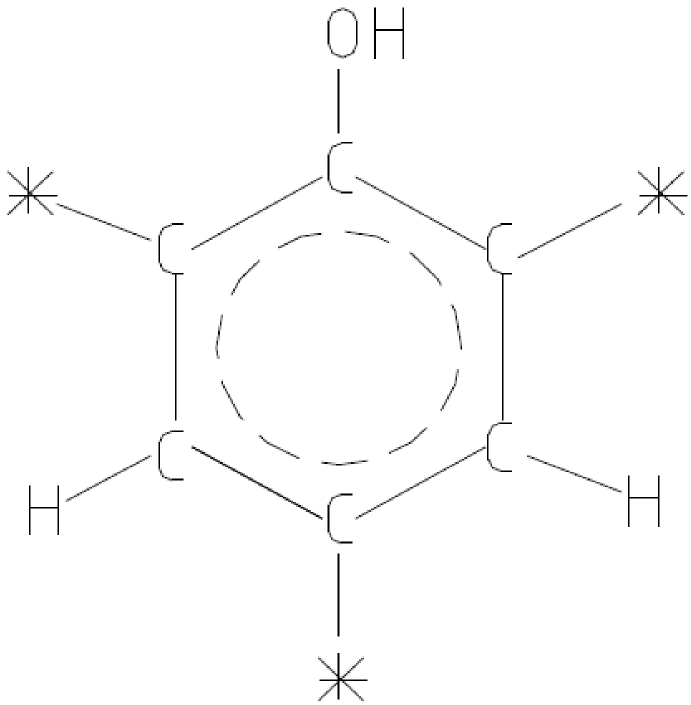

Figure 2. 4: Phenol with active sites marked *

As can be seen in the figure above, Phenol has three active sites on the benzene ring which is one more than polymerisation requires and thus cross linking can take place during reaction.

2.6.1 Resoles and Novolacs

The condensation reaction of phenolics can be carried out in two different conditions resulting in different intermediate materials: Resoles and Novolacs. Both of these intermediate products are used in the molding process, although Novolacs are more common (Shackelford, 1992; Smith and Hashemir, 2006).

Resoles are formed by carrying out by a controlled condensation polymerisation reaction in an alkali solution with excess formaldehyde. These results in the formation of a linear, non-crosslinked polymer liquid called resole. The resole can be molded by heating the viscous liquid which achieves cross linking. Since a crosslinked part can be achieved by simply heating the resoles, these are called as one-stage resins (Smith and Hashemir, 2006)

Novolacs are made by the reaction between phenol and insufficient formaldehyde in an acid solution at 100 ºC. Here insufficient formaldehyde has been used as opposed to the excess use in the case of resole formation. The initial reaction results in the formation of a brittle thermoplastic resin that can be melted but on heat treatment will not become solid. A common curing agent is required to overcome this. Commonly a curing agent called hexamethylene tetramine (Hexa) is added. Hexa decomposes on heat treatment producing ammonia which provides the required methylene cross linked structure. Since, a second material must be added to Novolacs, they are called two-stage resins. The temperature required for the cross linking ranges from 120 to 177 ºC. Fillers can then be added as they reduce shrinkage during molding, lower the costs and improve strength. They can also be used to improve electrical and thermal insulating properties and chemical resistance (Shackelford, 1992; Smith and Hashemir, 2006; Strong, 2006; Clark, 1996).

Chapter 3 Experimental Methodology

3.1 Manufacture of Phenolic Resin Composites

3.1.1 Sawdust Sieving

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

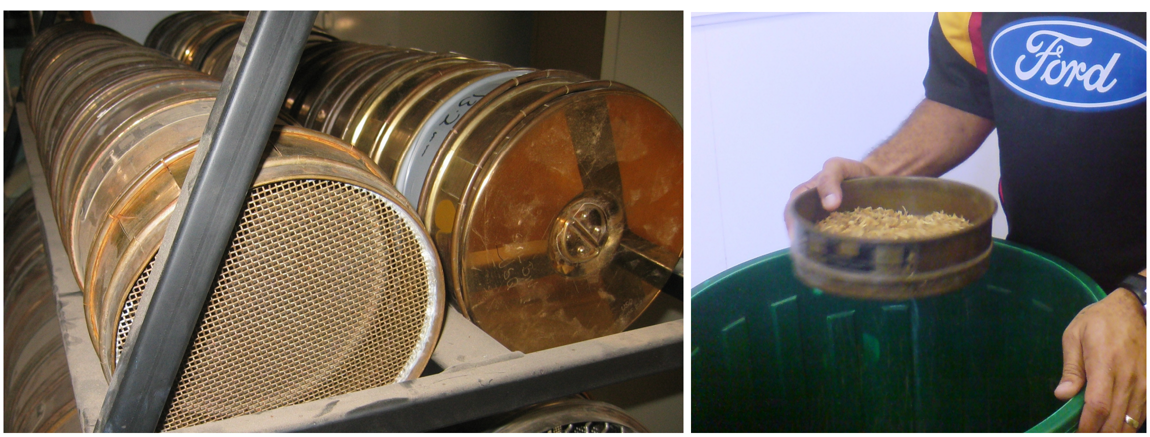

Figure 3. 1: Sieves and manual sieving

3.1.2 Preparation of the Open Mold/ Cast

It is very important to prepare the mold before mixing of resin, catalyst and sawdust. The reason being that once the ingredients are mixed the curing process and reactions have already started to take place and with time the fluidity of the mixture decrease rapidly making it very difficult for us to pour it into the mold.

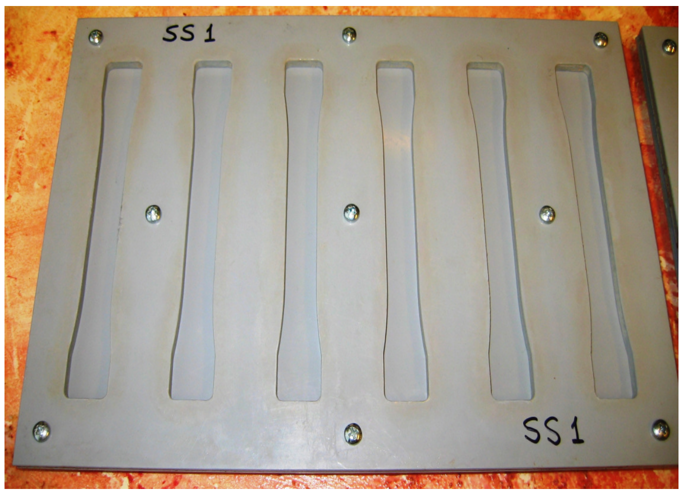

Figure 3. 2: Prepared PVC mold

Firstly we need to clean the mold surface very nicely using scrapper, etc. This initial cleaning facilitates the specimen removal after the curing has taken place. After this we clamp the upper and lower molds together using screws and wing nuts. Finally apply some wax over the surface where the molten material is going to come in contact with the mold.

Figure 3. 3: Application of wax (lubricant) to the mold

Earlier instead of wax, canola oil was also tried for lubrication, but results were not that satisfactory which could be due to the unstable nature of the liquid oil. It tends to form globules and did not stay evenly spread after a while.

3.1.3 Preparation and Weighing Of Ingredients

The resin is now measured using an electronic measuring scale in a clean container. Catalyst and appropriate size of sawdust is also measured separately and kept in clean containers ready to do the mixing.

3.1.4 Mixing Of the Ingredients

Before we proceed for mixing, the ventilator in the laboratory must be started in exhaust mode so as to get rid of toxic fumes being generated during mixing process.

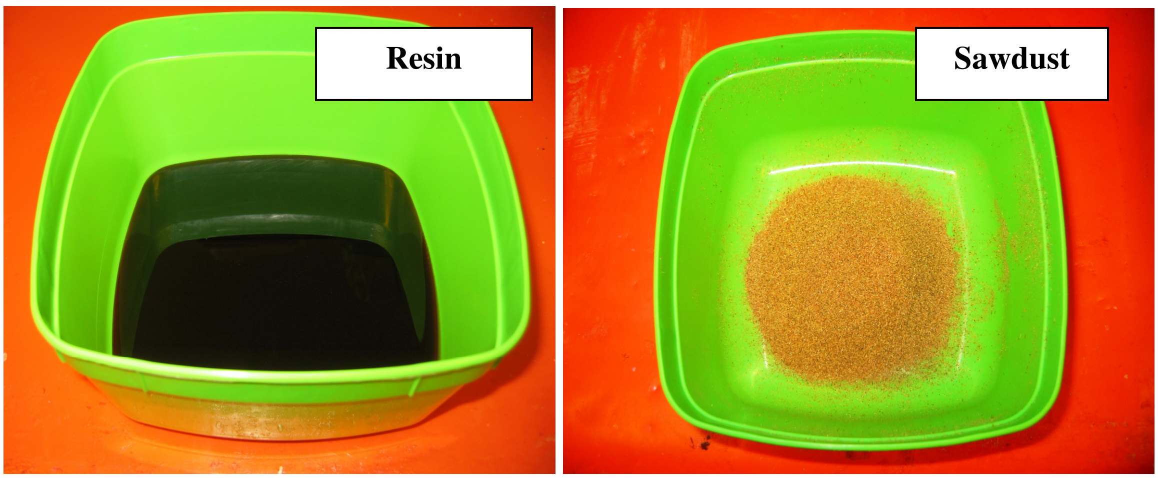

Figure 3. 4: Measured resin and sawdust (ready to be mixed)

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

Figure 3. 5: Resin, sawdust and catalyst mixed by gradual stirring

It must be noted that the inclusion of air bubbles into this mixture at this stage will result in the production of inferior specimens. These specimens would give lesser mechanical properties upon testing.

3.1.5 Pouring In the Mold

Figure 3. 6: Resin, catalyst and sawdust mixture poured in the mold

The prepared mixture is then poured very carefully in the already prepared molds using spoon. Care must be taken as to over-fill or under-fill. We need to get the correct thickness in the specimens. Overfilled molds would also pose difficulty when we try to take the specimens out from the molds.

3.1.6 Natural Curing (Hardening Process)

Figure 3. 7: Natural curing of resin mixture at room temperature for 48 hours or more

The molds are now left, after proper marking, at a safe place for natural curing at room temperature. It has been found that the specimens take from 24 – 48 hours to set. Still, the specimens could be left a bit longer to cure as it will make sure that they have set properly.

As can be seen we are producing 06 nos. specimens for each mixture. The specimen is as follows: Length- 150 mm, Width at widest point- 20 mm, Width at centre- 15 mm and thickness- 4 mm.

3.1.7 Post Curing (Heat Treatment in Oven)

Figure 3. 8: Naturally cured specimen after removal from mold (Ready for heat treatment)

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

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

Post curing of lightly cured resin composite will reduce the negative effects of polymerization shrinkage and an increase in the hardness and wear resistance of the composite. [Marais J. T et al, 1999, 54(3) p. 123-5].

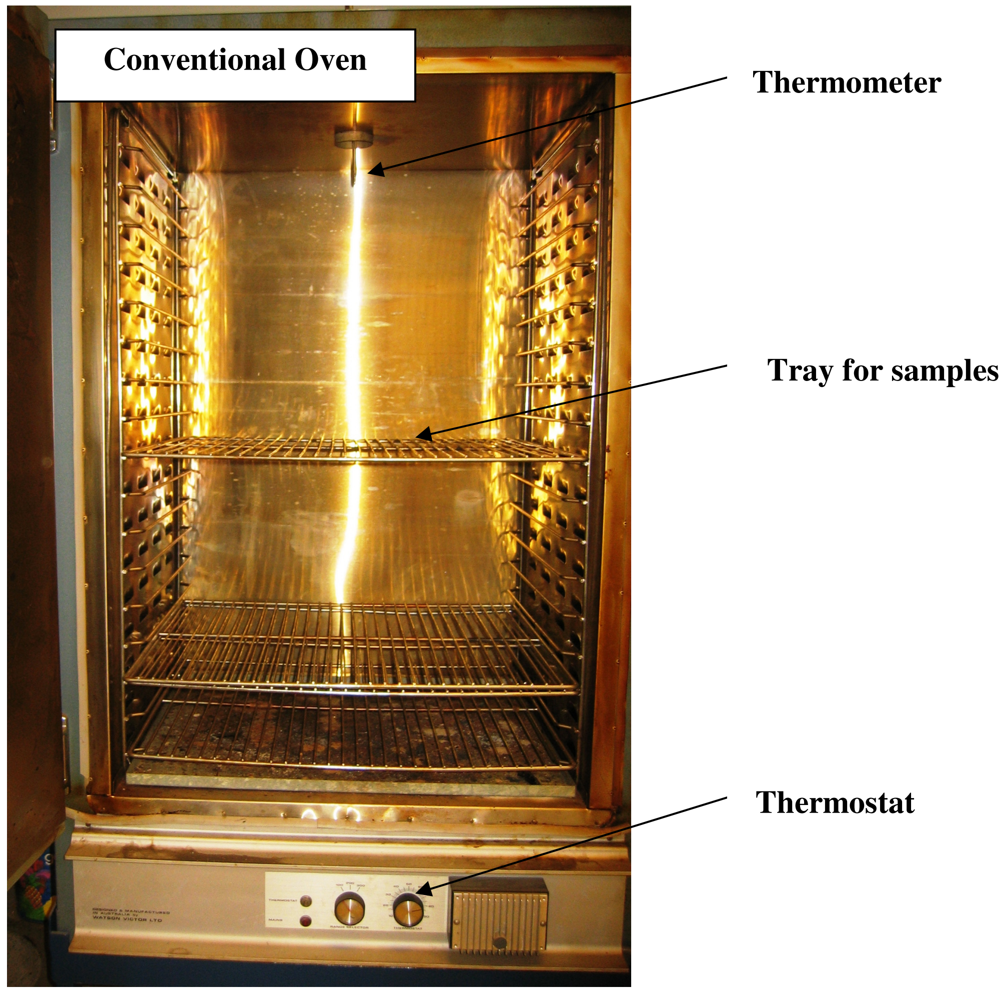

Figure 3. 9: Oven for heat treatment of specimen

It has been found by earlier experiments that heating the specimens directly at high temperature would increase brittleness in the specimens. Hence the heating is required to be done gradually in stages.

We must be quite carefully during the heating process as it has been found in earlier experiments that the specimens tend to warp during heating. To prevent this from happening, the bunch of specimen is made and weights put at the ends during the heating. This will produce generally straight and uniform shape.

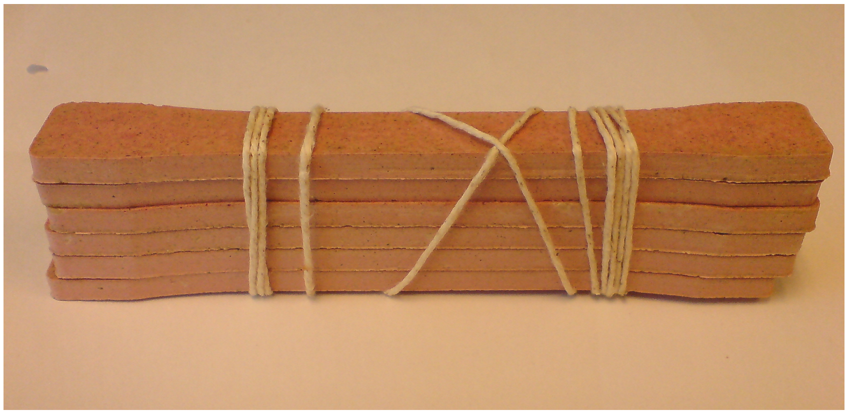

Figure 3. 10: Specimen tied together with thread to prevent warping during heat treatment

One of the advantages of using conventional oven is that the heating of the samples will be even. Although on its flip side, conventional ovens take more time and are power hungry.

The resin in discussion is Phenol- formaldehyde (PF), which are formed by the reaction of phenol with formaldehyde. We can produce different types of resin composites by doing variations during the formation process: variation in the reaction time, ratio of formaldehyde to phenol, reaction temperature, catalyst type, etc.

The phenolic resins are formed as a result of complex polymerization along with the generation of water and formaldehyde. Some voids are also formed as a consequence. This makes the temperature controlled heating of these materials to enable the elimination of volatile byproducts. This will result in the formation of defect free and robust components.

3.2 Tensile Property Testing (ASTM D 638)

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

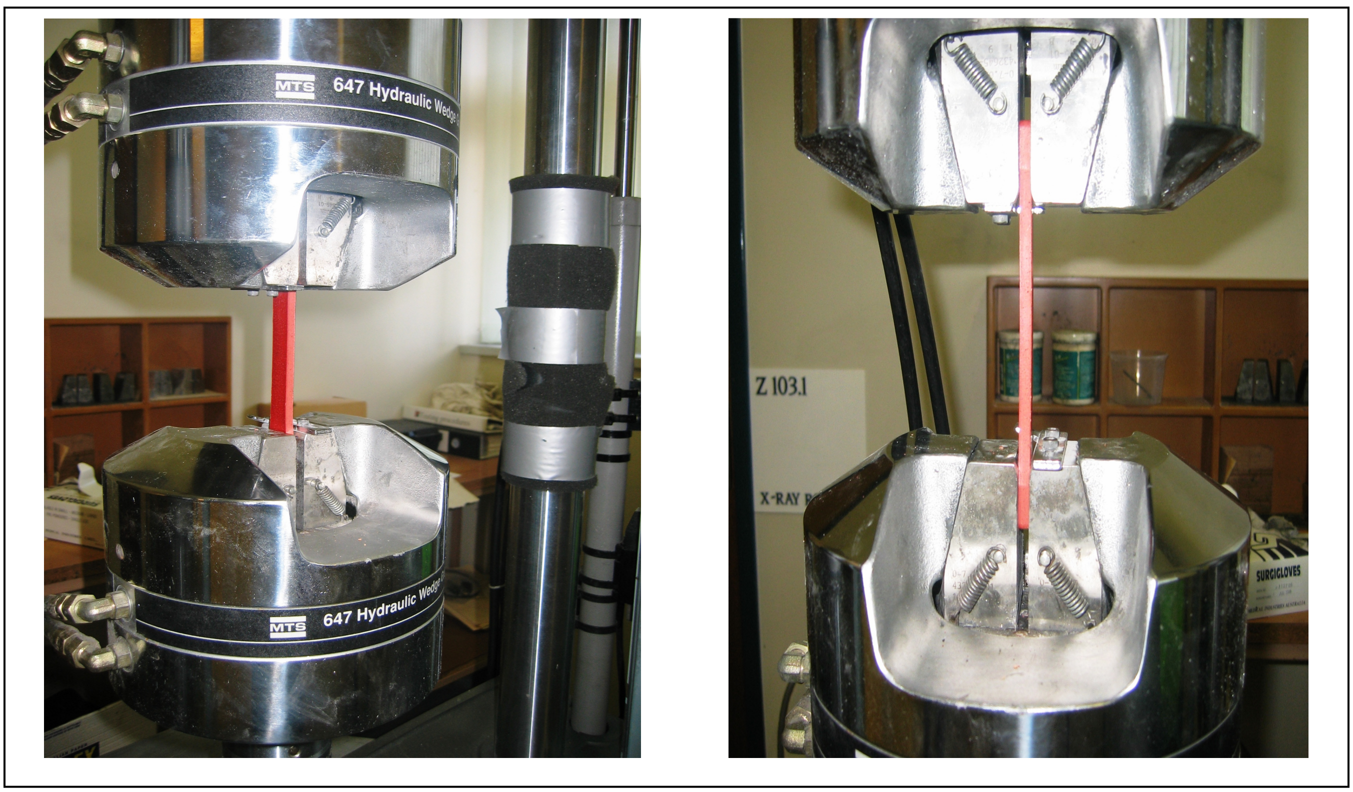

Figure 3. 11: Specimen held in the hydraulic wedge grips of Tensile Testing Machine (Ready for testing)

The generally accepted test method standard for plastics and low strength composites is ASTM D 638 [‘Test Method for Tensile Properties of Polymer Matrix Composite Materials”, ASTM Standard D 638-95, ASTM, Philadelphia, PA (1996).] This incorporates an un-tabbed, dog-boned, flat specimen of various prescribed geometries. The ends are to increase the cross sectional area and thus reduce the stresses there as compared to that in the gage length and thus hopefully maintaining failure in the gage length during the testing.

Universal testing machine in USQ lab uses hydraulic wedge grips, where the gripping pressure is controlled by the operator. These specially designed grips also prevent the side ways movement of the samples during testing. Some other types of testing devices also use mechanical type of grips where gripping pressure is independent of the operator. Hydraulic type gripping gives greater control but the pressure has to be right. If too little a pressure is applied, the specimen will slip, hence ruining the test. Otherwise too much of pressure could possibly crush the specimen ends, ruining the tests again.

Before commencing the testing, the specimen is measured for their thickness and breadth using digital vernier calipers. These values are then fed into the software we would be using, namely: TestStar 2s. We then select the specific type of test that we need to do in this software. The parameters for specific tests, in this case tensile test (ASTM D 638) are already fed into the database of TestStar 2s. The specimen is held in the hydraulic vices of the machine and the test is then RUN and various parameters recorded and saved on connected computer for analysis later. The software will use the user input data and experimental data to evaluate the stress values at various critical points during the elongation.

It is critical for achieving precise data from these tests that the specimen is of correct shape and size among other factors. The warped or bent samples would not give true readings, also thicker or thinner samples would give incorrect test data. The care must be also taken during the casting phase, especially making sure that there is no inclusion of air bubbles during mixing or pouring of mixture into molds. Also, the samples must be allowed to get cured completely before trying to remove from the molds. Extra care taken by putting weight on top of specimen during heat treatment goes a long way in getting best samples for testing by eliminating pre-stress factors.

3.3 Safety Issues and Precautions

We need to be fully aware of the workplace safety and health regulations before we proceed to do the work in the laboratories. This objective is generally achieved by a safety familiarization demonstration conducted by laboratory staff. Material Safety Data Sheet (MSDS) is also provided beforehand such that we are familiar with the chemicals we are going to deal with during the project. The MSDS provides information on the hazards, preventive and emergency measures associated with the chemical handling procedure. The figures given below show the hazard ratings of resin: Hexion Cellobond J2027L and catalyst: Hexion Phencat 15. It is always advisable to keep a copy of the MSDS near to the chemical handling area (laboratory).

We must be careful and don proper personal protective equipments (PPE) at all times during our stay in the laboratories. PPE generally includes, safety shoes, safety gloves, protective glasses, covered clothing. Also the work area must be properly lit and ventilated at all times. The work in the laboratories must only be commenced after informing the lab in-charge. Housekeeping is very essential and all the chemicals, tools, etc. must be stowed nicely after use.

3.4 Resource Analysis

The experiments basically need various resources required to carry out the experiments and produce the final specimens.

The most critical to the experiments are the supply of resins and catalyst. The suppliers for Resin: Hexion Cellobond J2027J and Catalyst: Hexion Phencat 15 is:

- Hexion Specialty Chemicals Pty Ltd, Murarrie (QLD) and
- Hexion Specialty Chemicals Pty Ltd, Laverton North (VIC).

The sawdust can be procured in bulk, free of cost from local sawmills. Care must be taken to take dry sawdust with no contamination with soil, leaves, etc.

The safety gears are provided by the supervisor. These gears normally include:

- Safety chemical grade gloves
- Disposable surgical gloves and other disposable gloves
- Chemical mask and dust masks
- Safety glasses.

Other things needed to do the experiments vary as per the need:

- Cast/ molds (02 sets)
- Plastic containers, plastic spoons, rags, wax, scrapper, screws and wing nuts, screw driver, etc.

The estimate should be made and things have to be ordered for acquisition much more in advance. The requirements are to be reported to the supervisor directly such that he can place the orders as per the demand and budget allocated for the project. It must be kept in mind that the project has limited budget allocated and hence resources needs to be used judiciously and wastage has to be kept to minimum. Care must be taken in storing the resources as well. After use, the chemicals and other tools must be returned to their original place so that others may find it without hassle. The experimental work such as casting, natural curing, etc. is mostly done in USQ laboratory- Z106.

Other very critical equipments for the successful completion of the research are:

- Tensile testing machine (USQ laboratory- Z105)
- Conventional oven (USQ laboratory- Z113)

Chapter 4 Results and Discussions

Table 4.1 below shows the values of tensile strength for specimens related to this research work. Tensile strength has been found for a sample with no sawdust. This is for reference and to also compare the improvement in the tensile strength on addition of sawdust as fillers in phenolic resin composite materials.

<u>0% Sawdust:</u>

We can see in the Table 4.1 that the tensile strength for 0% sawdust is only 1.17 MPa, which is relatively very low as compared to other values for sawdust reinforced resins.

<u>300 µm Sawdust:</u>

We can see that the maximum tensile strength achieved is 12.38 MPa for 5% sawdust w/w (300 µm). Also, 15% sawdust for same size sawdust gives us strength of 11.07 MPa. The tensile strength for 15% sawdust is only slightly lower (1.31 MPa) than for 5% sawdust but this would mean much lower manufacturing cost due to increased sawdust content in the final composite. The value of tensile strength for 10% sawdust is lower than both 5% and 10% sawdust specimens.

<u>425 µm Sawdust:</u>

The tensile strength for 15% w/w of sawdust is 10.63 which is more than tensile strength for 5% (2.77 MPa) and 10% (4.95 MPa) sawdust. The strength trend is increasing as we are increasing the percentage of sawdust of this size.

The use of a particular combination of sawdust percentage and particle size would depend upon the application and factors such as strength, cost, etc. The best strength is obtained for 5% sawdust (300 µm).

Tables of calculated values of tensile strength for oven cured composite specimen.

Tensile Strength (MPa) = Peak Stress (MPa)

Specimen #	**1**	**2**	**3**	**4**	**5**	**6**	**Average**
No Sawdust							
0% Sawdust	1.07	1.04	1.40	NA	NA	NA	**1.17**
300 µm Sawdust							
5% Sawdust	13.50	11.79	11.30	12.94	11.70	13.06	**12.38**
10% Sawdust	6.42	6.59	9.78	9.70	6.74	4.21	**7.24**
15% Sawdust	10.46	14.16	10.56	9.10	NA	NA	**11.07**
425 µm Sawdust							
5% Sawdust	1.63	3.69	2.68	2.79	3.33	2.52	**2.77**
10% Sawdust	5.23	4.99	2.67	7.14	5.02	4.65	**4.95**
15% Sawdust	8.11	10.98	13.31	9.16	12.02	10.18	**10.63**
1.18 mm Sawdust							
5% Sawdust	1.67	1.64	1.81	1.65	1.94	1.85	**1.76**

Table 4. 1: Tensile strength of specimen for various sizes and percentage of sawdust

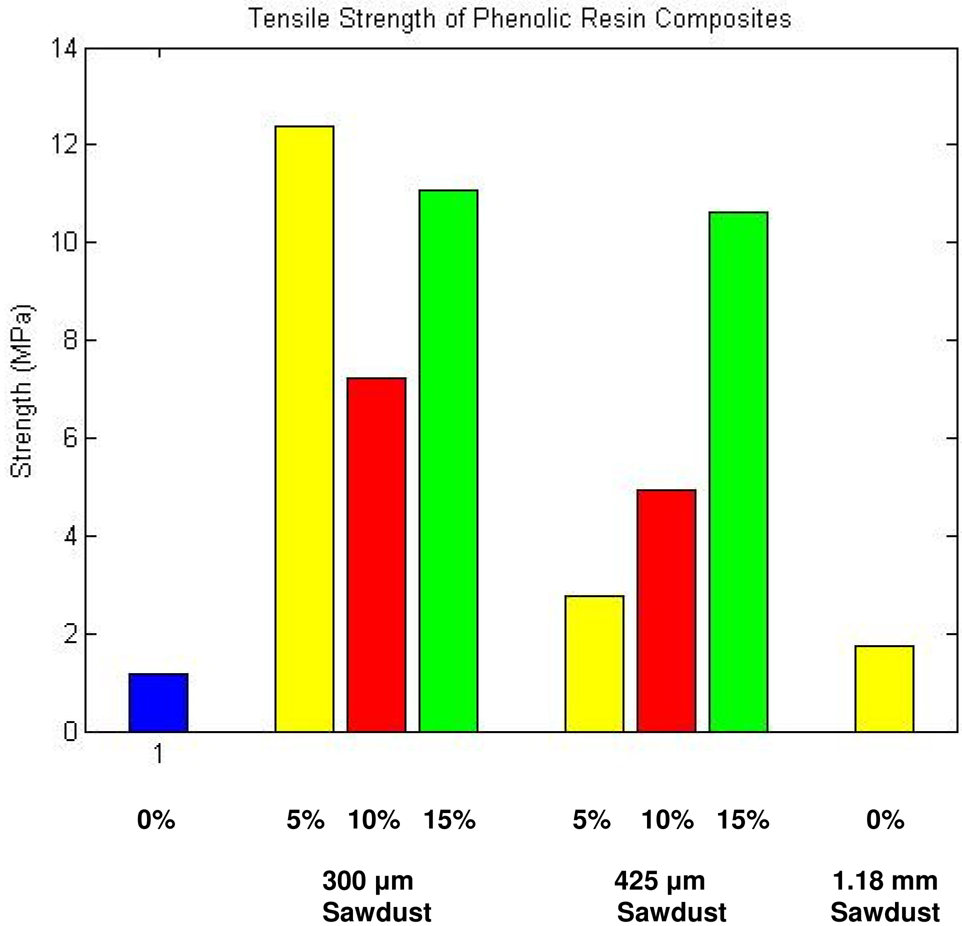

Figure 4. 1: Tensile strength of various phenolic resin specimens

Conclusion

The bar chart (Figure 4.1) given above depicts the values of tensile strength for comparison. Clearly the 300 μm sawdust gives the best results, the highest value being 12.38 MPa for 5% sawdust w/w. This is approximately 10.5 times more than the tensile strength of composite with no sawdust (1.17 MPa). This clearly demonstrates that sawdust gives additional strength to the composite matrix due to its fibrous nature and significantly increases the strength. The addition of sawdust also brings down the overall cost of the composite material. The density of sawdust is less than the resin and catalyst and thus they can replace them in larger volume to cut down cost.

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Appendix A: Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

VERSION B

FOR:	**SHASHI SHEKHAR (00500 694 75)**
TOPIC:	TENSILE STRENGTH OF SAWDUST REINFORCED PHENOLIC COMPOSITES**.**
SUPERVISOR:	Dr. Harry Ku
SPONSOR/S:	Dr. Harry Ku and Dr. F. Cardona (Faculty of Engineering and Surveying, USQ)
ENROLMENT:	ENG4111 – S1 2008; ENG4112 – S2 2008
PROJECT AIM:	The project involves the production of a range of phenolic resin composite specimens with different percentage by weight of saw dust as fillers. Tests will be conducted on the specimens after preliminary curing and post curing in ovens to evaluate its tensile properties. Findings will be analysed in detail in order to establish behaviour trends and formulae that can be used for theoretical prediction of filled polymer behaviour.

PROGRAMME TIMELINE:

1. Safety orientation in the lab, equipment familiarisation and literature reviews.

   Begin : 3rd March 2008

   Completion : 20th March 2008

   Approx. Hours : 30 hours

2. Sieving and segregating sawdust for the tests.

   Begin : 25th March 2008

   Completion : 7th April 2008

   Approx. Hours : 30 hours

3. Casting specimens in the laboratory and curing.

   Begin : 9th April 2008

   Completion : 18th April 2008

   Approx. Hours : 25 hours

4. Perform tensile strength test and examination of specimens.

   Begin : 21st April 2008

   Completion : 16th May 2008

   Approx. Hours : 40 hours

5. Analysis of results.

   Begin : 19th May 2008

   Completion : 2nd June 2008

   Approx. Hours : 40 hours

6. Draw up conclusions.

Begin : 3rd June 2008

Completion : 27th June 2008

Approx. Hours : 50 hours

7. Software package analysis (Time permitting)

Begin : 30th June 2008

Completion : 11th July 2008

Approx. Hours : 20 hours

8. Discussion for the thesis outline with supervisors.

Begin : 14th July 2008

Completion : 1st August 2008

Approx. Hours : 20 hours

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

Begin : 4th August 2008

Completion : 22nd August 2008

Approx. Hours : 60 hours

10. Final draft of thesis for incorporating modifications suggested by supervisor.

Begin : 25th August 2008

Completion : 12th Sept 2008

Approx. Hours : 60 hours

11. Complete the thesis in requested format.

Begin	: 15th September 2008
Completion	: 31st October 2008
Approx. Hours	: 40 hours

AGREED:

___________________ (Student)   __________________________ (Supervisor)

(Date)_____/______/____   _____/_____/______

Appendix B: Formation of Phenol Formaldehyde

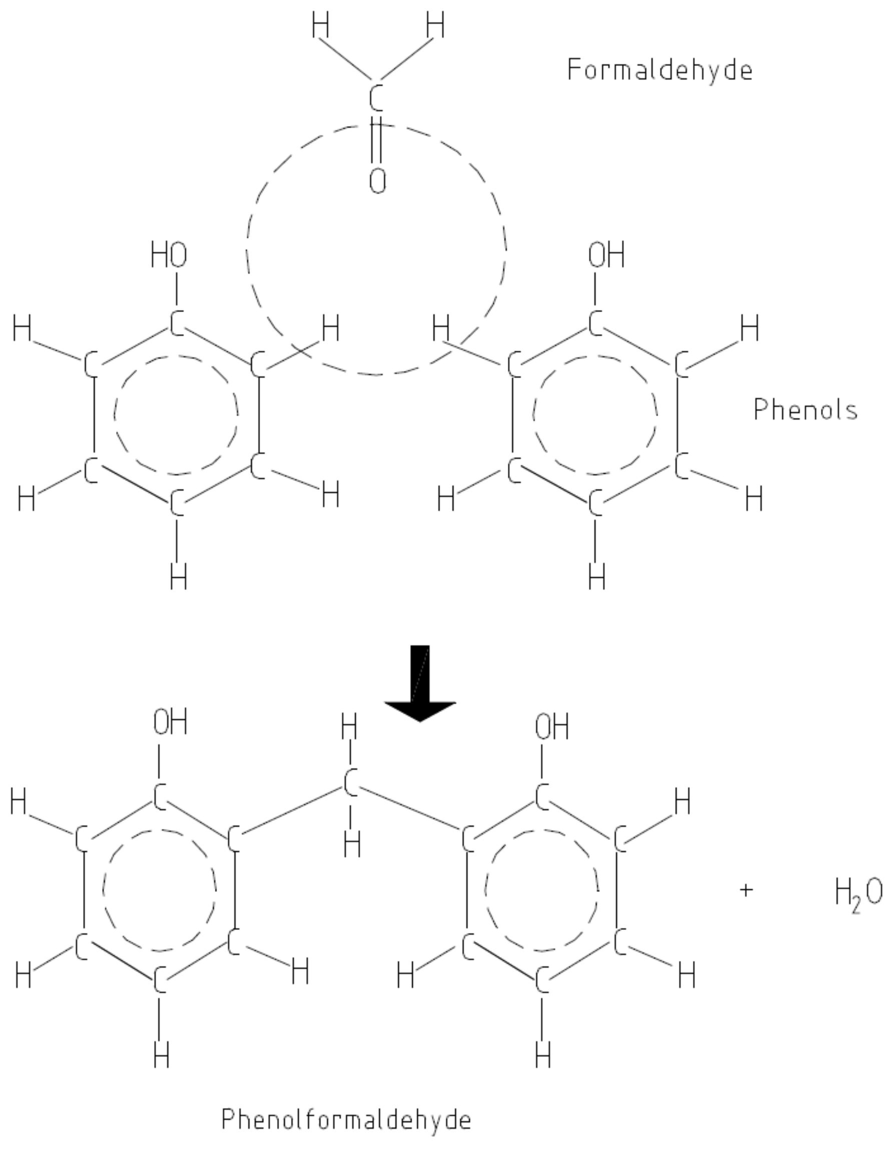


Figure B. 1: Condensation polymerization of Phenolformaldehyde resins

Appendix C: Phenol with Active Sites

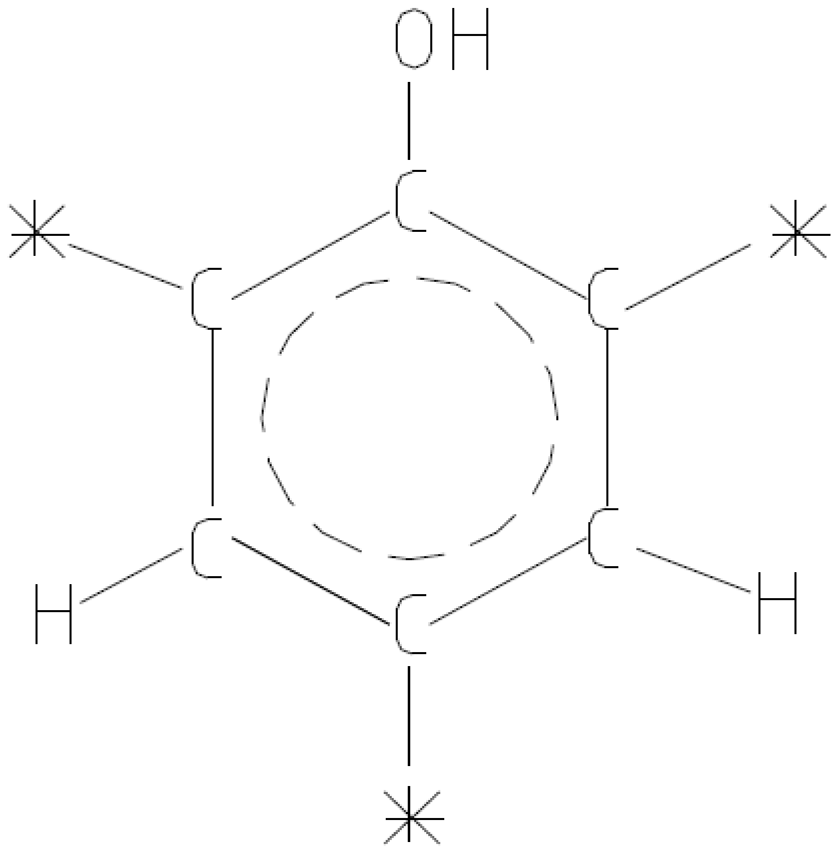


Figure C. 1: Phenol with active sites marked 

Appendix D: MTS 810 Tensile Testing System Data & Plots

The generally accepted tensile test method standard for plastics and low strength composites is ASTM D 638.

Tensile Test Plot Obtained On MTS 810 For:

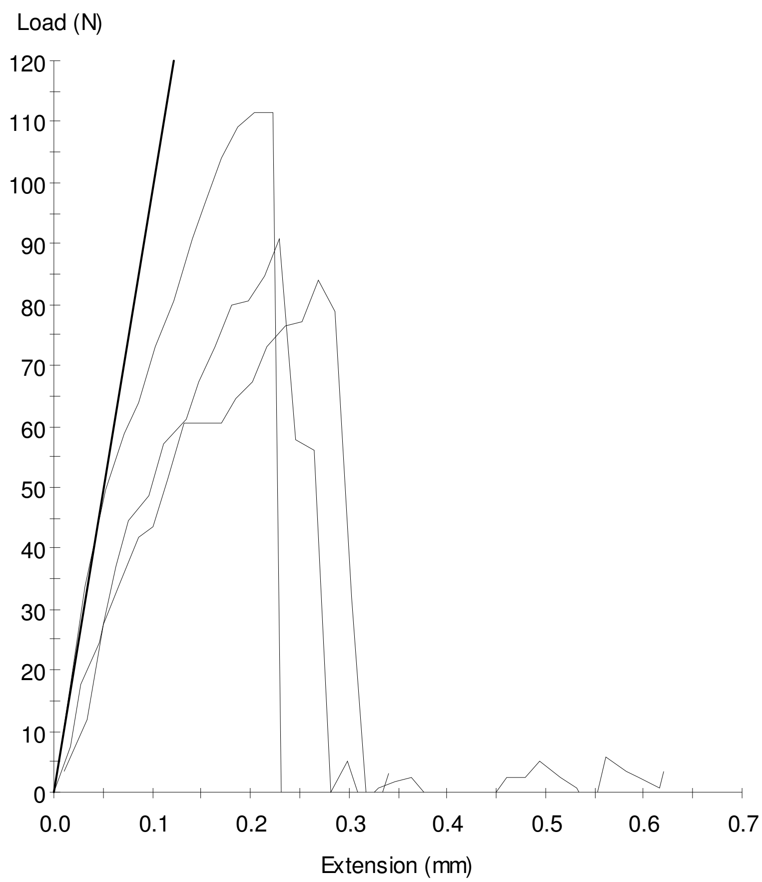
Sawdust: 0% by Weight

shashi-sd-0%

Test Date : 11/09/2008
Method : MMT Tensile Test with return.msm
Specimen Results:

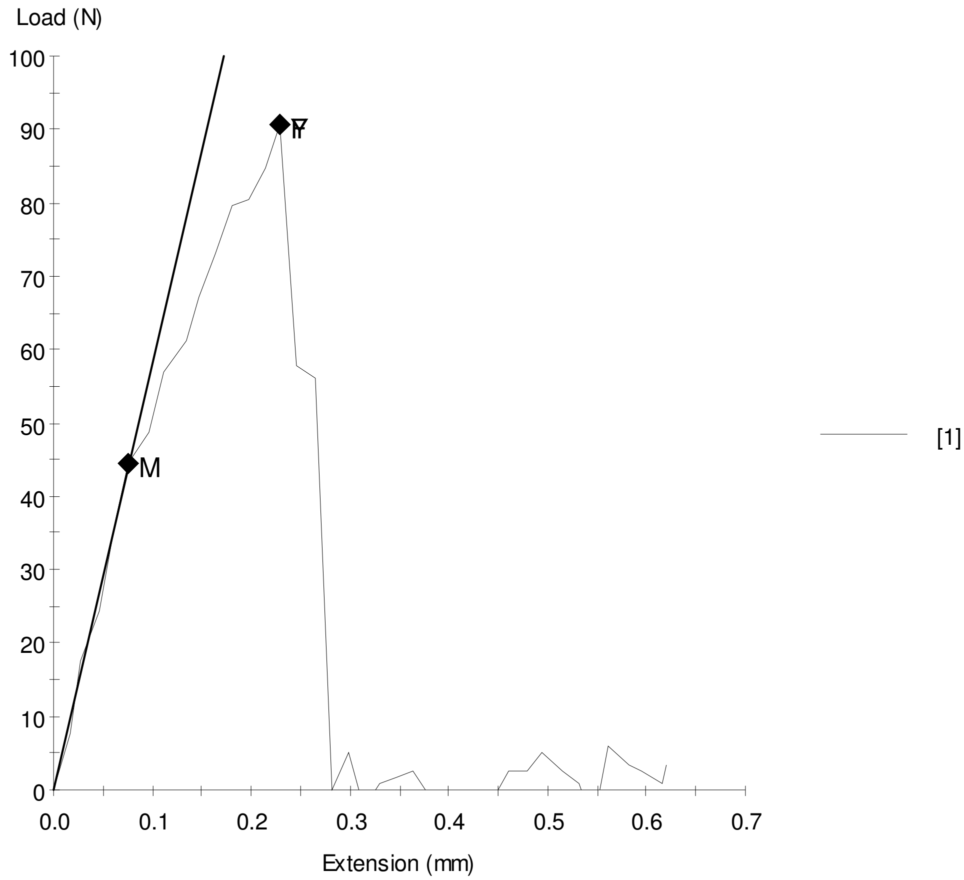
Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	5.800	14.550	84	91	1.07	91	1.07
2	5.620	14.380	81	84	1.04	79	0.98
3	5.500	14.450	79	112	1.40	112	1.40
Mean	**5.640**	**14.460**	**82**	**95**	**1.17**	**94**	**1.15**
Std Dev	**0.151**	**0.085**	**3**	**14**	**0.20**	**17**	**0.22**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.229	0.577	48.677				
2	0.287	0.748	60.427				
3	0.223	0.739	58.748				
Mean	**0.246**	**0.688**	**55.951**				
Std Dev	**0.035**	**0.096**	**6.355**				



11/09/2008

Sample ID: shashi-sd-0%-1.mss
Specimen Number: 1
Tagged: False

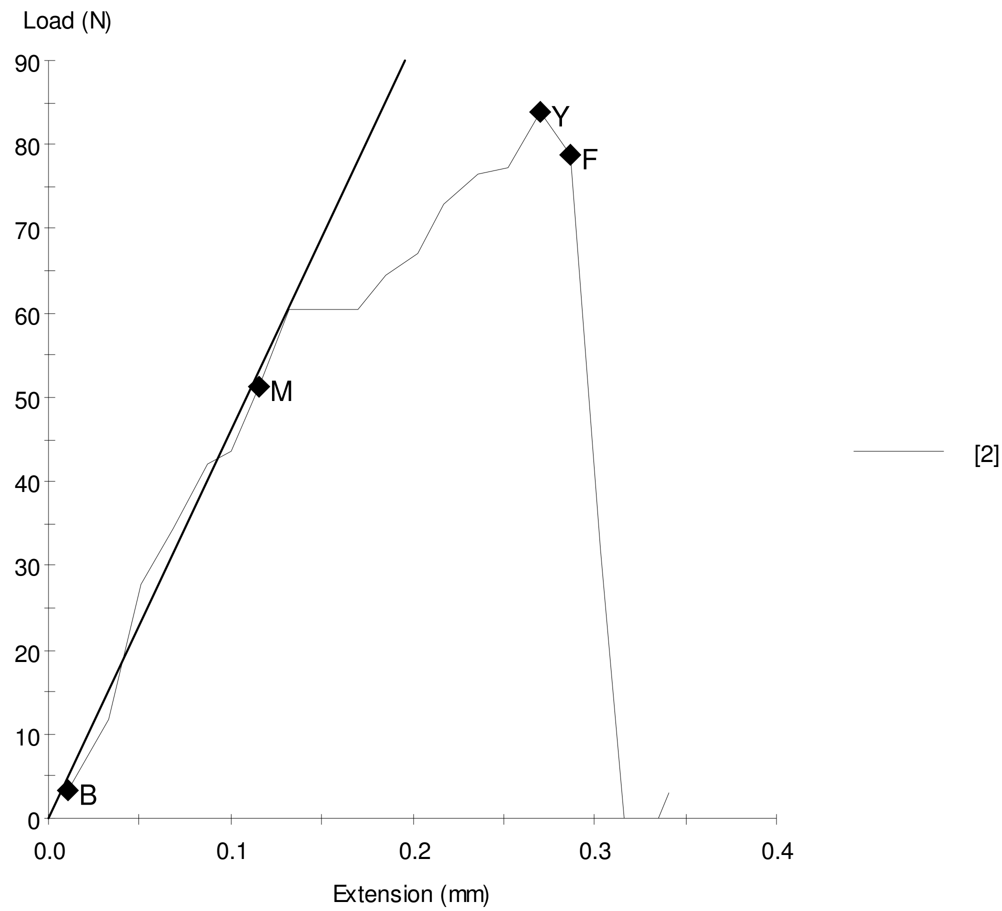


Specimen Results:

Name	Value	Units
Thickness	5.800	mm
Width	14.550	mm
Area	84	mm^2
Peak Load	91	N
Peak Stress	1.07	MPa
Break Load	91	N
Break Stress	1.07	MPa
Elongation At Break	0.229	mm
Stress At Offset Yield	0.577	MPa
Load At Offset Yield	48.677	N

11/09/2008

Sample ID: shashi-sd-0%-2.mss
Specimen Number: 2
Tagged: False

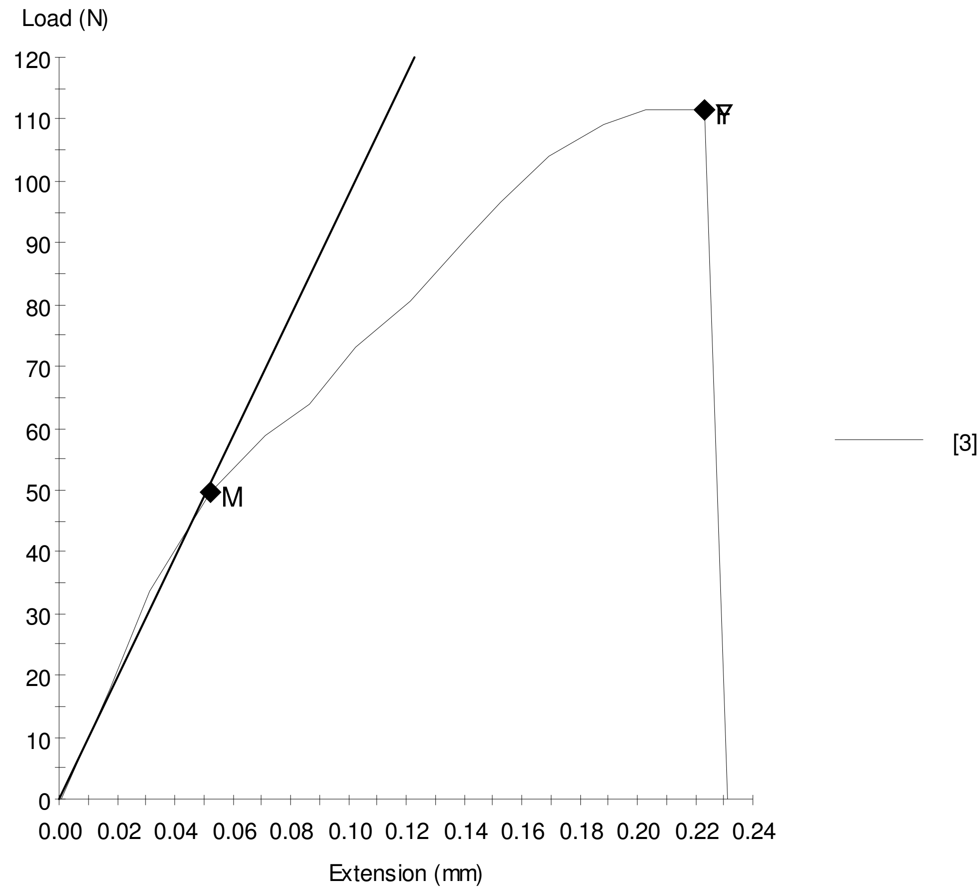


Specimen Results:

Name	Value	Units
Thickness	5.620	mm
Width	14.380	mm
Area	81	mm^2
Peak Load	84	N
Peak Stress	1.04	MPa
Break Load	79	N
Break Stress	0.98	MPa
Elongation At Break	0.287	mm
Stress At Offset Yield	0.748	MPa
Load At Offset Yield	60.427	N

11/09/2008

Sample ID: shashi-sd-0%-3.mss
Specimen Number: 3
Tagged: False



Specimen Results:

Name	Value	Units
Thickness	5.500	mm
Width	14.450	mm
Area	79	mm^2
Peak Load	112	N
Peak Stress	1.40	MPa
Break Load	112	N
Break Stress	1.40	MPa
Elongation At Break	0.223	mm
Stress At Offset Yield	0.739	MPa
Load At Offset Yield	58.748	N

Tensile Test Plot Obtained On MTS 810 For:

Sawdust: 300 Micron -5% by Weight

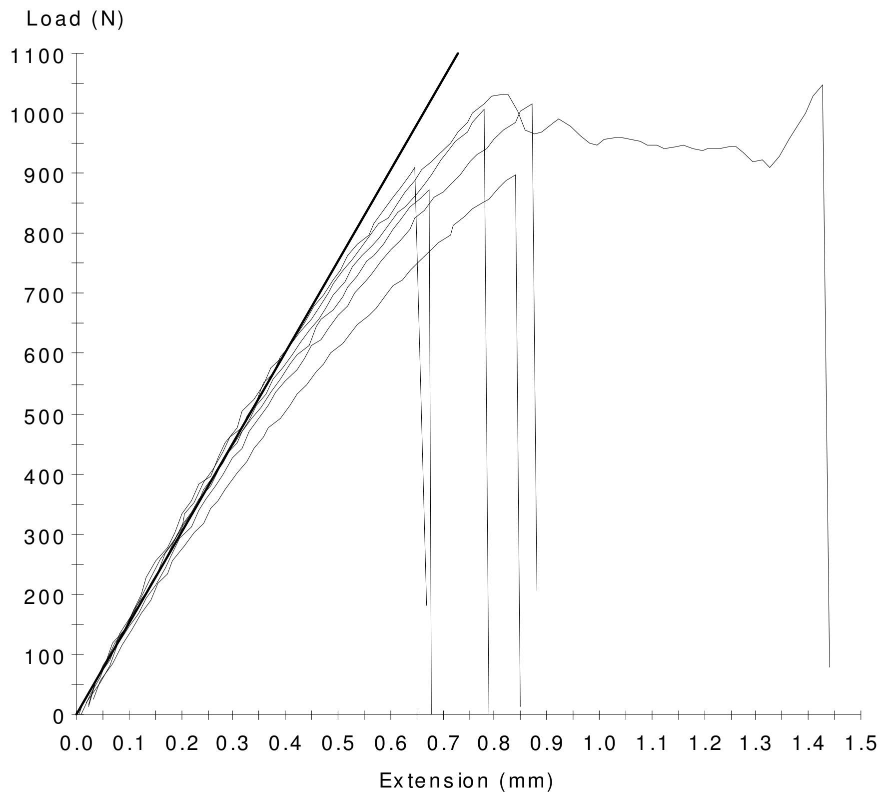
shashi-sd300-5%

Test Date : 13/05/2008
Method : MMT Tensile Test with return.msm

Specimen Results:

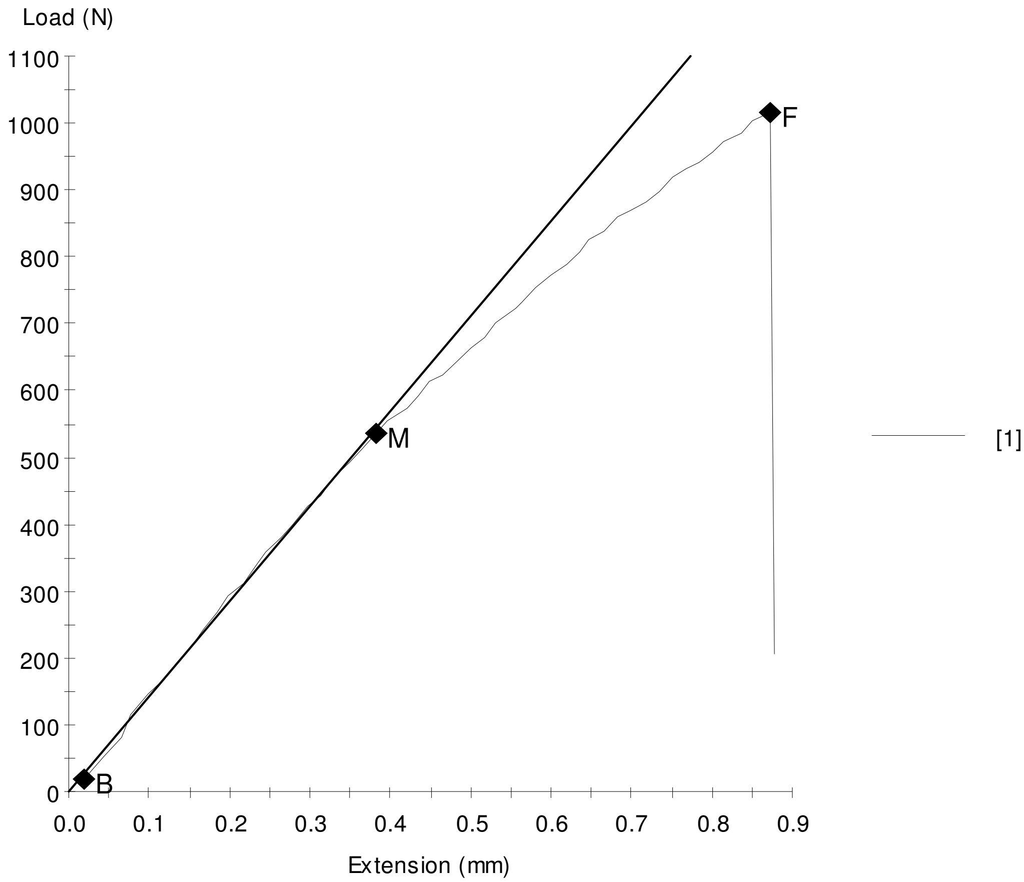
Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	5.200	14.480	75	1016	13.50	1016	13.50
2	5.280	14.440	76	899	11.79	899	11.79
3	5.440	14.800	81	910	11.30	910	11.30
4	5.500	14.690	81	1046	12.94	1046	12.94
5	5.200	14.350	75	873	11.70	873	11.70
6	5.280	14.580	77	1005	13.06	1005	13.06
Mean	**5.317**	**14.557**	**77**	**958**	**12.38**	**958**	**12.38**
Std Dev	**0.125**	**0.167**	**3**	**73**	**0.90**	**73**	**0.90**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.871	7.624	574.053				
2	0.841	6.473	493.484				
3	0.649	6.505	523.698				
4	1.426	7.604	614.338				
5	0.672	6.613	493.484				
6	0.779	7.501	577.410				
Mean	**0.873**	**7.053**	**546.078**				
Std Dev	**0.285**	**0.576**	**49.913**				


Load (N)
1100
1000
900
800
700
600
500
400
300
200
100
0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5
Extension (mm)

13/05/2008

Sample ID: shashi-sd300-5%-1.mss
Specimen Number: 1
Tagged: False

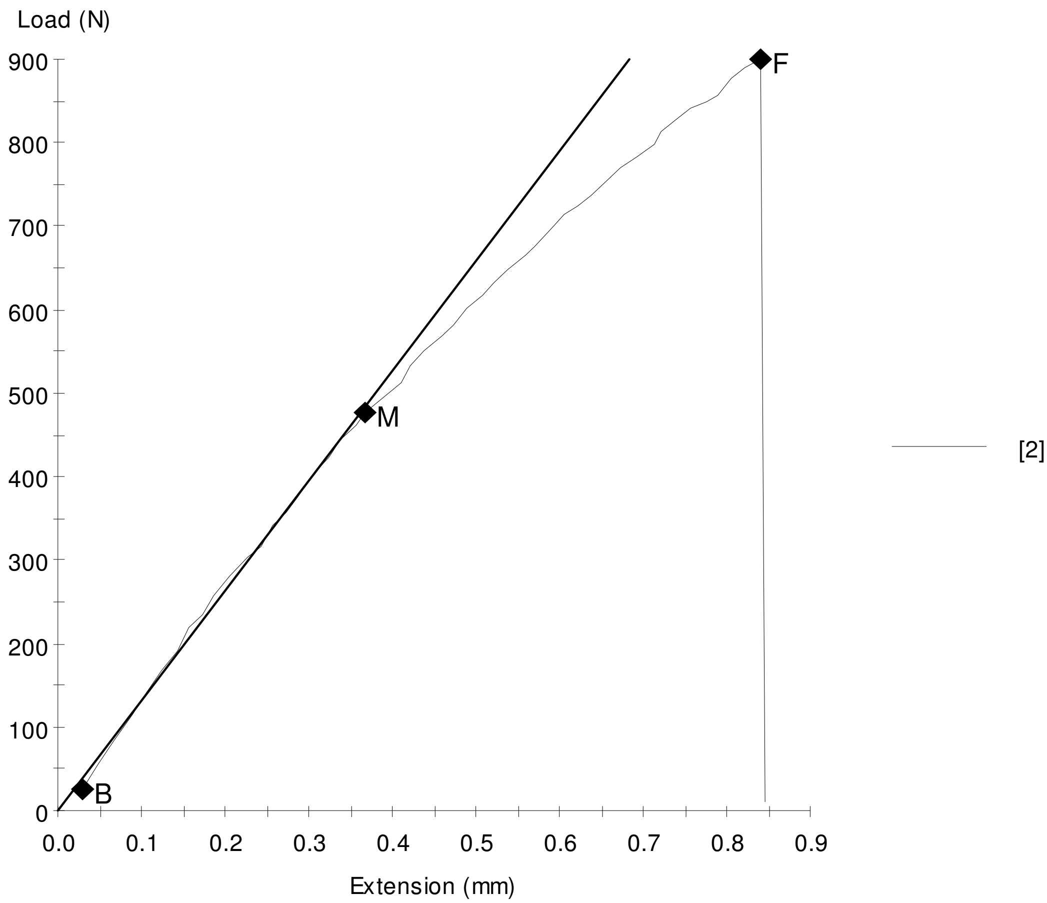


Specimen Results:

Name	Value	Units
Thickness	5.200	mm
Width	14.480	mm
Area	75	mm^2
Peak Load	1016	N
Peak Stress	13.50	MPa
Break Load	1016	N
Break Stress	13.50	MPa
Elongation At Break	0.871	mm
Stress At Offset Yield	7.624	MPa
Load At Offset Yield	574.053	N

13/05/2008

Sample ID: shashi-sd300-5%-2.mss
Specimen Number: 2
Tagged: False

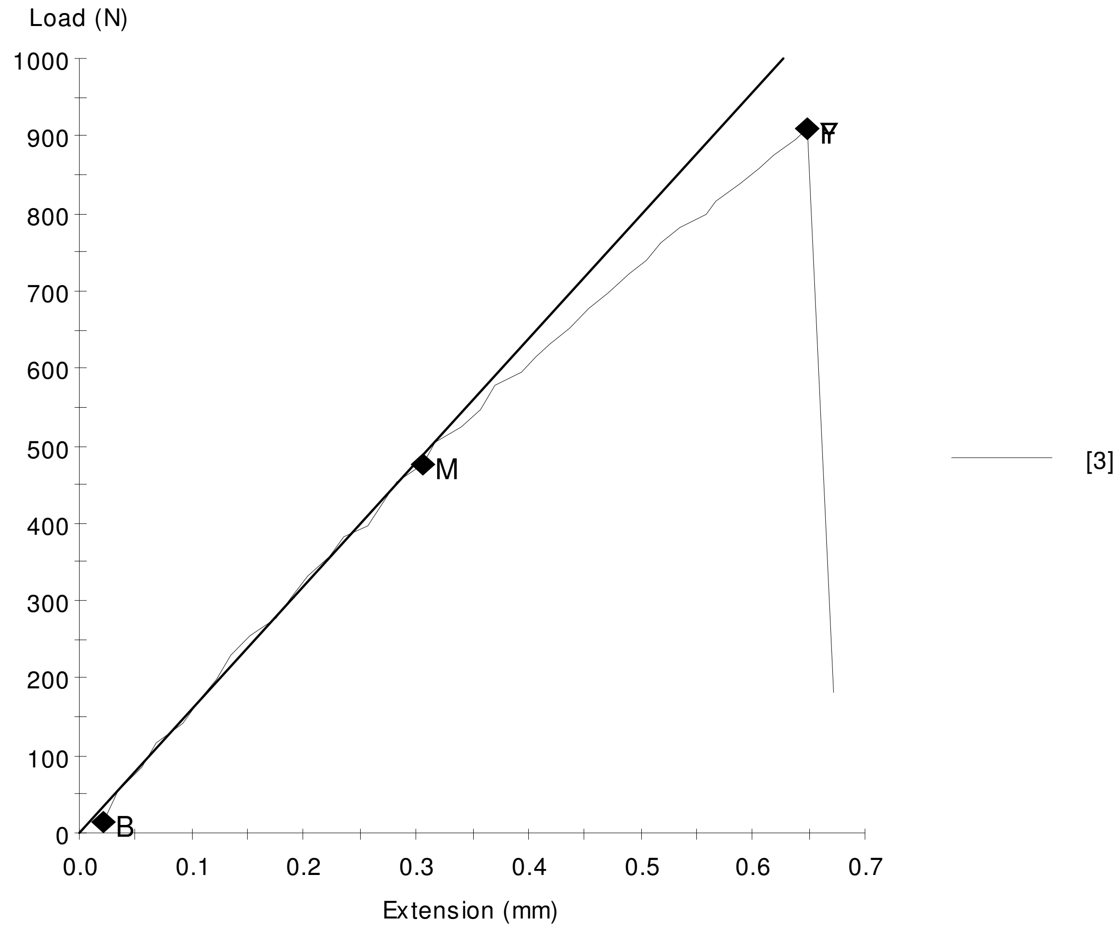


Specimen Results:

Name	Value	Units
Thickness	5.280	mm
Width	14.440	mm
Area	76	mm^2
Peak Load	899	N
Peak Stress	11.79	MPa
Break Load	899	N
Break Stress	11.79	MPa
Elongation At Break	0.841	mm
Stress At Offset Yield	6.473	MPa
Load At Offset Yield	493.484	N

13/05/2008

Sample ID: shashi-sd300-5%-3.mss
Specimen Number: 3
Tagged: False

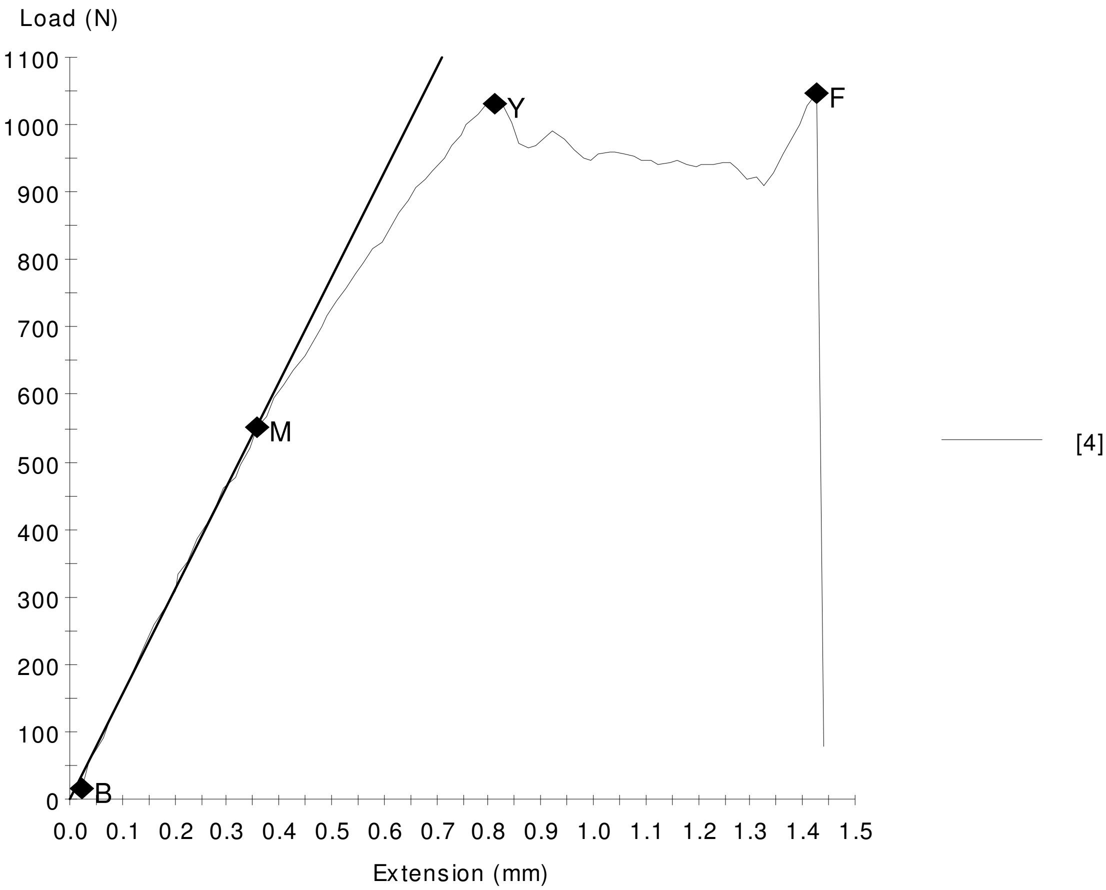


Specimen Results:

Name	Value	Units	
Thickness		5.440	mm
Width	14.800	mm	
Area	81	mm^2	
Peak Load		910	N
Peak Stress		11.30	MPa
Break Load		910	N
Break Stress		11.30	MPa
Elongation At Break		0.649	mm
Stress At Offset Yield		6.505	MPa
Load At Offset Yield		523.698	N

13/05/2008

Sample ID: shashi-sd300-5%-4.mss
Specimen Number: 4
Tagged: False

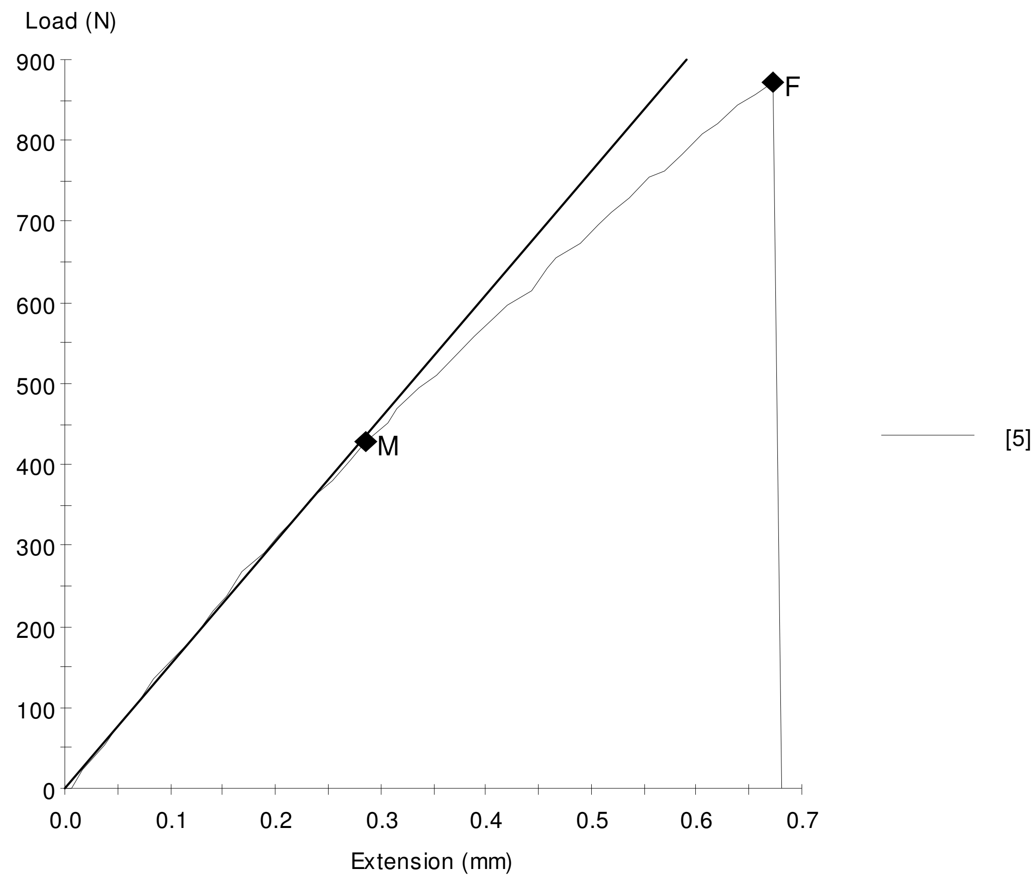


Specimen Results:

Name	Value	Units
Thickness	5.500	mm
Width	14.690	mm
Area	81	mm^2
Peak Load	1046	N
Peak Stress	12.94	MPa
Break Load	1046	N
Break Stress	12.94	MPa
Elongation At Break	1.426	mm
Stress At Offset Yield	7.604	MPa
Load At Offset Yield	614.338	N

13/05/2008

Sample ID: shashi-sd300-5%-5.mss
Specimen Number: 5
Tagged: False

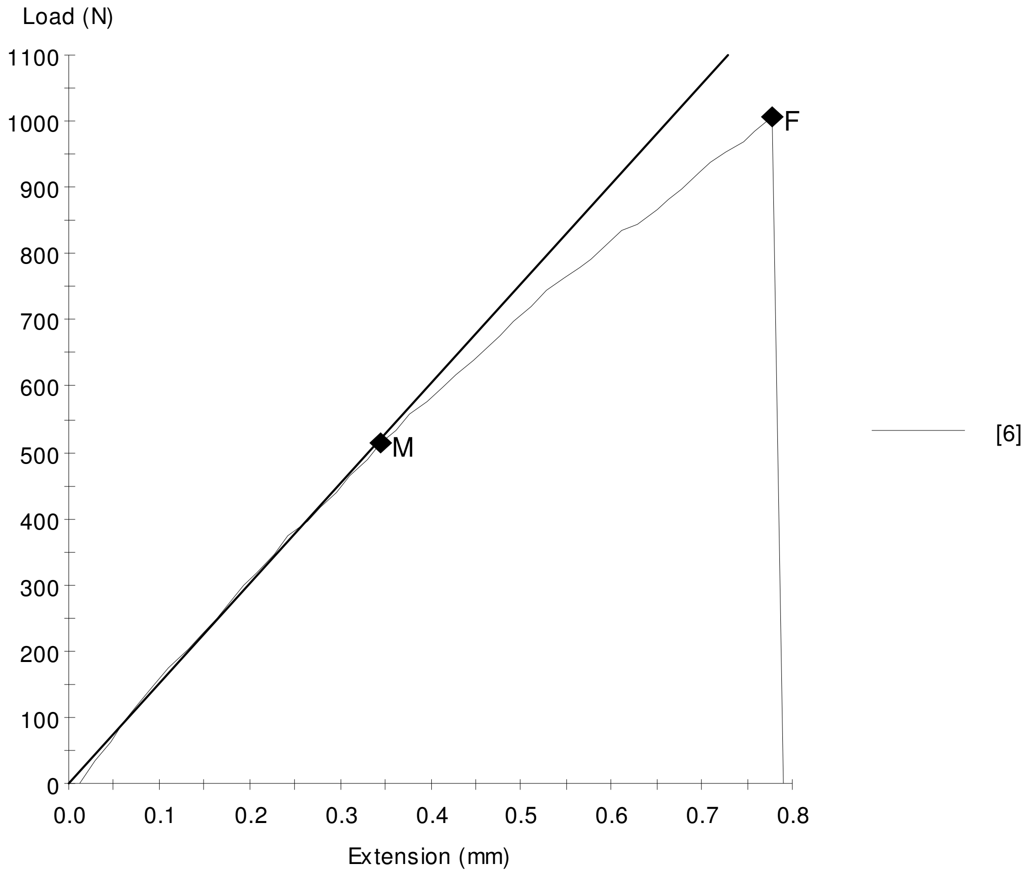


Specimen Results:

Name	Value	Units
Thickness	5.200	mm
Width	14.350	mm
Area	75	mm^2
Peak Load	873	N
Peak Stress	11.70	MPa
Break Load	873	N
Break Stress	11.70	MPa
Elongation At Break	0.672	mm
Stress At Offset Yield	6.613	MPa
Load At Offset Yield	493.484	N

13/05/2008

Sample ID: shashi-sd300-5%-6.mss
Specimen Number: 6
Tagged: False



Specimen Results:

Name	Value	Units
Thickness	5.280	mm
Width	14.580	mm
Area	77	mm^2
Peak Load	1005	N
Peak Stress	13.06	MPa
Break Load	1005	N
Break Stress	13.06	MPa
Elongation At Break	0.779	mm
Stress At Offset Yield	7.501	MPa
Load At Offset Yield	577.410	N

Tensile Test Plot Obtained On MTS 810 For:

Sawdust: 300 Micron -10% by Weight

shashi-sd300-10%

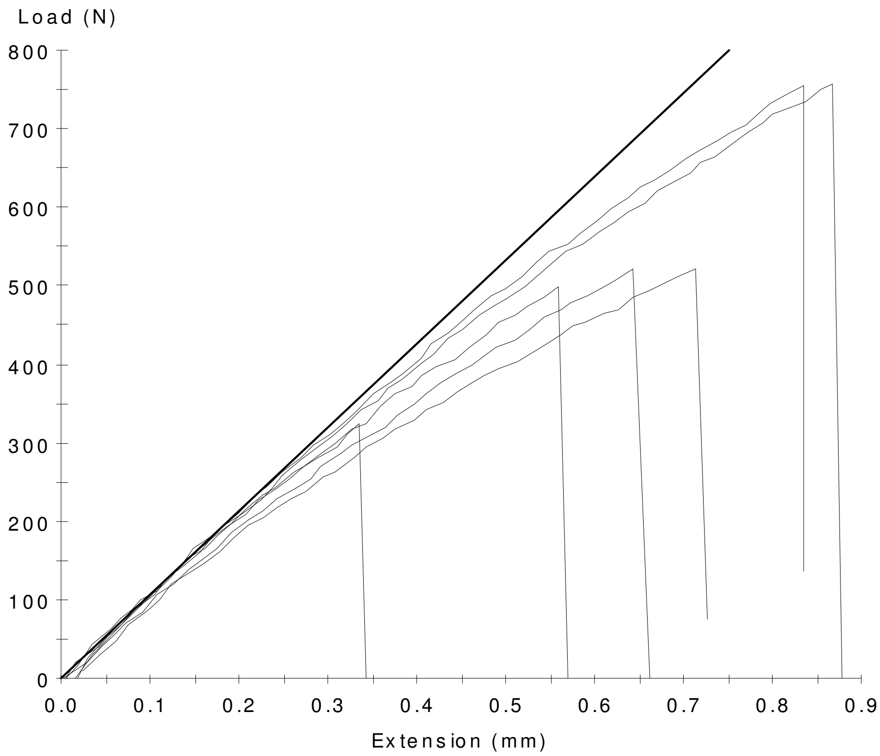
Test Date : 13/05/2008

Method : MMT Tensile Test with return.msm

Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	5.340	14.560	78	499	6.42	499	6.42
2	5.390	14.690	79	522	6.59	522	6.59
3	5.280	14.590	77	754	9.78	754	9.78
4	5.350	14.610	78	758	9.70	758	9.70
5	5.280	14.630	77	520	6.74	520	6.74
6	5.270	14.580	77	323	4.21	323	4.21
Mean	**5.318**	**14.610**	**78**	**563**	**7.24**	**563**	**7.24**
Std Dev	**0.049**	**0.046**	**1**	**167**	**2.15**	**167**	**2.15**

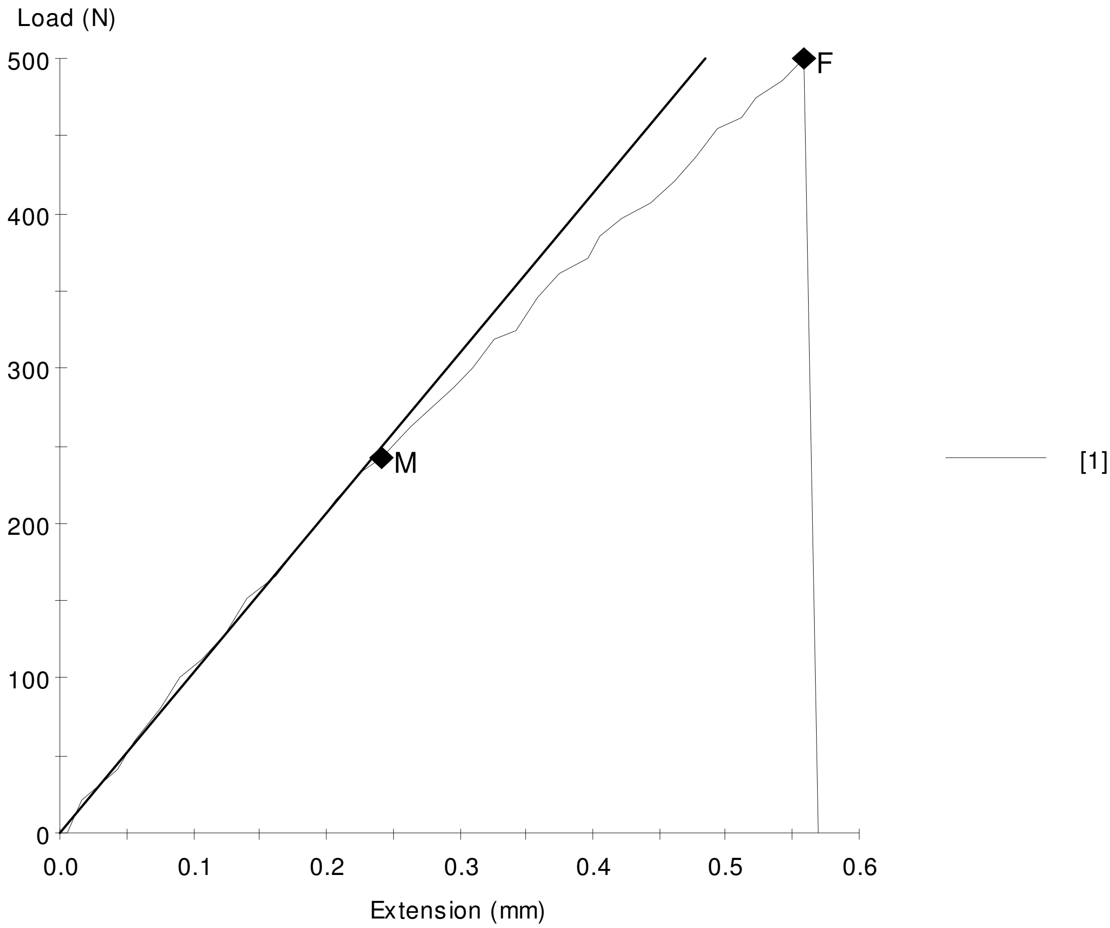
Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.559	3.476	270.241				
2	0.712	3.858	305.490				
3	0.834	5.284	407.041				
4	0.868	5.272	412.076				
5	0.642	3.998	308.847				
6	0.336	2.709	208.136				
Mean	**0.659**	**4.099**	**318.639**				
Std Dev	**0.196**	**1.017**	**79.205**				



Load (N)
800
700
600
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Extension (mm)

13/05/2008

Sample ID: shashi-sd300-10%-1.mss
Specimen Number: 1
Tagged: False

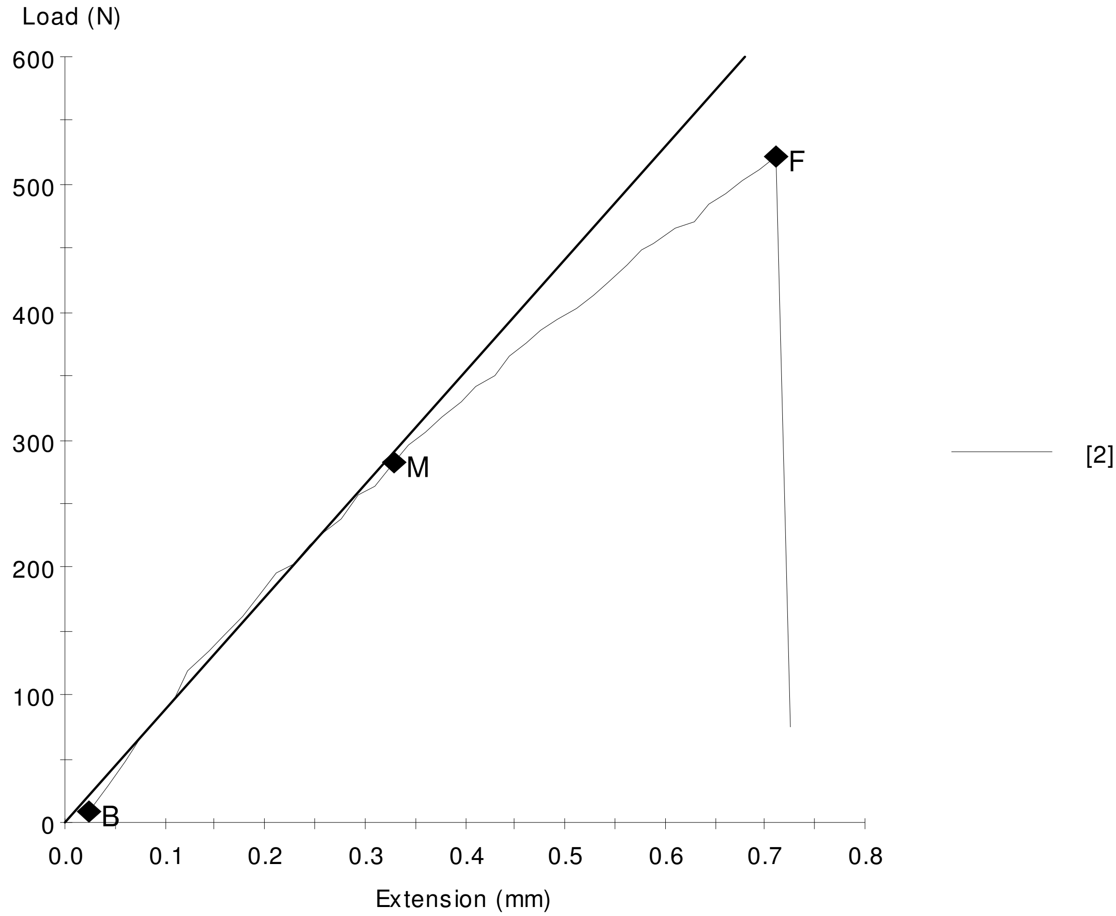


Specimen Results:

Name	Value	Units
Thickness	5.340	mm
Width	14.560	mm
Area	78	mm^2
Peak Load	499	N
Peak Stress	6.42	MPa
Break Load	499	N
Break Stress	6.42	MPa
Elongation At Break	0.559	mm
Stress At Offset Yield	3.476	MPa
Load At Offset Yield	270.241	N

13/05/2008

Sample ID: shashi-sd300-10%-2.mss
Specimen Number: 2
Tagged: False

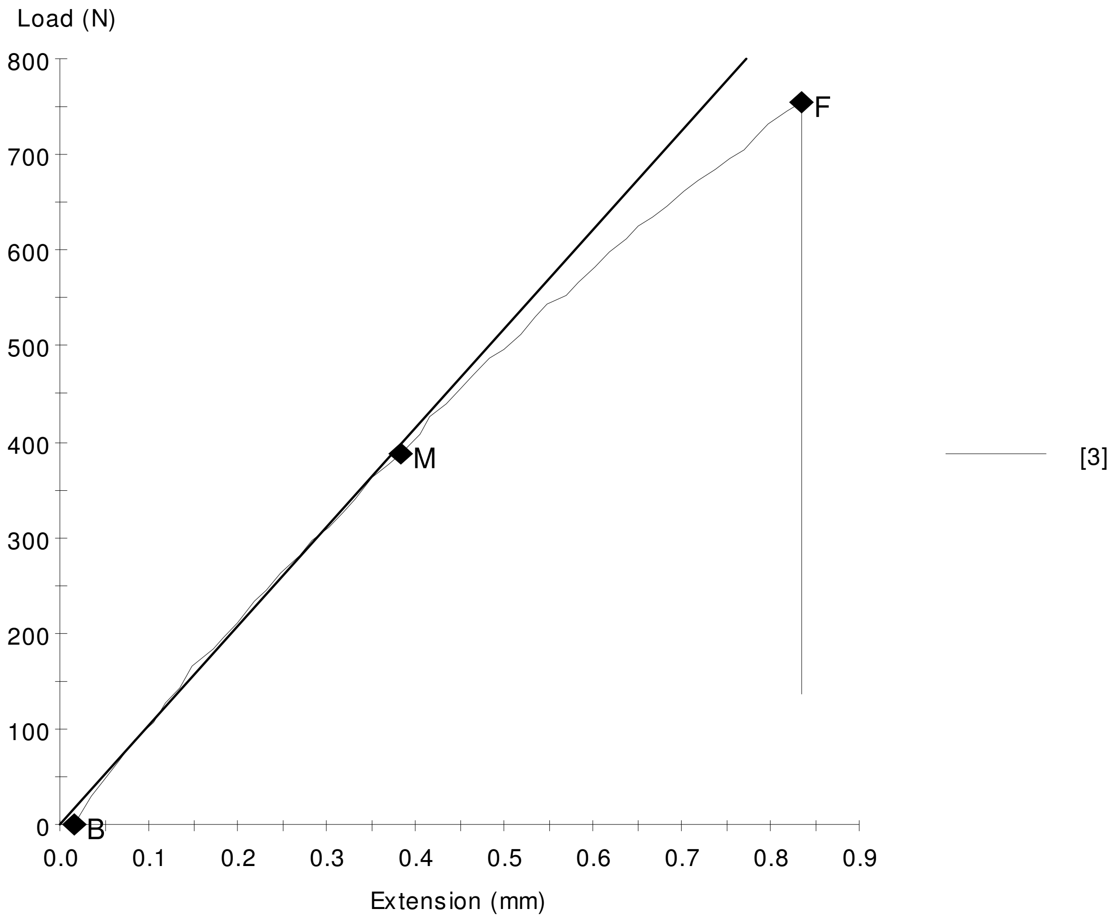


Specimen Results:

Name	Value	Units
Thickness	5.390	mm
Width	14.690	mm
Area	79	mm^2
Peak Load	522	N
Peak Stress	6.59	MPa
Break Load	522	N
Break Stress	6.59	MPa
Elongation At Break	0.712	mm
Stress At Offset Yield	3.858	MPa
Load At Offset Yield	305.490	N

13/05/2008

Sample ID: shashi-sd300-10%-3.mss
Specimen Number: 3
Tagged: False

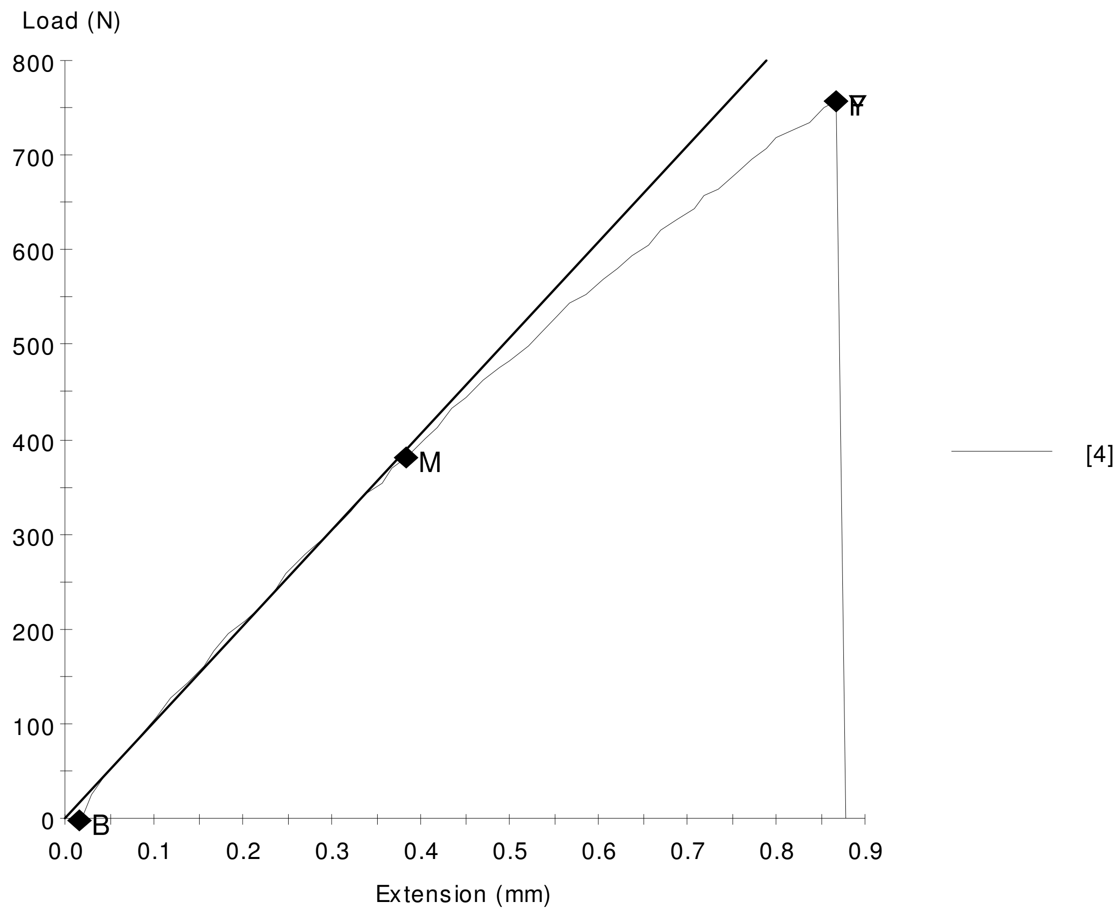


Specimen Results:

Name	Value	Units
Thickness	5.280	mm
Width	14.590	mm
Area	77	mm^2
Peak Load	754	N
Peak Stress	9.78	MPa
Break Load	754	N
Break Stress	9.78	MPa
Elongation At Break	0.834	mm
Stress At Offset Yield	5.284	MPa
Load At Offset Yield	407.041	N

13/05/2008

Sample ID: shashi-sd300-10%-4.mss
Specimen Number: 4
Tagged: False

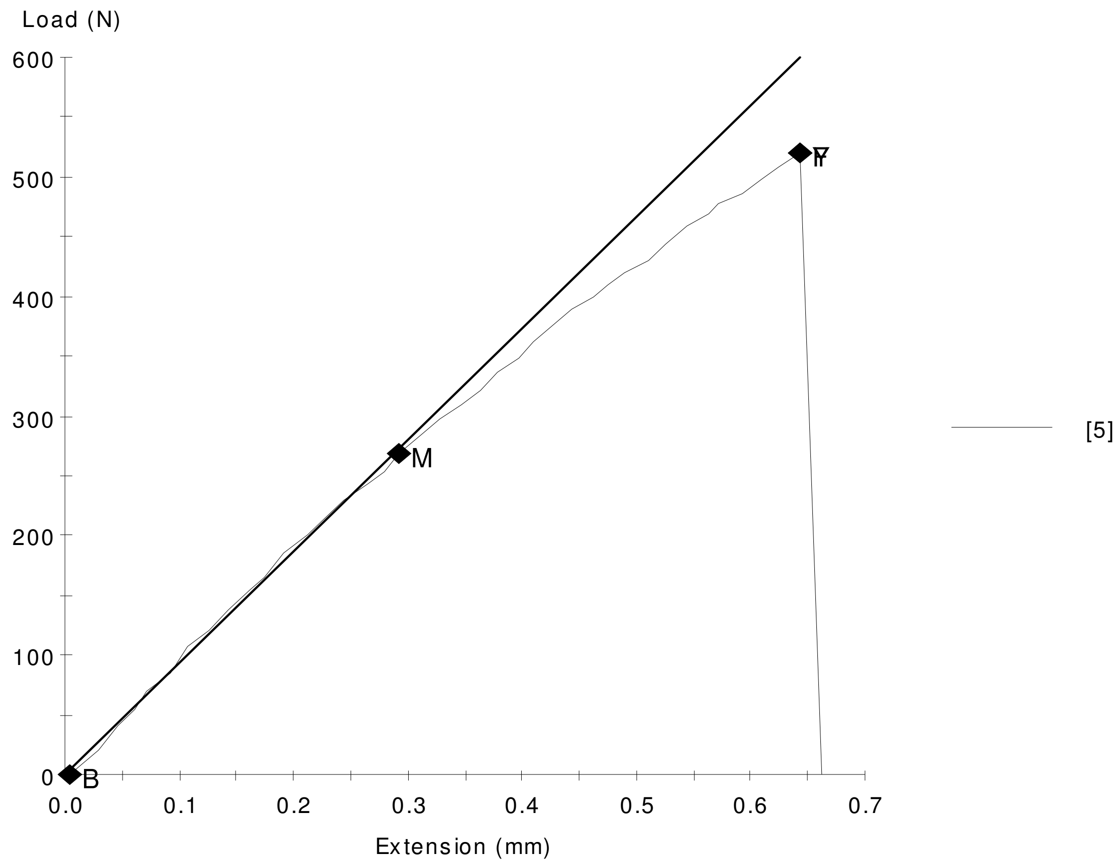


Specimen Results:

Name	Value	Units
Thickness	5.350	mm
Width	14.610	mm
Area	78	mm^2
Peak Load	758	N
Peak Stress	9.70	MPa
Break Load	758	N
Break Stress	9.70	MPa
Elongation At Break	0.868	mm
Stress At Offset Yield	5.272	MPa
Load At Offset Yield	412.076	N

13/05/2008

Sample ID: shashi-sd300-10%-5.mss
Specimen Number: 5
Tagged: False

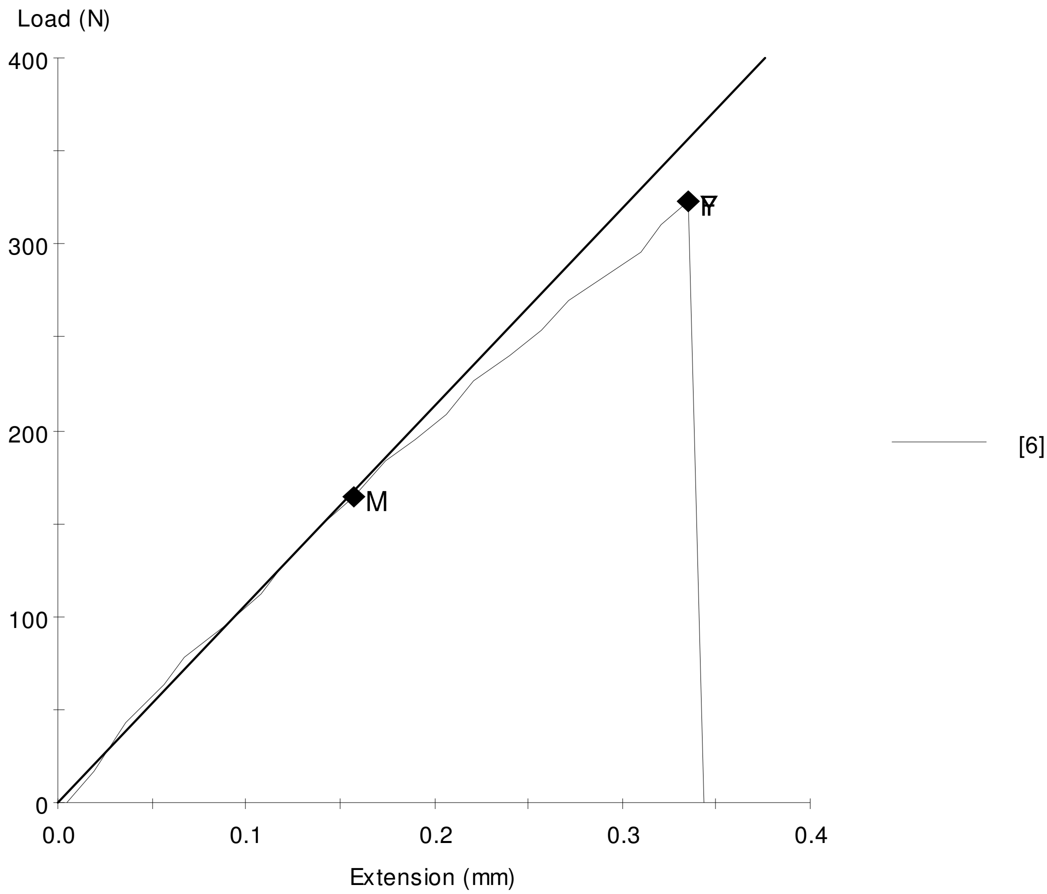


Specimen Results:

Name	Value	Units	
Thickness		5.280	mm
Width	14.630	mm	
Area	77	mm^2	
Peak Load		520	N
Peak Stress		6.74	MPa
Break Load		520	N
Break Stress		6.74	MPa
Elongation At Break		0.642	mm
Stress At Offset Yield		3.998	MPa
Load At Offset Yield		308.847	N

13/05/2008

Sample ID: shashi-sd300-10%-6.mss
Specimen Number: 6
Tagged: False



Specimen Results:

Name	Value	Units
Thickness	5.270	mm
Width	14.580	mm
Area	77	mm^2
Peak Load	323	N
Peak Stress	4.21	MPa
Break Load	323	N
Break Stress	4.21	MPa
Elongation At Break	0.336	mm
Stress At Offset Yield	2.709	MPa
Load At Offset Yield	208.136	N

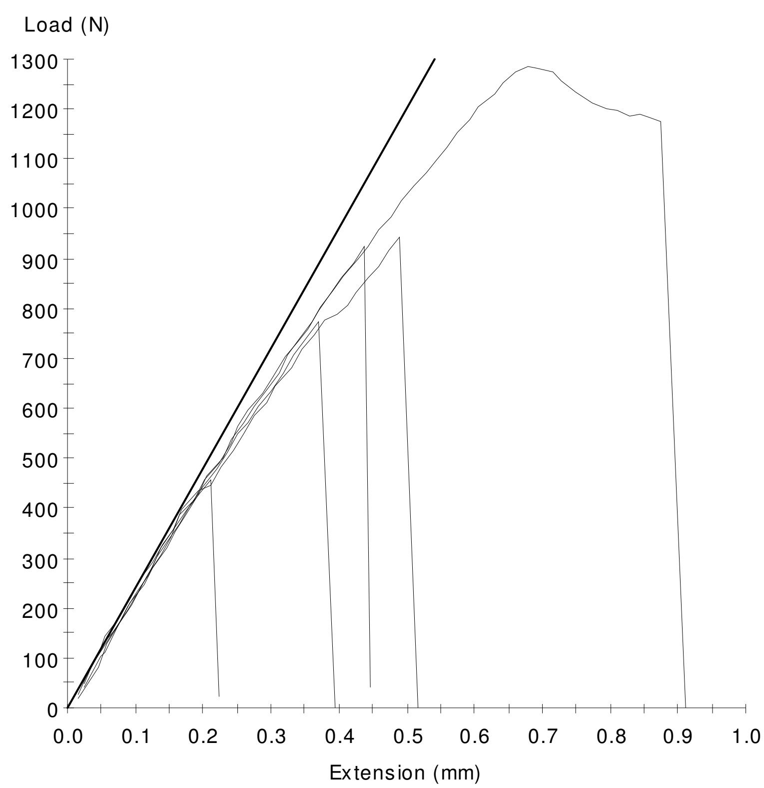
Tensile Test Plot Obtained On MTS 810 For:

Sawdust: 300 Micron -15% by Weight

shashi-sd300-15%
Test Date : 11/09/2008
Method : MMT Tensile Test with return.msm
Specimen Results:

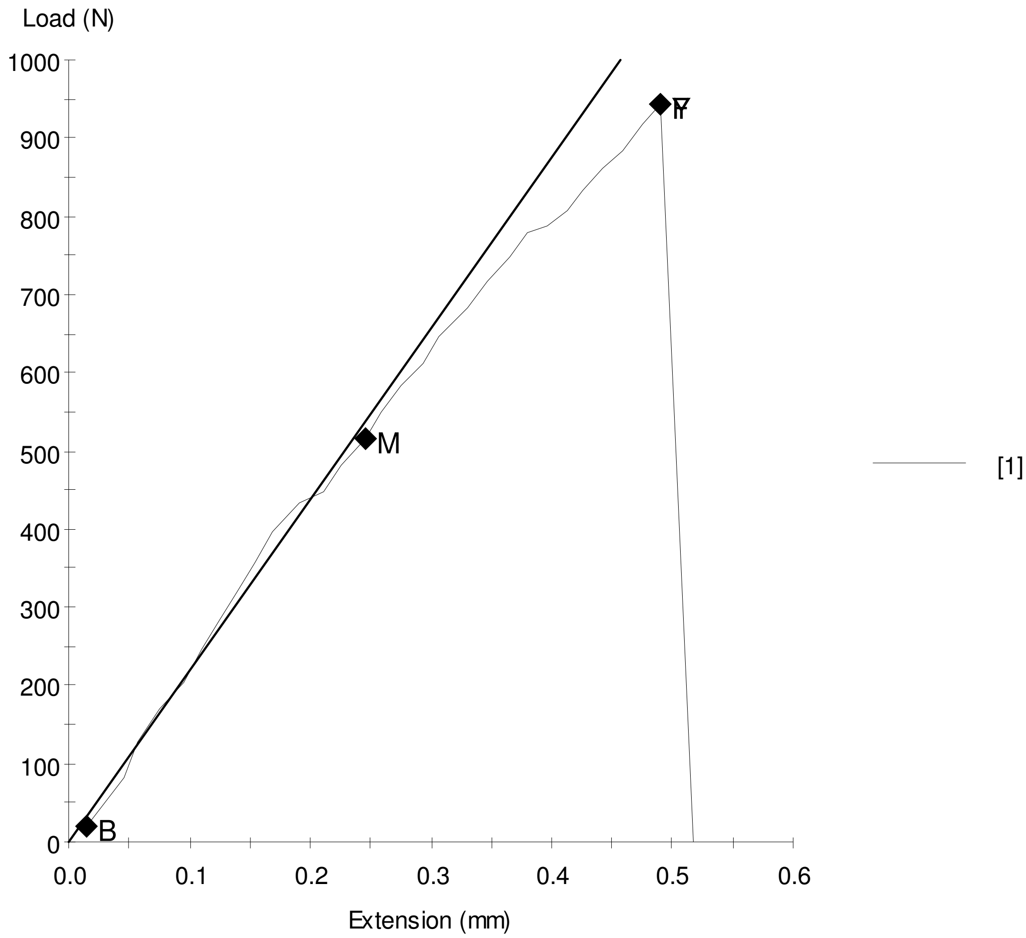
Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	6.200	14.550	90	943	10.46	943	10.46
2	6.150	14.750	91	1285	14.16	1175	12.95
3	6.020	14.520	87	923	10.56	923	10.56
4	5.850	14.550	85	775	9.10	775	9.10
5	6.030	14.650	88	456	5.16	456	5.16
Mean	**6.050**	**14.604**	**88**	**876**	**9.89**	**854**	**9.65**
Std Dev	**0.136**	**0.095**	**2**	**300**	**3.24**	**265**	**2.87**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.489	6.782	611.820				
2	0.873	9.539	865.276				
3	0.437	8.689	759.529				
4	0.371	7.454	634.480				
5	0.212	4.864	429.701				
Mean	**0.476**	**7.466**	**660.161**				
Std Dev	**0.245**	**1.805**	**164.358**				



11/09/2008

Sample ID: shashi-sd300-15%-1.mss
Specimen Number: 1
Tagged: False

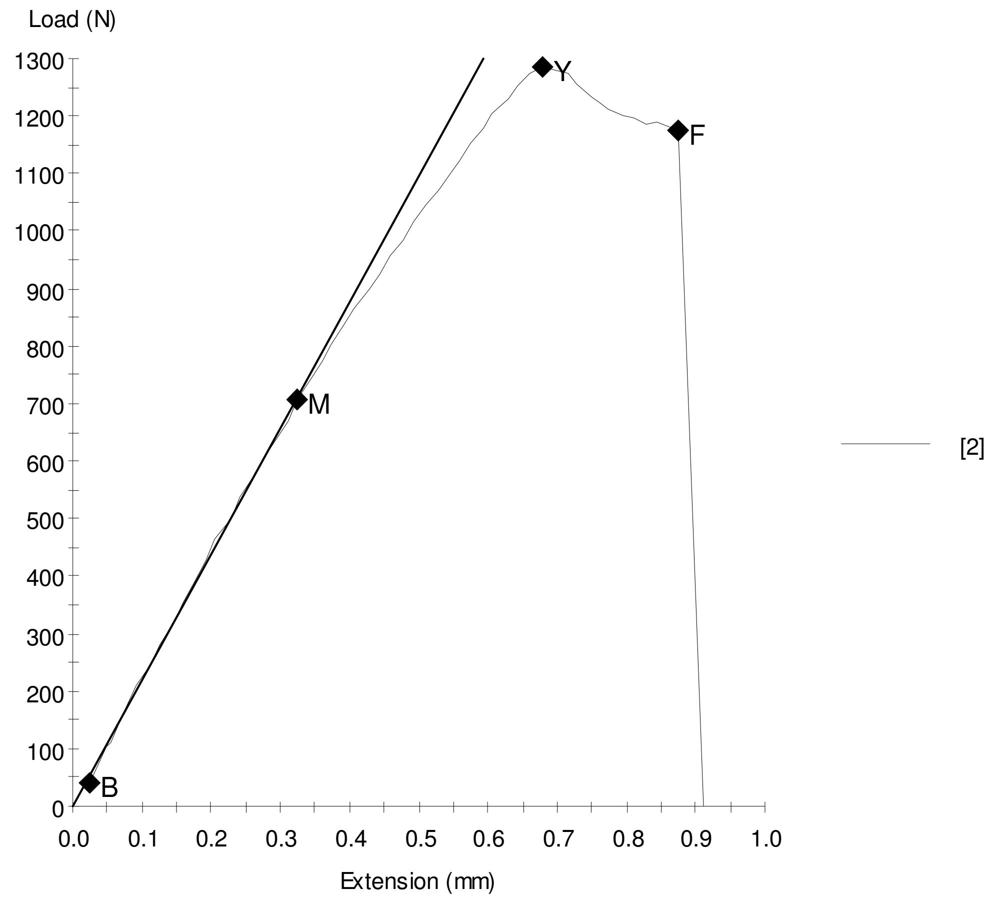


Specimen Results:

Name	Value	Units
Thickness	6.200	mm
Width	14.550	mm
Area	90	mm^2
Peak Load	943	N
Peak Stress	10.46	MPa
Break Load	943	N
Break Stress	10.46	MPa
Elongation At Break	0.489	mm
Stress At Offset Yield	6.782	MPa
Load At Offset Yield	611.820	N

11/09/2008

Sample ID: shashi-sd300-15%-2.mss
Specimen Number: 2
Tagged: False

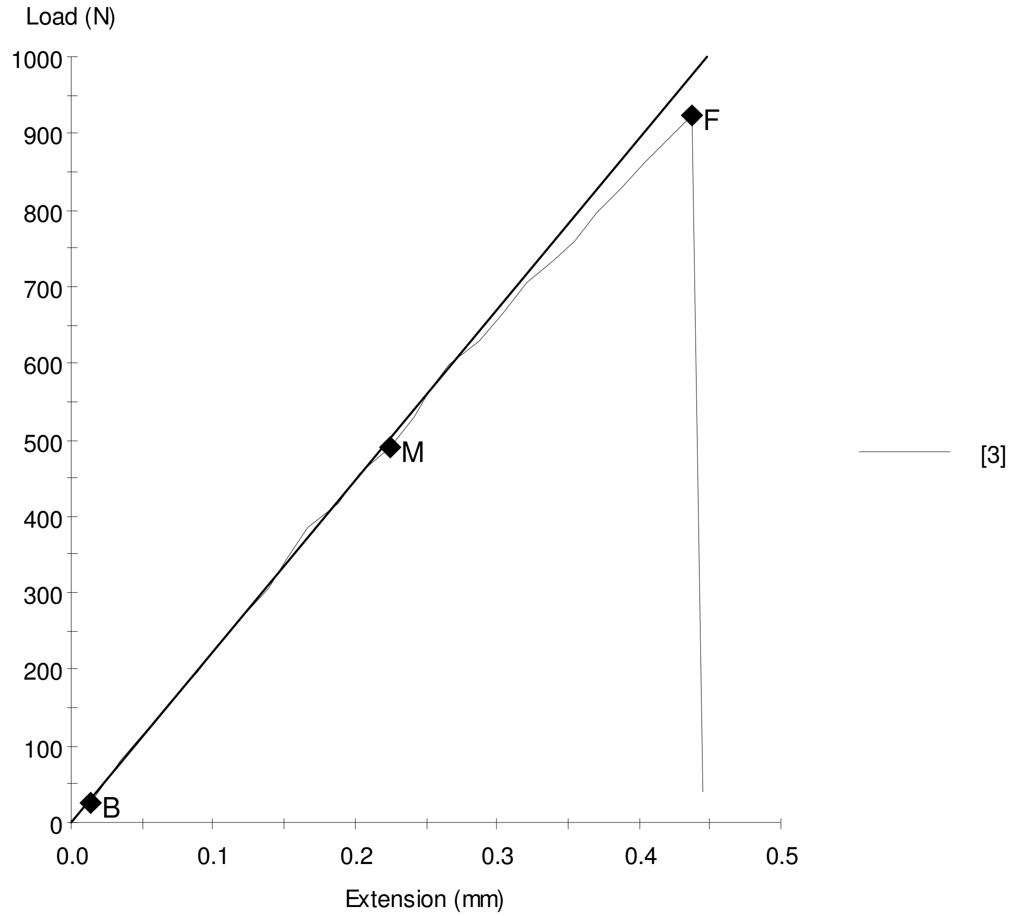


Specimen Results:

Name	Value	Units
Thickness	6.150	mm
Width	14.750	mm
Area	91	mm^2
Peak Load	1285	N
Peak Stress	14.16	MPa
Break Load	1175	N
Break Stress	12.95	MPa
Elongation At Break	0.873	mm
Stress At Offset Yield	9.539	MPa
Load At Offset Yield	865.276	N

11/09/2008

Sample ID: shashi-sd300-15%-3.mss
Specimen Number: 3
Tagged: False

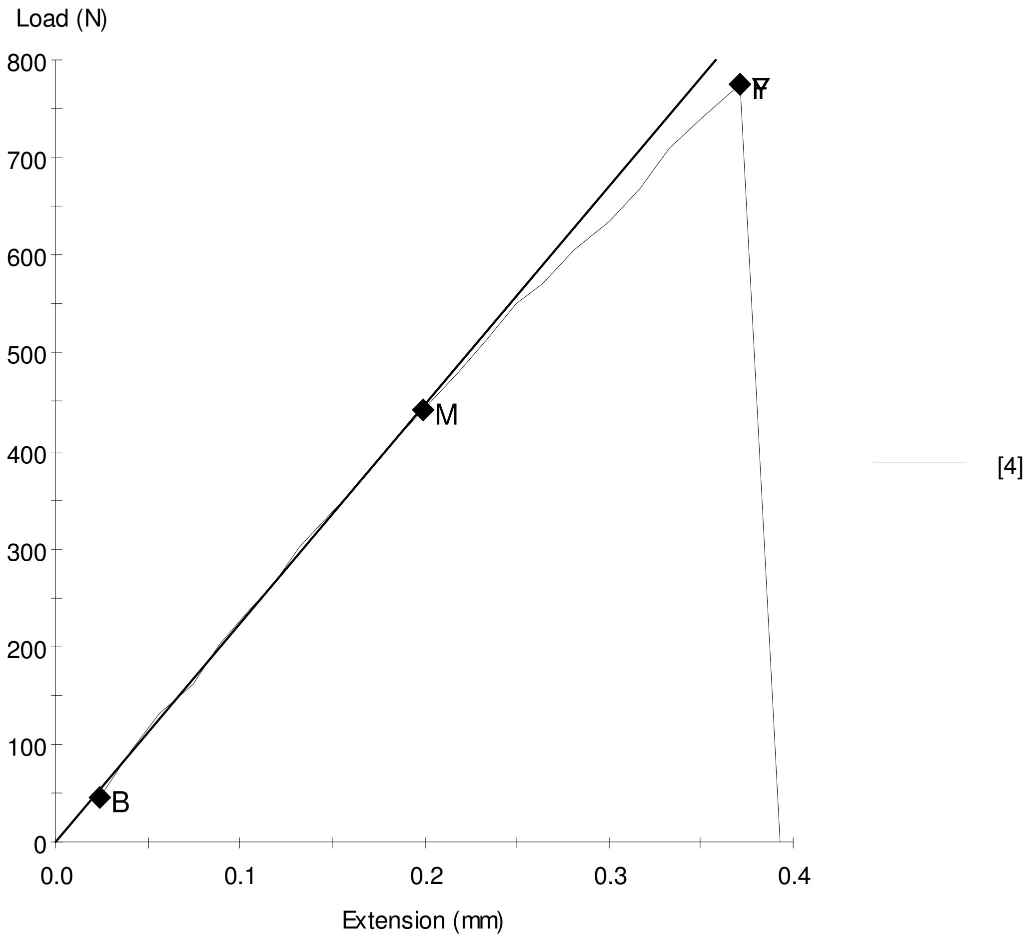


Specimen Results:

Name	Value	Units
Thickness	6.020	mm
Width	14.520	mm
Area	87	mm^2
Peak Load	923	N
Peak Stress	10.56	MPa
Break Load	923	N
Break Stress	10.56	MPa
Elongation At Break	0.437	mm
Stress At Offset Yield	8.689	MPa
Load At Offset Yield	759.529	N

11/09/2008

Sample ID: shashi-sd300-15%-4.mss
Specimen Number: 4
Tagged: False



Specimen Results:

Name	Value	Units	
Thickness		5.850	mm
Width	14.550	mm	
Area	85	mm^2	
Peak Load		775	N
Peak Stress		9.10	MPa
Break Load		775	N
Break Stress		9.10	MPa
Elongation At Break		0.371	mm
Stress At Offset Yield		7.454	MPa
Load At Offset Yield		634.480	N

Tensile Test Plot Obtained On MTS 810 For:

Sawdust: 425 Micron -5% by Weight

shashi-sd425-5%

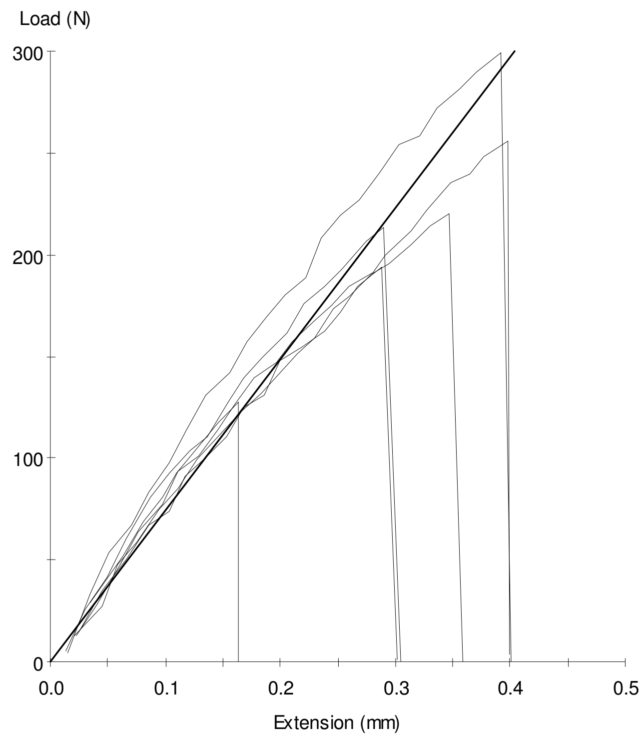
Test Date : 11/09/2008

Method : MMT Tensile Test with return.msm

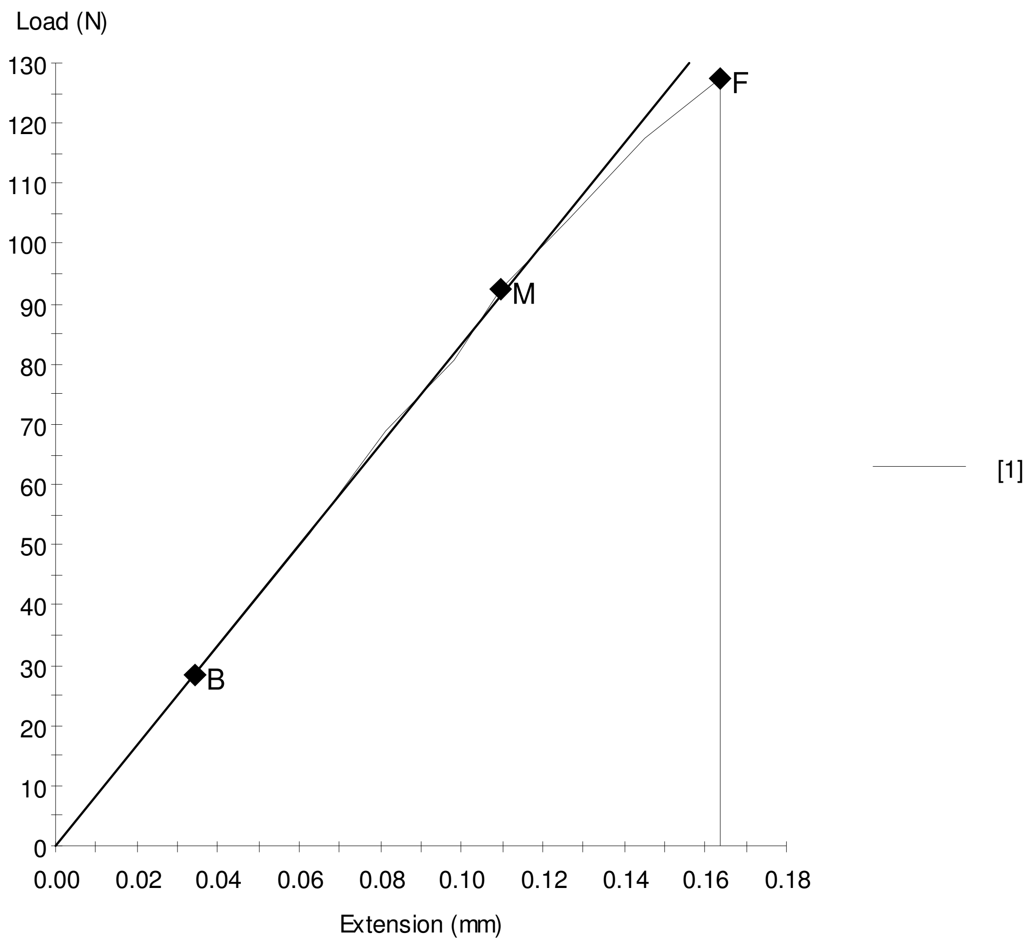
Specimen Results:

Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	5.350	14.660	78	128	1.63	128	1.63
2	5.610	14.450	81	299	3.69	299	3.69
3	5.510	14.460	80	213	2.68	213	2.68
4	5.410	14.560	79	220	2.79	220	2.79
5	5.300	14.490	77	256	3.33	256	3.33
6	5.280	14.550	77	194	2.52	194	2.52
Mean	**5.410**	**14.528**	**79**	**218**	**2.77**	**218**	**2.77**
Std Dev	**0.129**	**0.079**	**2**	**58**	**0.71**	**58**	**0.71**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.164	1.626	127.567				
2	0.392	2.226	180.441				
3	0.289	2.022	161.138				
4	0.347	1.918	151.067				
5	0.398	2.186	167.852				
6	0.288	2.010	154.424				
Mean	**0.313**	**1.998**	**157.081**				
Std Dev	**0.087**	**0.216**	**17.846**				



Sample ID: shashi-sd425-5%-1.mss
Specimen Number: 1
Tagged: False



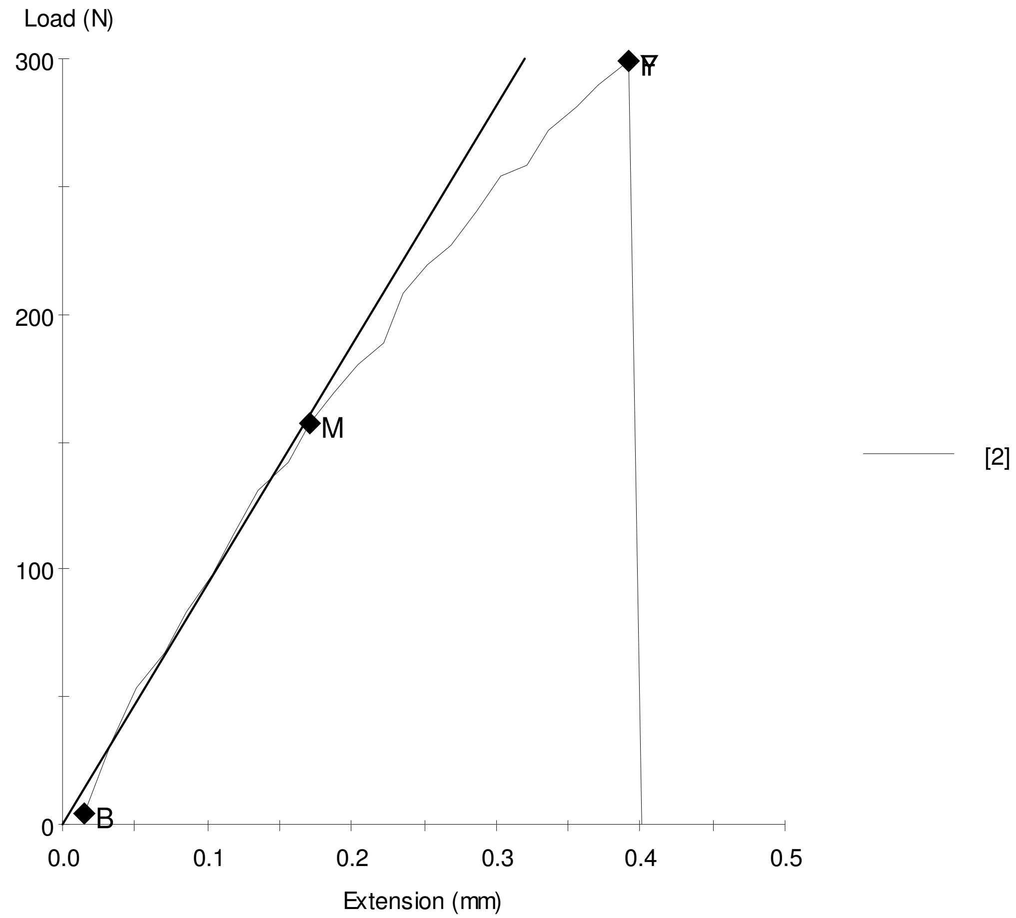
Specimen Results:

Name	Value	Units	
Thickness		5.350	mm
Width	14.660	mm	
Area	78	mm^2	
Peak Load		128	N
Peak Stress		1.63	MPa
Break Load		128	N
Break Stress		1.63	MPa
Elongation At Break		0.164	mm
Stress At Offset Yield		1.626	MPa
Load At Offset Yield		127.567	N

11/09/2008

Sample ID: shashi-sd425-5%-2.mss
Specimen Number: 2

Tagged: False



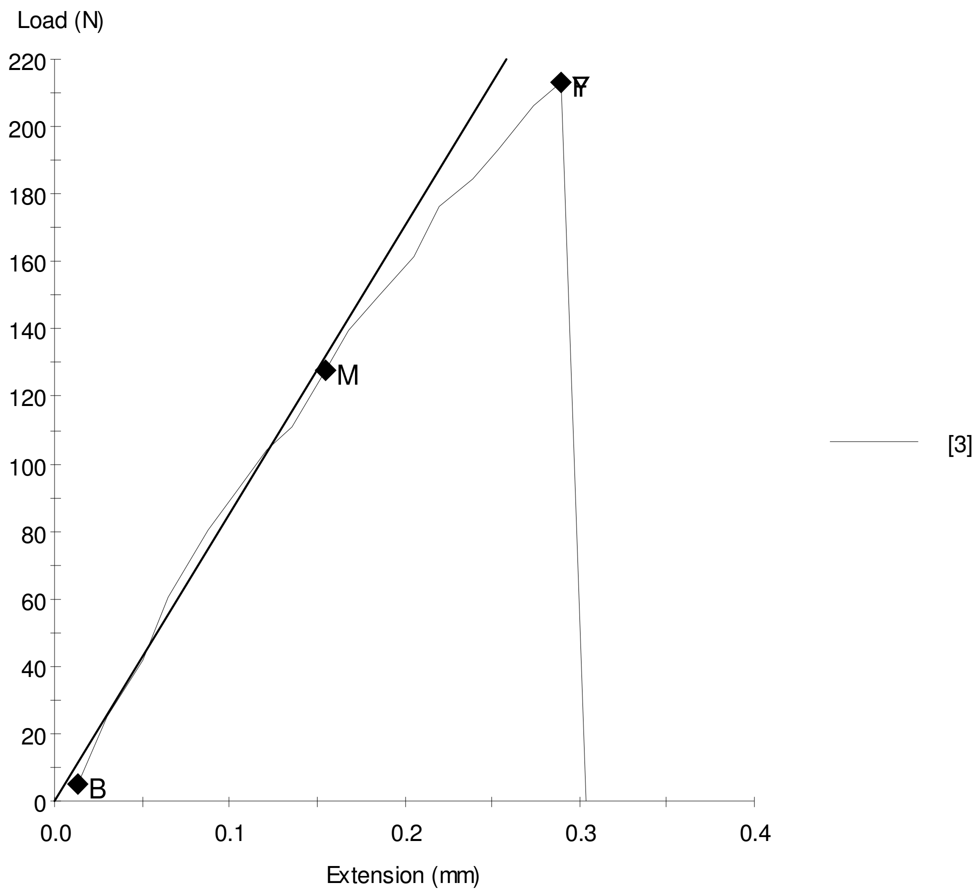
Specimen Results:

Name	Value	Units	
Thickness		5.610	mm
Width	14.450	mm	
Area	81	mm^2	
Peak Load		299	N
Peak Stress		3.69	MPa
Break Load		299	N
Break Stress		3.69	MPa
Elongation At Break		0.392	mm
Stress At Offset Yield		2.226	MPa
Load At Offset Yield		180.441	N

11/09/2008

Sample ID: shashi-sd425-5%-3.mss
Specimen Number: 3

Tagged: False

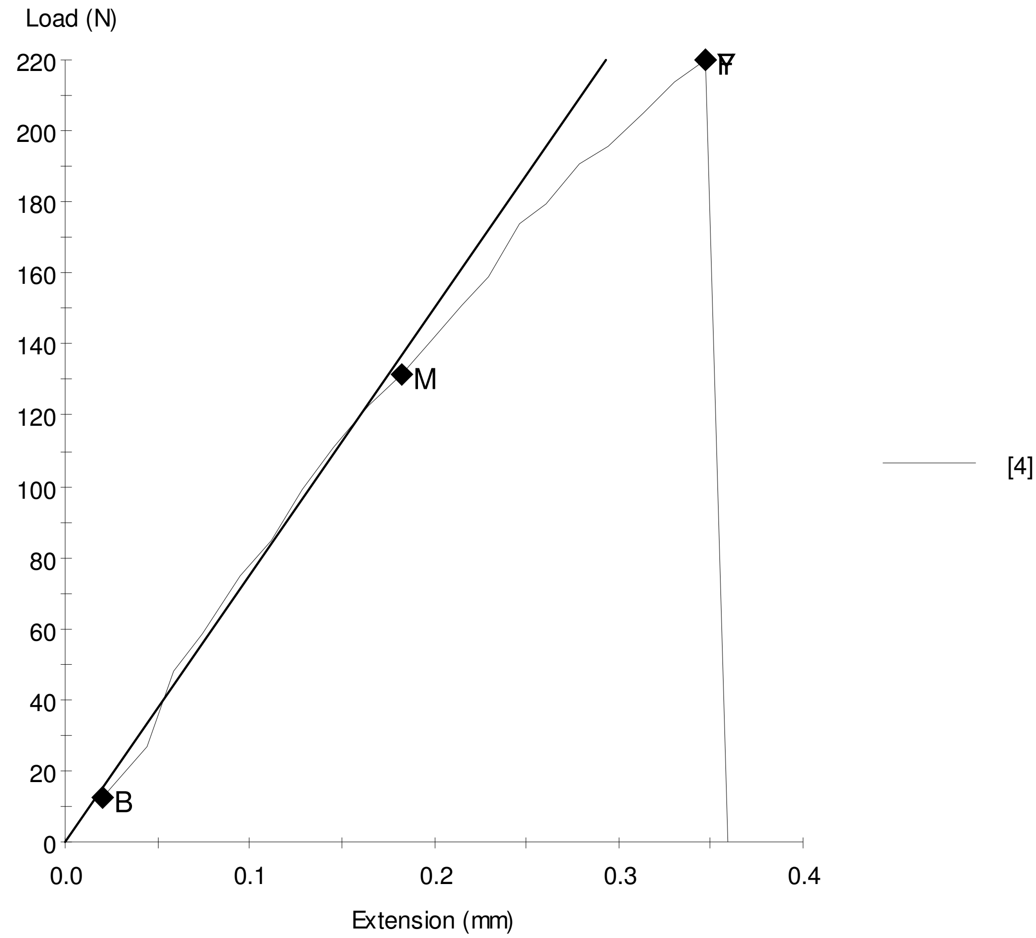


Specimen Results:

Name	Value	Units
Thickness	5.510	mm
Width	14.460	mm
Area	80	mm^2
Peak Load	213	N
Peak Stress	2.68	MPa
Break Load	213	N
Break Stress	2.68	MPa
Elongation At Break	0.289	mm
Stress At Offset Yield	2.022	MPa
Load At Offset Yield	161.138	N

11/09/2008

Sample ID: shashi-sd425-5%-4.mss
Specimen Number: 4
Tagged: False

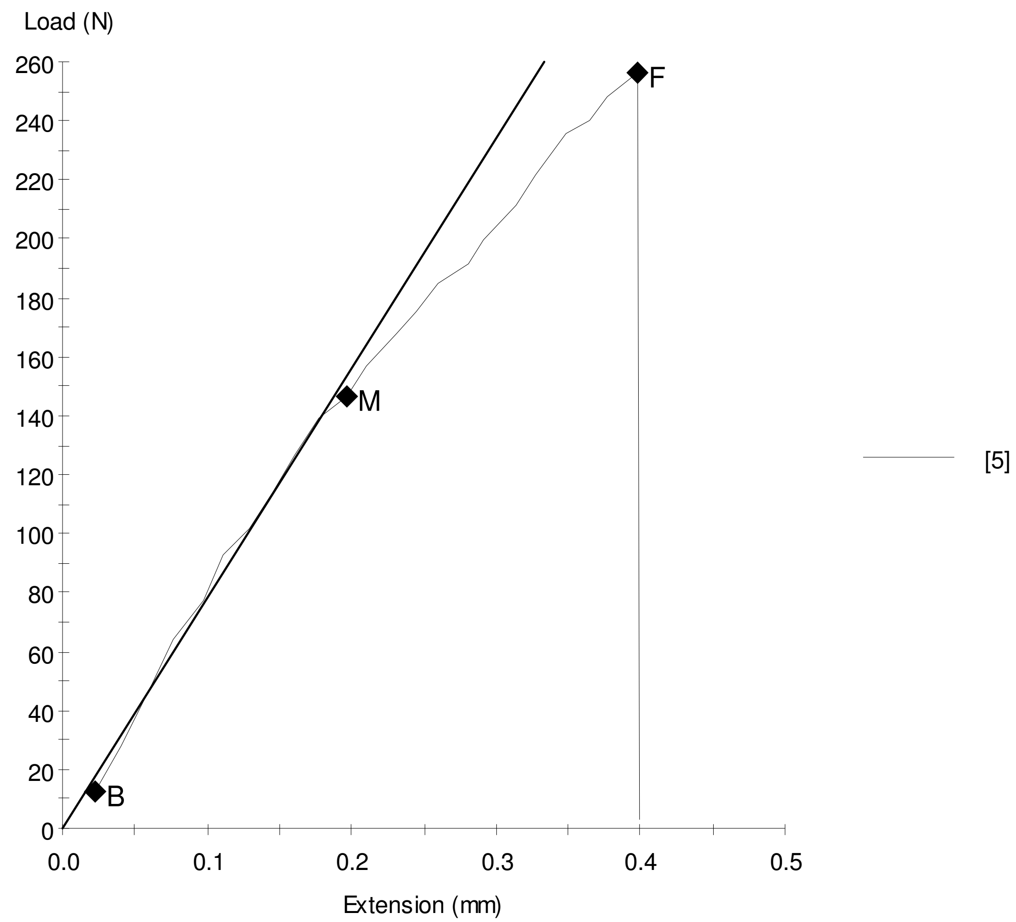


Specimen Results:

Name	Value	Units
Thickness	5.410	mm
Width	14.560	mm
Area	79	mm^2
Peak Load	220	N
Peak Stress	2.79	MPa
Break Load	220	N
Break Stress	2.79	MPa
Elongation At Break	0.347	mm
Stress At Offset Yield	1.918	MPa
Load At Offset Yield	151.067	N

11/09/2008

Sample ID: shashi-sd425-5%-5.mss
Specimen Number: 5
Tagged: False

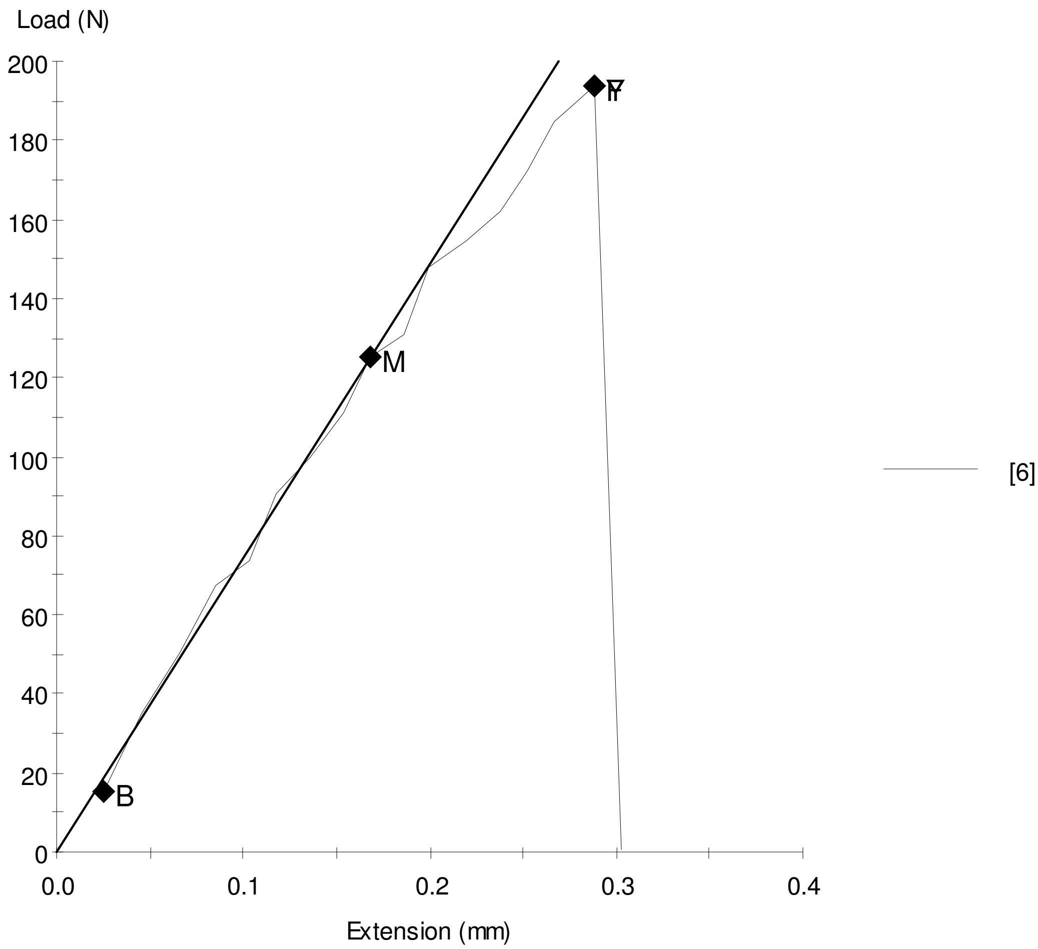


Specimen Results:

Name	Value	Units
Thickness	5.300	mm
Width	14.490	mm
Area	77	mm^2
Peak Load	256	N
Peak Stress	3.33	MPa
Break Load	256	N
Break Stress	3.33	MPa
Elongation At Break	0.398	mm
Stress At Offset Yield	2.186	MPa
Load At Offset Yield	167.852	N

11/09/2008

Sample ID: shashi-sd425-5%-6.mss
Specimen Number: 6
Tagged: False



Specimen Results:

Name	Value	Units
Thickness	5.280	mm
Width	14.550	mm
Area	77	mm^2
Peak Load	194	N
Peak Stress	2.52	MPa
Break Load	194	N
Break Stress	2.52	MPa
Elongation At Break	0.288	mm
Stress At Offset Yield	2.010	MPa
Load At Offset Yield	154.424	N

Tensile Test Plot Obtained On MTS 810 For:

Sawdust: 425 Micron -10% by Weight

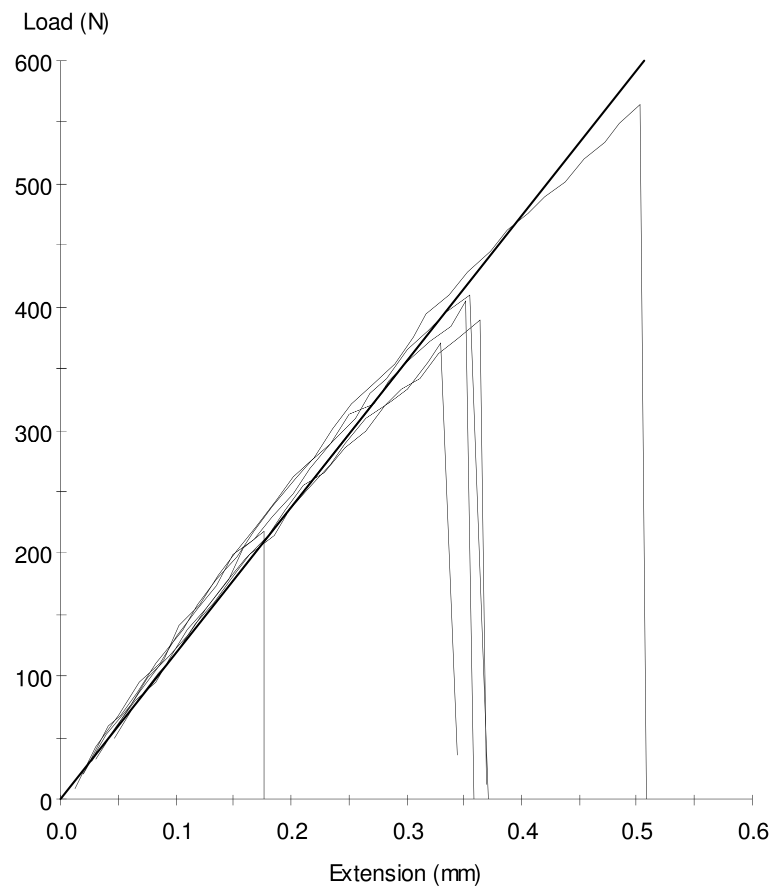
shashi-sd425-10%

Test Date : 11/09/2008
Method : MMT Tensile Test with return.msm

Specimen Results:

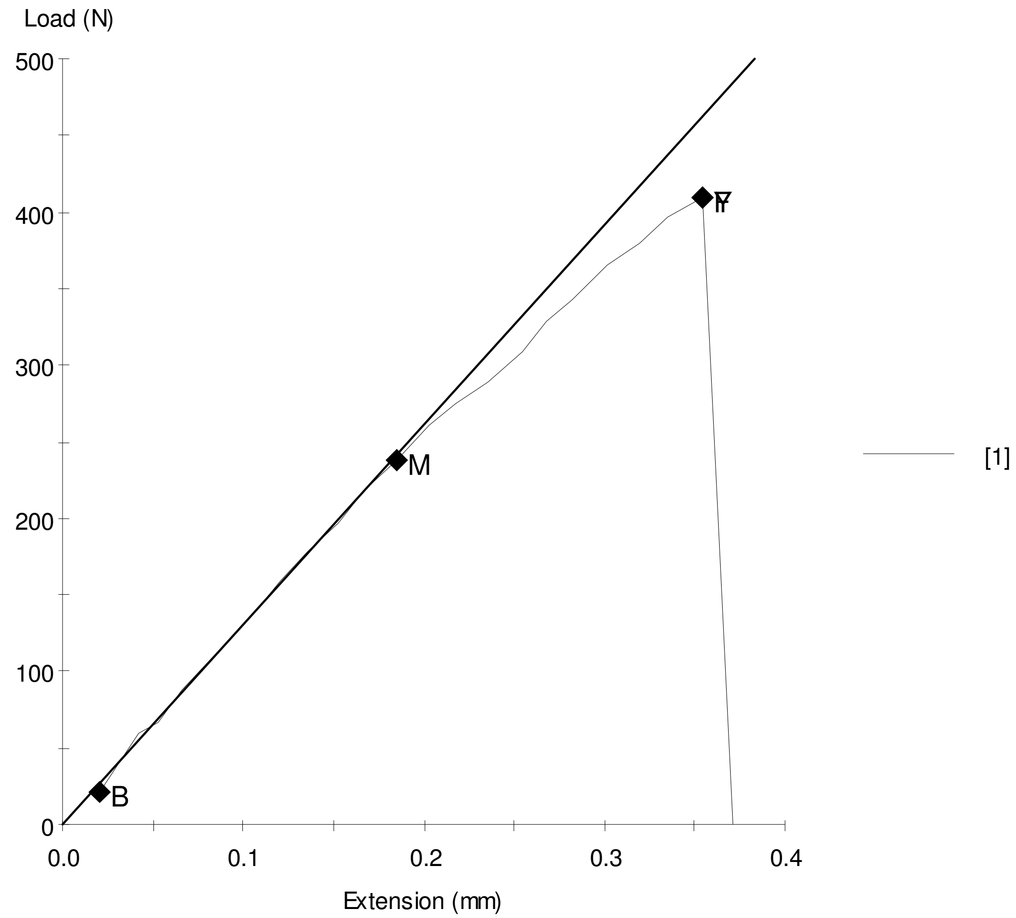
Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	5.440	14.400	78	410	5.23	410	5.23
2	5.420	14.400	78	389	4.99	389	4.99
3	5.660	14.460	82	218	2.67	218	2.67
4	5.430	14.550	79	564	7.14	564	7.14
5	5.460	14.770	81	405	5.02	405	5.02
6	5.420	14.700	80	370	4.65	370	4.65
Mean	**5.472**	**14.547**	**80**	**393**	**4.95**	**393**	**4.95**
Std Dev	**0.093**	**0.157**	**1**	**110**	**1.43**	**110**	**1.43**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.355	3.685	288.705				
2	0.365	3.828	298.776				
3	0.176	-0.046	-3.760				
4	0.503	4.483	354.167				
5	0.351	3.580	288.705				
6	0.330	4.045	322.275				
Mean	**0.347**	**3.263**	**258.145**				
Std Dev	**0.104**	**1.652**	**130.726**				


Load (N)
600
500
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Extension (mm)

11/09/2008

Sample ID: shashi-sd425-10%-1.mss
Specimen Number: 1
Tagged: False

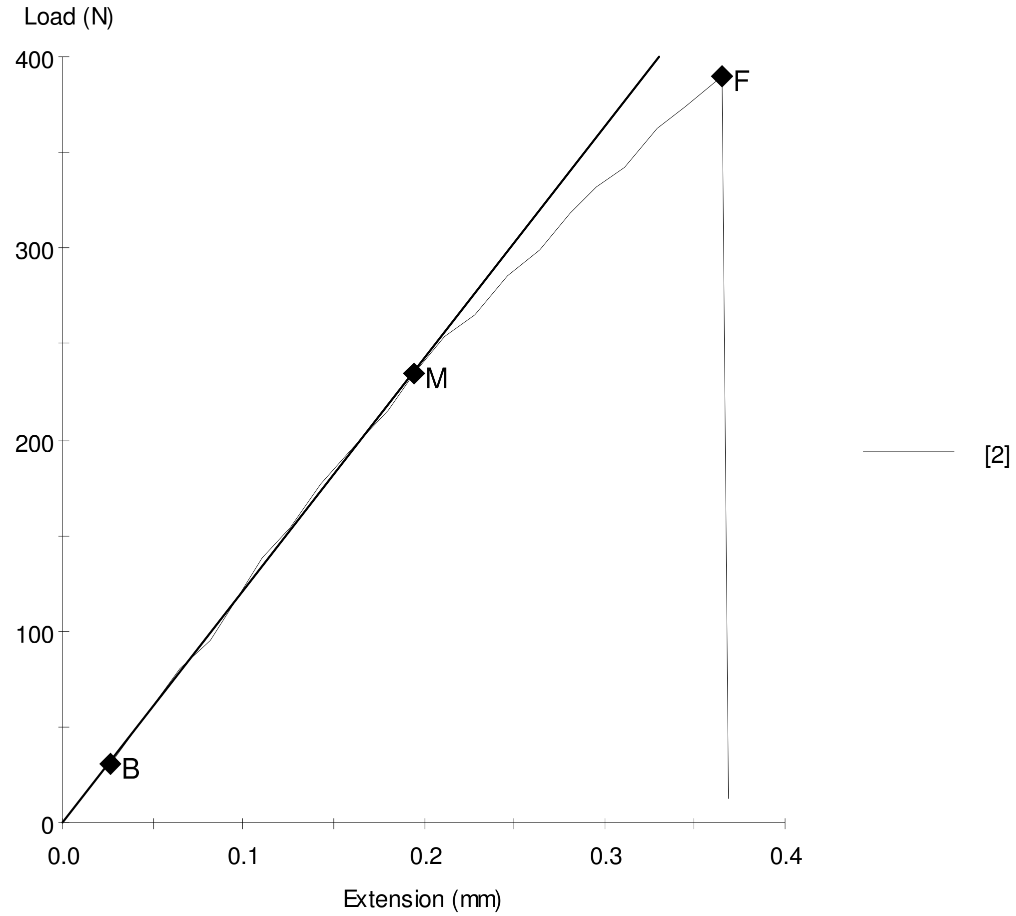


Specimen Results:

Name	Value	Units
Thickness	5.440	mm
Width	14.400	mm
Area	78	mm^2
Peak Load	410	N
Peak Stress	5.23	MPa
Break Load	410	N
Break Stress	5.23	MPa
Elongation At Break	0.355	mm
Stress At Offset Yield	3.685	MPa
Load At Offset Yield	288.705	N

11/09/2008

Sample ID: shashi-sd425-10%-2.mss
Specimen Number: 2
Tagged: False

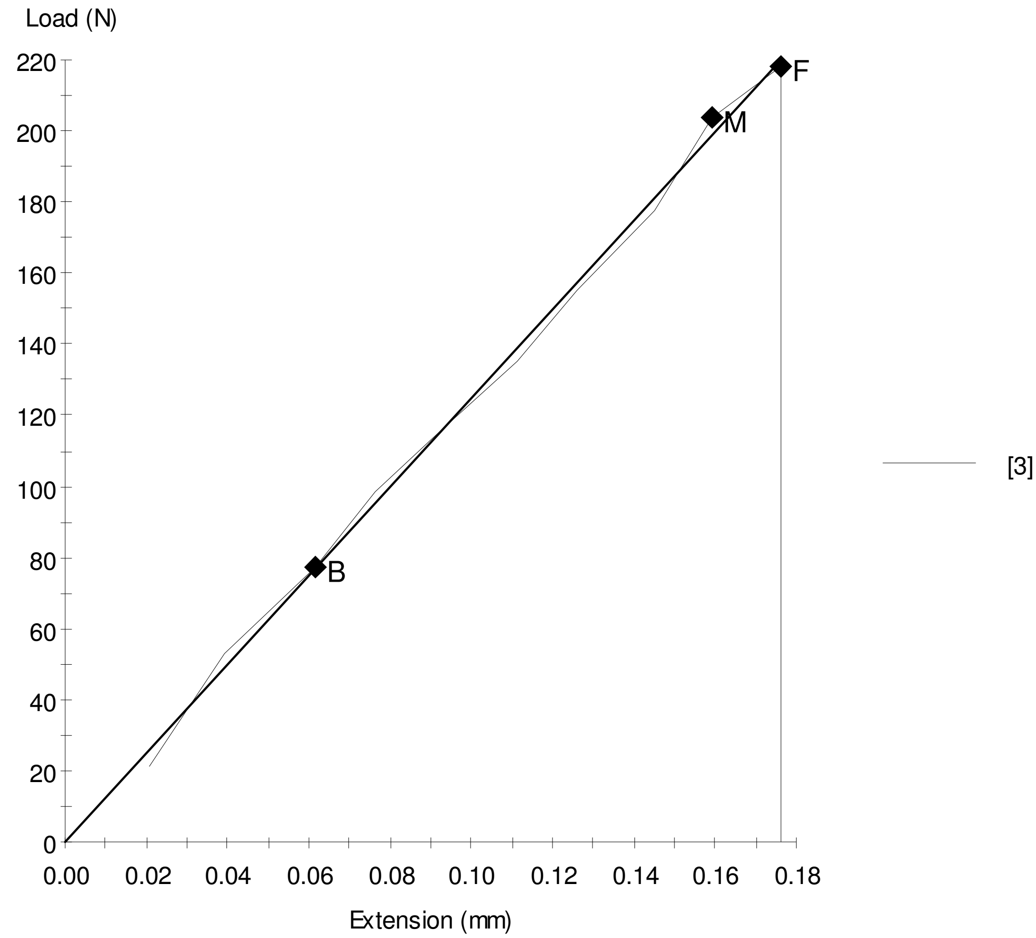


Specimen Results:

Name	Value	Units
Thickness	5.420	mm
Width	14.400	mm
Area	78	mm^2
Peak Load	389	N
Peak Stress	4.99	MPa
Break Load	389	N
Break Stress	4.99	MPa
Elongation At Break	0.365	mm
Stress At Offset Yield	3.828	MPa
Load At Offset Yield	298.776	N

11/09/2008

Sample ID: shashi-sd425-10%-3.mss
Specimen Number: 3
Tagged: False

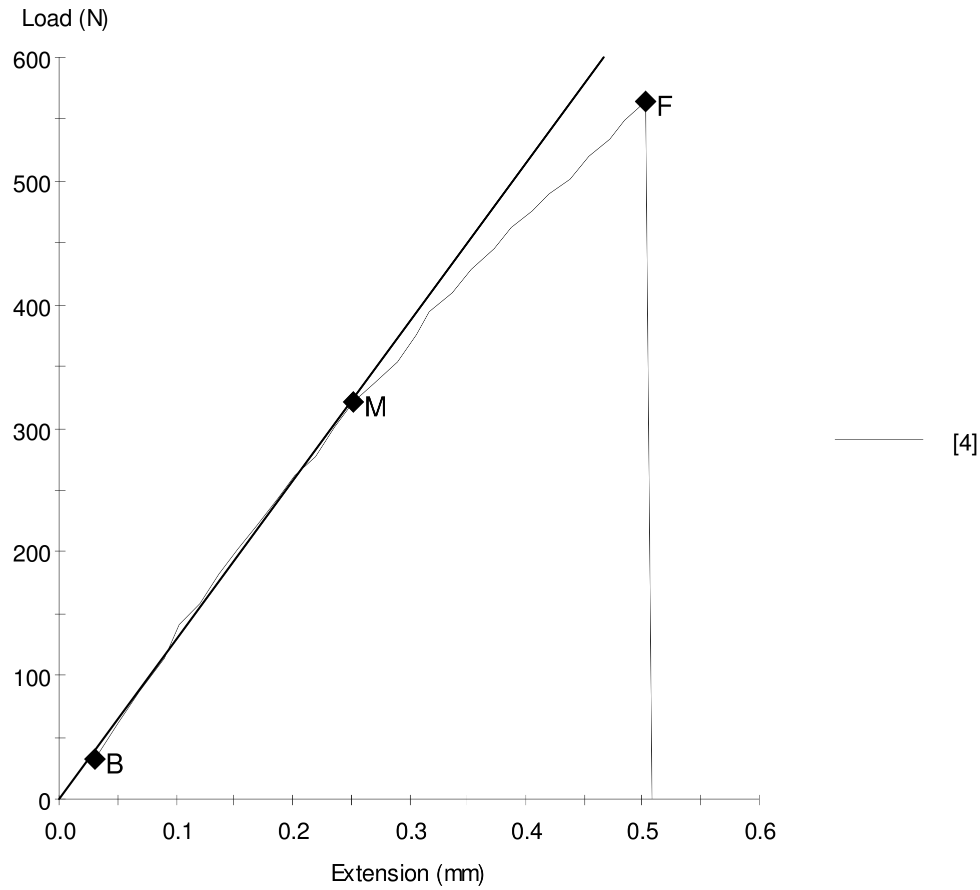


Specimen Results:

Name	Value	Units	
Thickness		5.660	mm
Width	14.460	mm	
Area	82	mm^2	
Peak Load		218	N
Peak Stress		2.67	MPa
Break Load		218	N
Break Stress		2.67	MPa
Elongation At Break		0.176	mm
Stress At Offset Yield		-0.046	MPa
Load At Offset Yield		-3.760	N

11/09/2008

Sample ID: shashi-sd425-10%-4.mss
Specimen Number: 4
Tagged: False

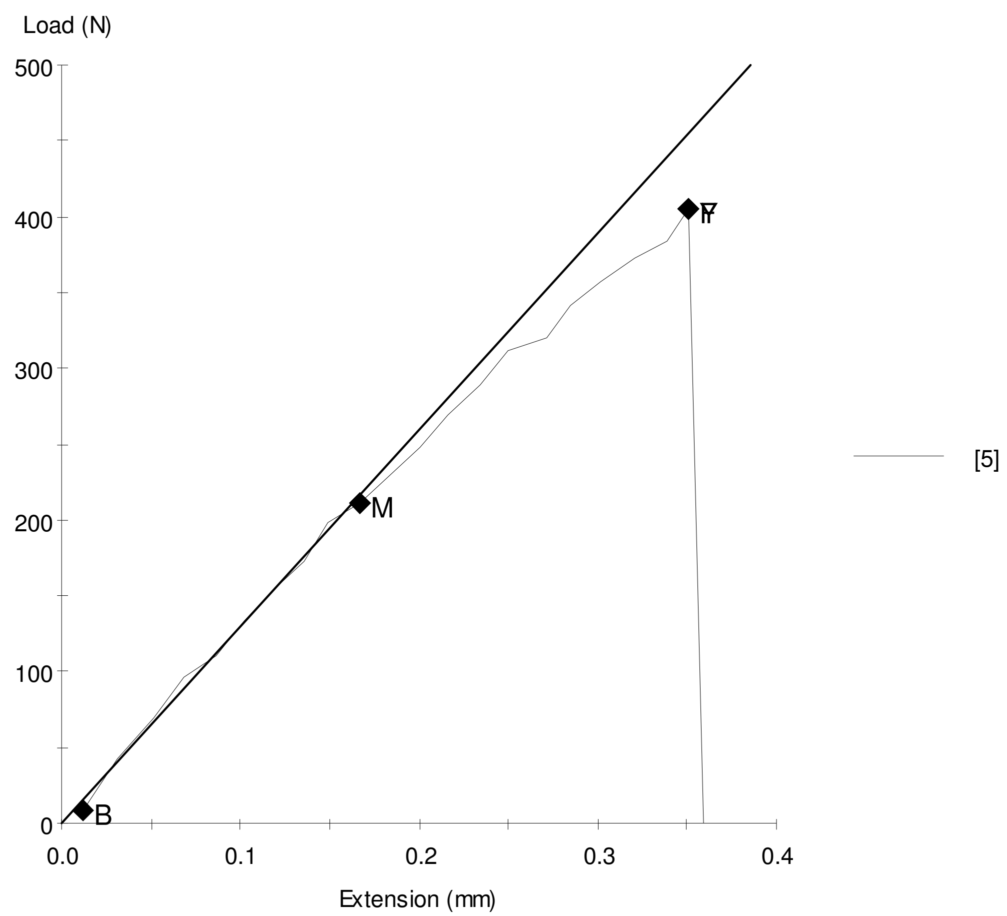


Specimen Results:

Name	Value	Units
Thickness	5.430	mm
Width	14.550	mm
Area	79	mm^2
Peak Load	564	N
Peak Stress	7.14	MPa
Break Load	564	N
Break Stress	7.14	MPa
Elongation At Break	0.503	mm
Stress At Offset Yield	4.483	MPa
Load At Offset Yield	354.167	N

11/09/2008

Sample ID: shashi-sd425-10%-5.mss
Specimen Number: 5
Tagged: False

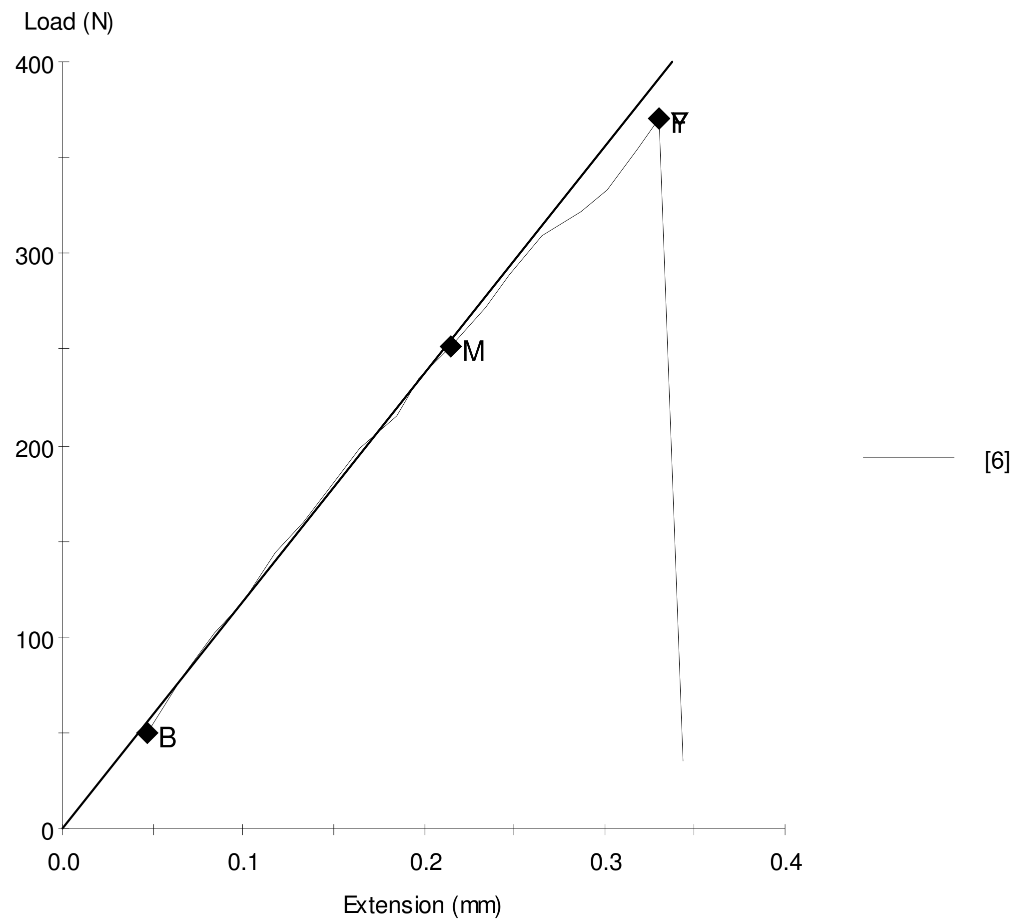


Specimen Results:

Name	Value	Units	
Thickness		5.460	mm
Width	14.770	mm	
Area	81	mm^2	
Peak Load		405	N
Peak Stress		5.02	MPa
Break Load		405	N
Break Stress		5.02	MPa
Elongation At Break		0.351	mm
Stress At Offset Yield		3.580	MPa
Load At Offset Yield		288.705	N

11/09/2008

Sample ID: shashi-sd425-10%-6.mss
Specimen Number: 6
Tagged: False



Specimen Results:

Name	Value	Units
Thickness	5.420	mm
Width	14.700	mm
Area	80	mm^2
Peak Load	370	N
Peak Stress	4.65	MPa
Break Load	370	N
Break Stress	4.65	MPa
Elongation At Break	0.330	mm
Stress At Offset Yield	4.045	MPa
Load At Offset Yield	322.275	N

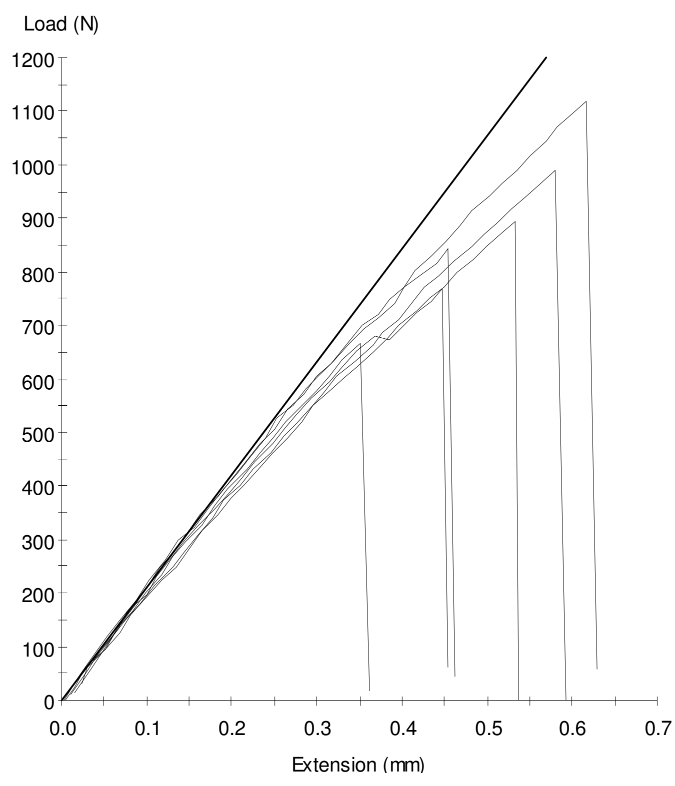
Tensile Test Plot Obtained On MTS 810 For:

Sawdust: 425 Micron -15% by Weight

shashi-sd425-15%
Test Date : 11/09/2008
Method : MMT Tensile Test with return.msm
Specimen Results:

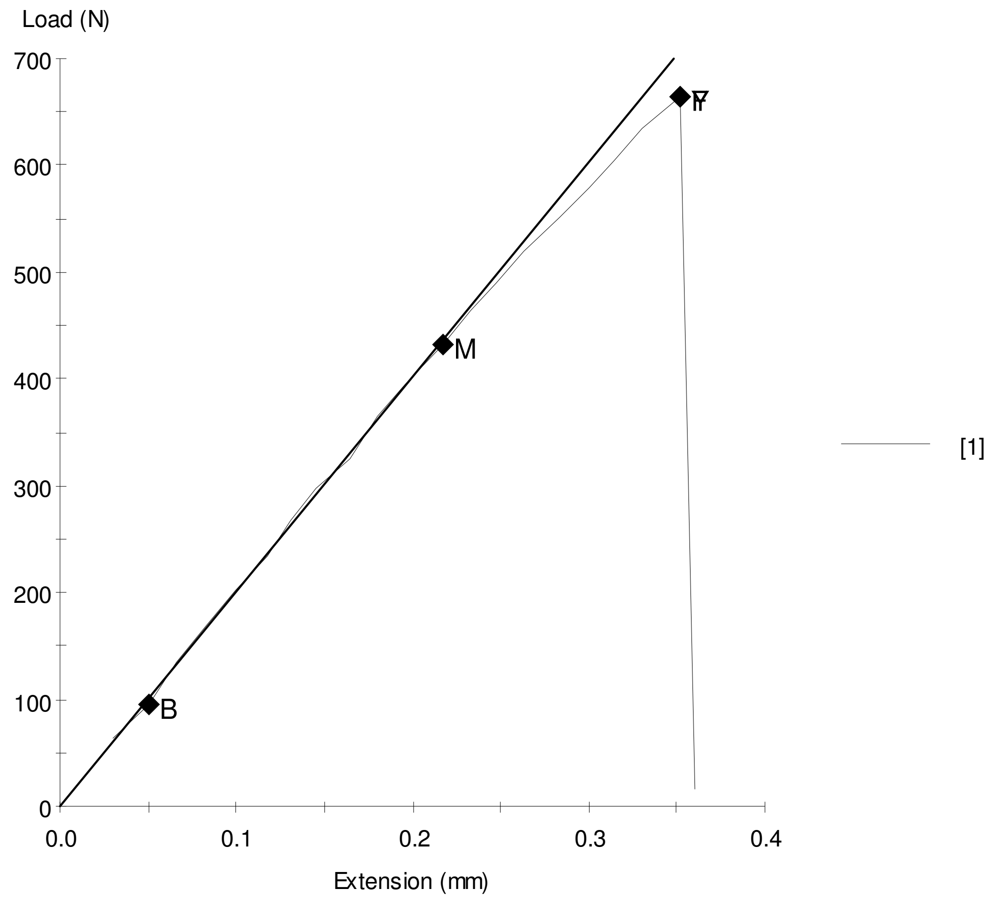
Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	5.610	14.610	82	665	8.11	665	8.11
2	5.550	14.650	81	893	10.98	893	10.98
3	5.760	14.590	84	1119	13.31	1119	13.31
4	5.720	14.690	84	770	9.16	770	9.16
5	5.620	14.620	82	988	12.02	988	12.02
6	5.750	14.420	83	844	10.18	844	10.18
Mean	**5.668**	**14.597**	**83**	**880**	**10.63**	**880**	**10.63**
Std Dev	**0.087**	**0.093**	**1**	**160**	**1.90**	**160**	**1.90**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.352	7.373	604.266				
2	0.534	7.391	600.909				
3	0.617	8.588	721.763				
4	0.448	6.712	563.982				
5	0.580	7.702	632.801				
6	0.453	7.004	580.767				
Mean	**0.497**	**7.462**	**617.415**				
Std Dev	**0.098**	**0.650**	**56.158**				



11/09/2008

Sample ID: shashi-sd425-15%-1.mss
Specimen Number: 1
Tagged: False

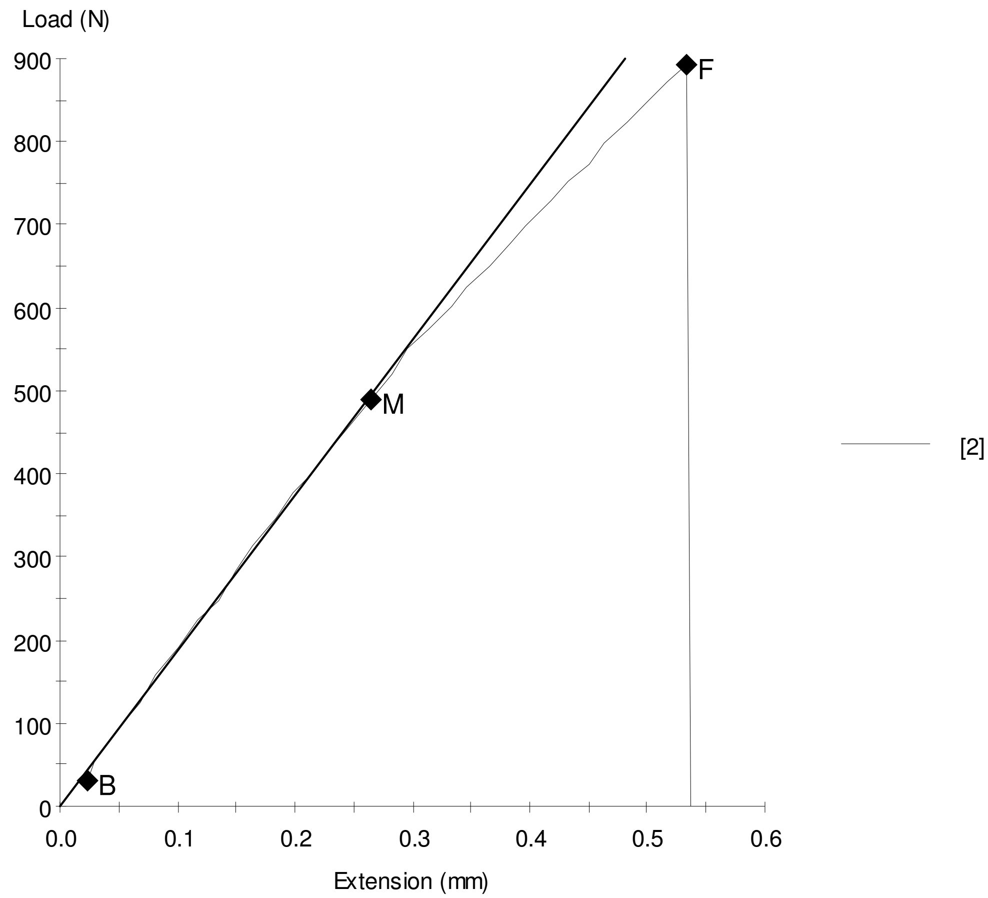


Specimen Results:

Name	Value	Units
Thickness	5.610	mm
Width	14.610	mm
Area	82	mm^2
Peak Load	665	N
Peak Stress	8.11	MPa
Break Load	665	N
Break Stress	8.11	MPa
Elongation At Break	0.352	mm
Stress At Offset Yield	7.373	MPa
Load At Offset Yield	604.266	N

11/09/2008

Sample ID: shashi-sd425-15%-2.mss
Specimen Number: 2
Tagged: False

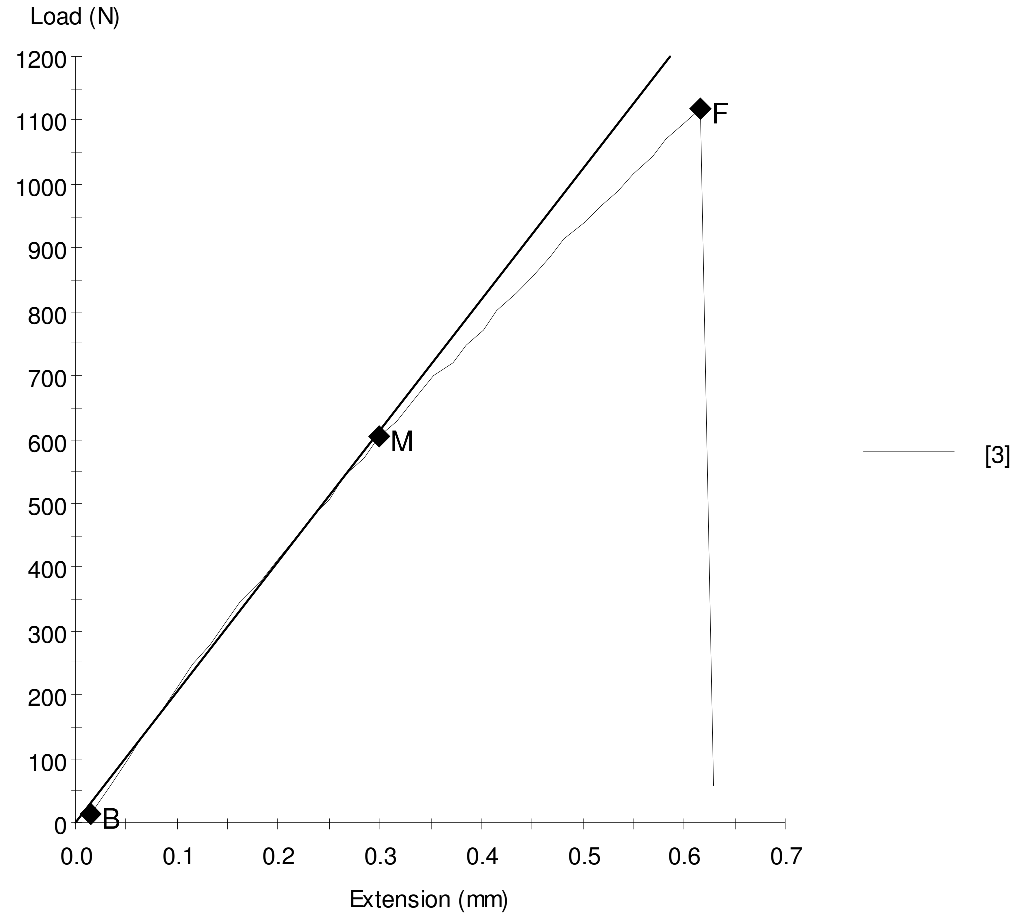


Specimen Results:

Name	Value	Units
Thickness	5.550	mm
Width	14.650	mm
Area	81	mm^2
Peak Load	893	N
Peak Stress	10.98	MPa
Break Load	893	N
Break Stress	10.98	MPa
Elongation At Break	0.534	mm
Stress At Offset Yield	7.391	MPa
Load At Offset Yield	600.909	N

11/09/2008

Sample ID: shashi-sd425-15%-3.mss
Specimen Number: 3
Tagged: False

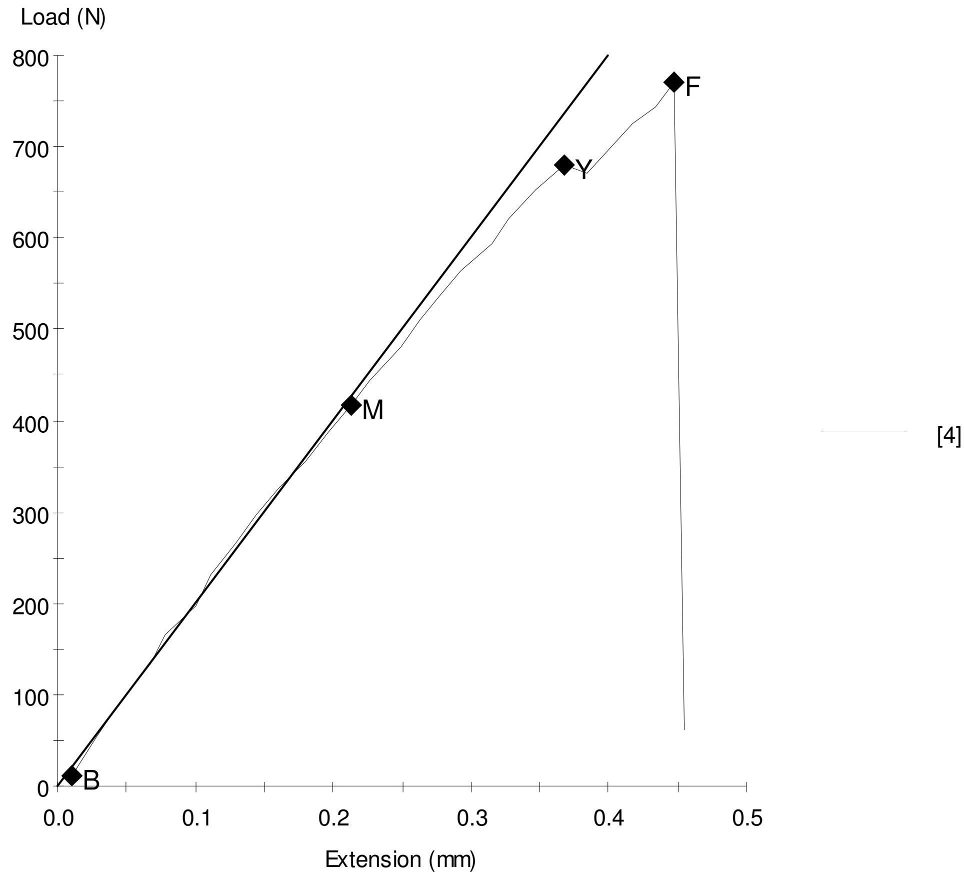


Specimen Results:

Name	Value	Units	
Thickness		5.760	mm
Width	14.590	mm	
Area	84	mm^2	
Peak Load		1119	N
Peak Stress		13.31	MPa
Break Load		1119	N
Break Stress		13.31	MPa
Elongation At Break		0.617	mm
Stress At Offset Yield		8.588	MPa
Load At Offset Yield		721.763	N

11/09/2008

Sample ID: shashi-sd425-15%-4.mss
Specimen Number: 4
Tagged: False

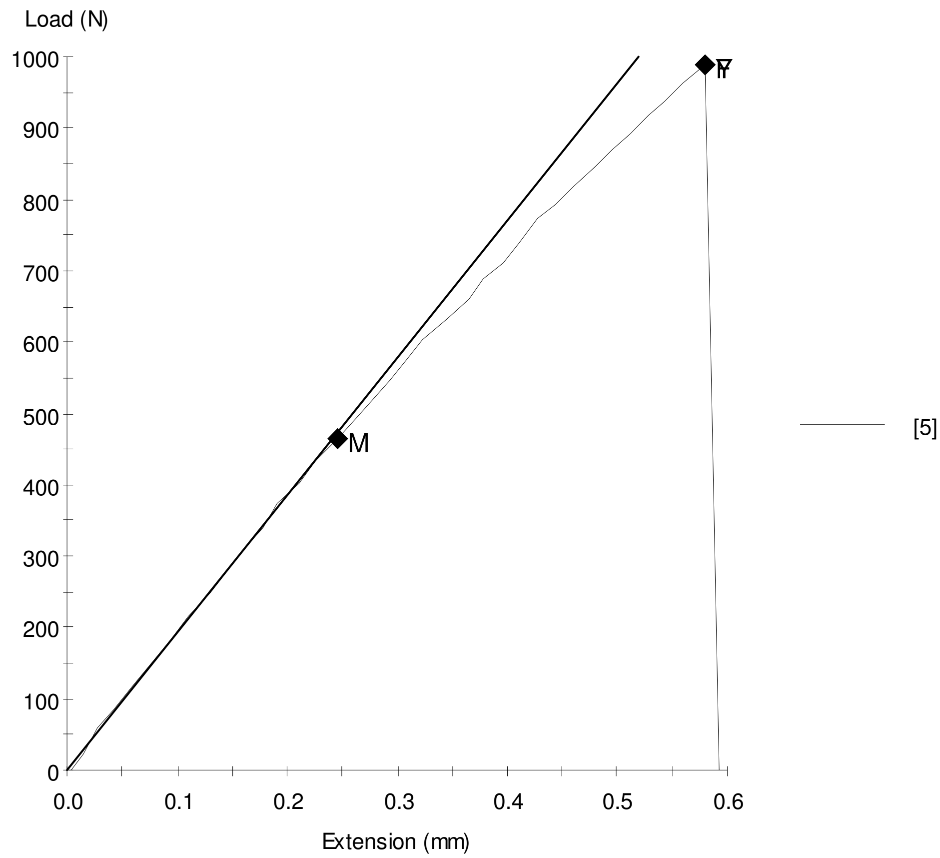


Specimen Results:

Name	Value	Units
Thickness	5.720	mm
Width	14.690	mm
Area	84	mm^2
Peak Load	770	N
Peak Stress	9.16	MPa
Break Load	770	N
Break Stress	9.16	MPa
Elongation At Break	0.448	mm
Stress At Offset Yield	6.712	MPa
Load At Offset Yield	563.982	N

11/09/2008

Sample ID: shashi-sd425-15%-5.mss
Specimen Number: 5
Tagged: False

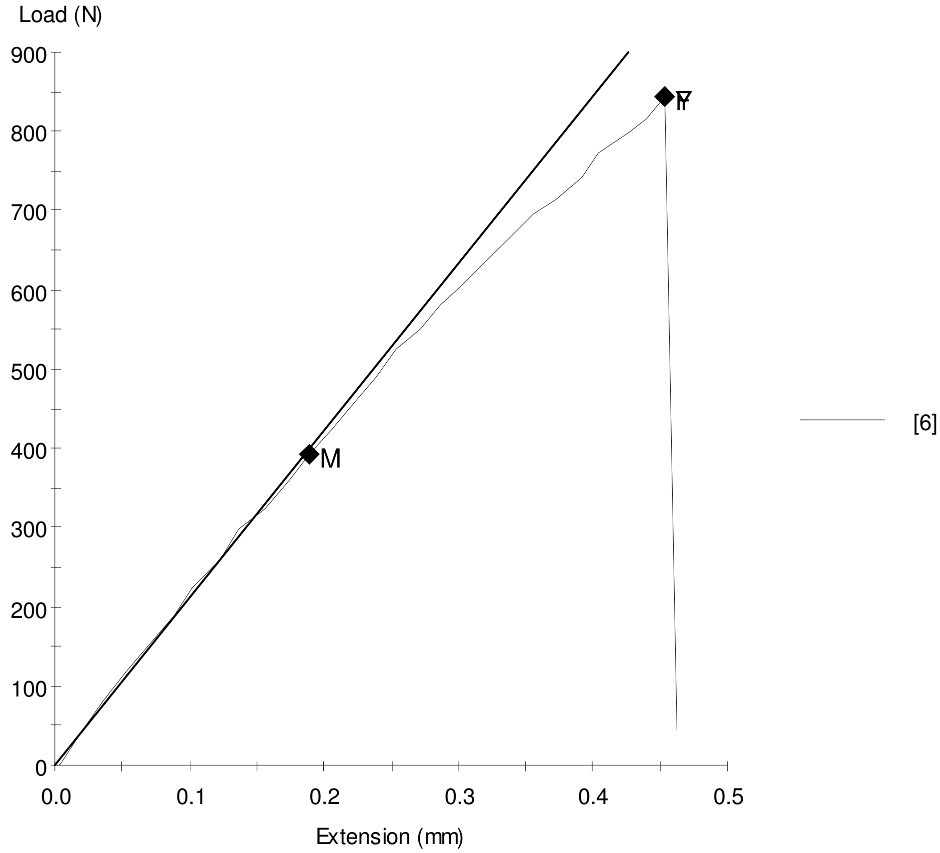


Specimen Results:

Name	Value	Units
Thickness	5.620	mm
Width	14.620	mm
Area	82	mm^2
Peak Load	988	N
Peak Stress	12.02	MPa
Break Load	988	N
Break Stress	12.02	MPa
Elongation At Break	0.580	mm
Stress At Offset Yield	7.702	MPa
Load At Offset Yield	632.801	N

11/09/2008

Sample ID: shashi-sd425-15%-6.mss
Specimen Number: 6
Tagged: False



Specimen Results:

Name	Value	Units
Thickness	5.750	mm
Width	14.420	mm
Area	83	mm^2
Peak Load	844	N
Peak Stress	10.18	MPa
Break Load	844	N
Break Stress	10.18	MPa
Elongation At Break	0.453	mm
Stress At Offset Yield	7.004	MPa
Load At Offset Yield	580.767	N

Tensile Test Plot Obtained On MTS 810 For:

Sawdust: 1.18 mm -5% by Weight

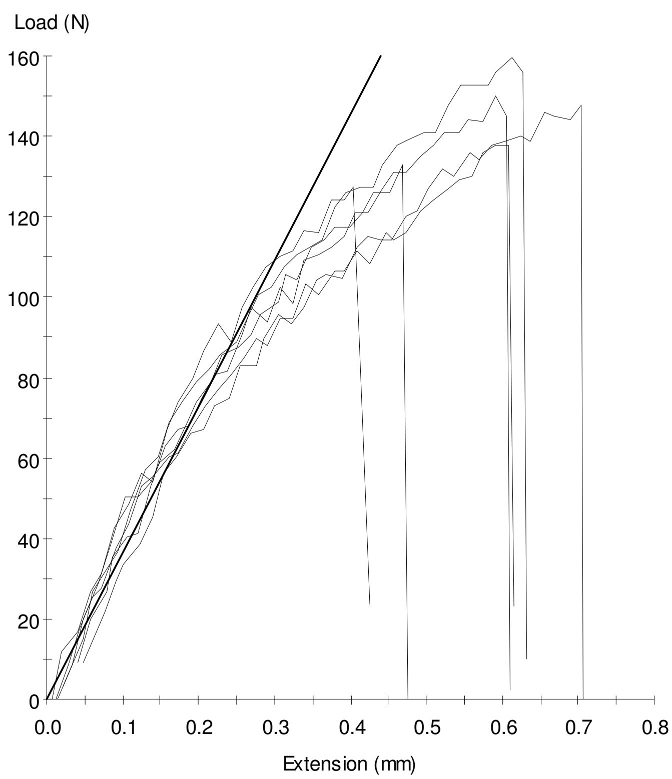
shashi-sd118-5%

Method : MMT Tensile Test with return.msm

Specimen Results:

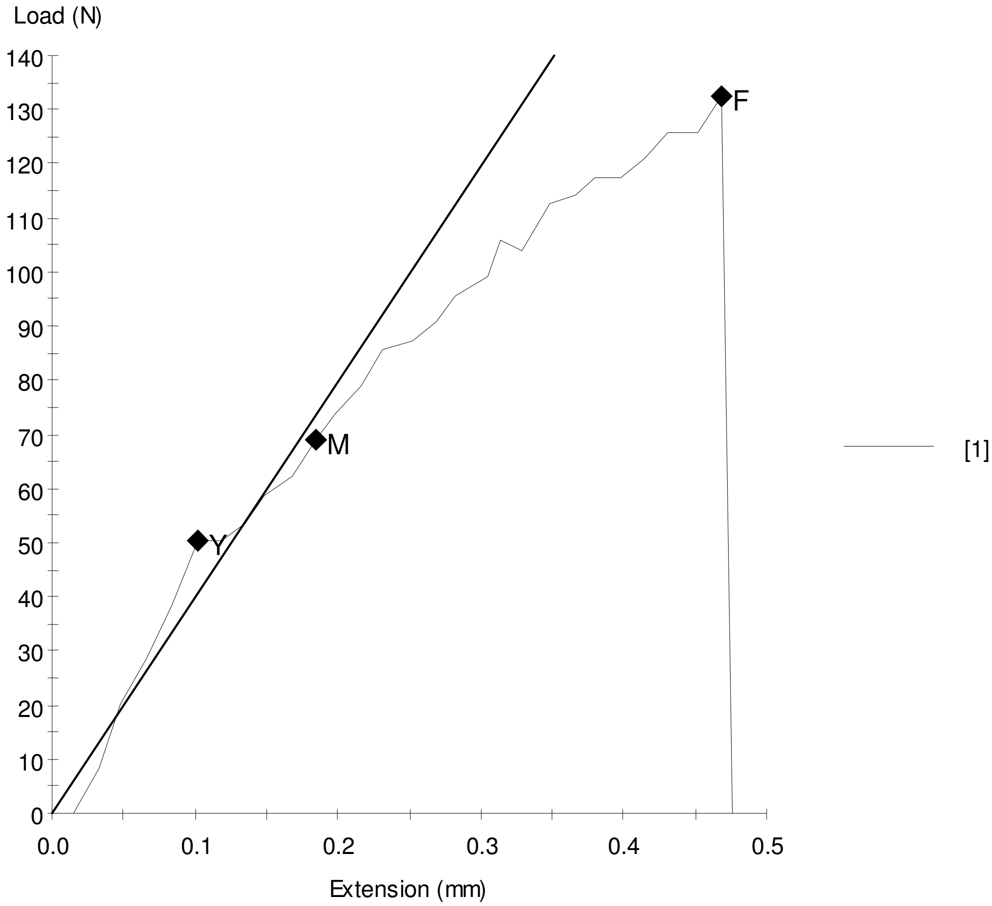
Specimen #	Thickness mm	Width mm	Area mm^2	Peak Load N	Peak Stress MPa	Break Load N	Break Stress MPa
1	5.520	14.410	80	133	1.67	133	1.67
2	5.350	14.550	78	128	1.64	128	1.64
3	5.560	14.700	82	148	1.81	148	1.81
4	5.620	14.800	83	138	1.65	138	1.65
5	5.650	14.580	82	159	1.94	156	1.89
6	5.520	14.720	81	150	1.85	145	1.79
Mean	**5.537**	**14.627**	**81**	**143**	**1.76**	**141**	**1.74**
Std Dev	**0.106**	**0.141**	**2**	**12**	**0.12**	**11**	**0.10**

Specimen #	Elongation At Break mm	Stress At Offset Yield MPa	Load At Offset Yield N				
1	0.469	0.865	68.819				
2	0.405	1.143	88.961				
3	0.704	1.140	93.158				
4	0.607	0.817	67.980				
5	0.626	1.039	85.604				
6	0.606	1.157	93.997				
Mean	**0.569**	**1.027**	**83.087**				
Std Dev	**0.111**	**0.151**	**11.774**				



11/09/2008

Sample ID: shashi-sd118-5%-1.mss
Specimen Number: 1
Tagged: False

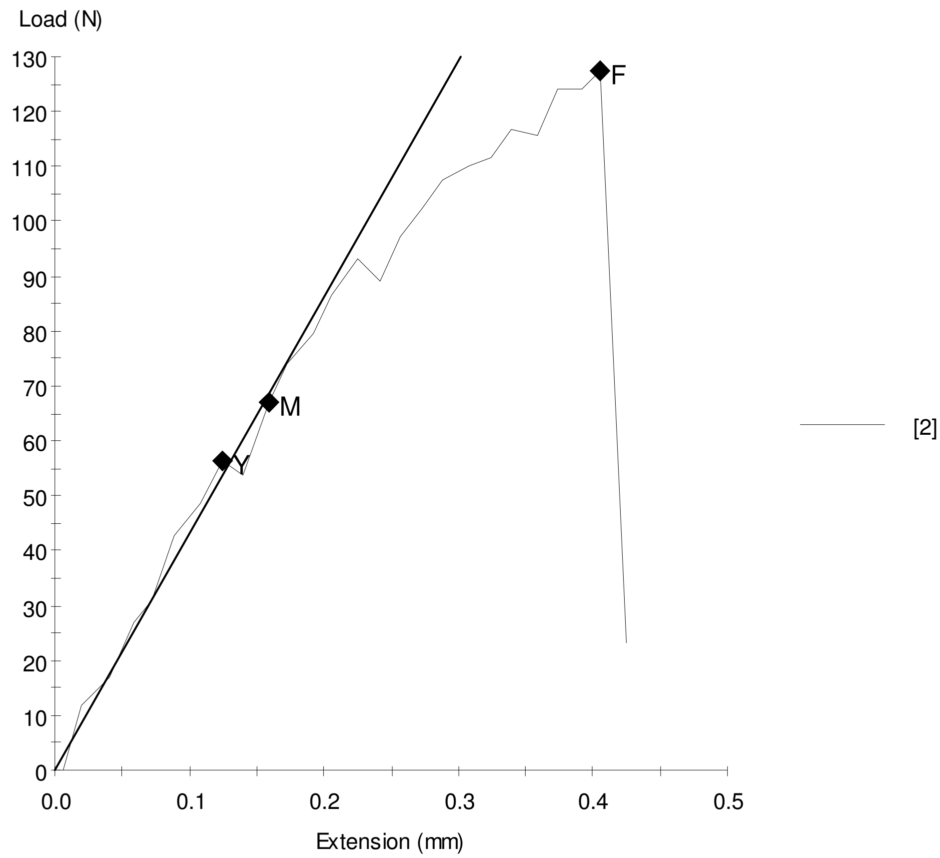


Specimen Results:

Name	Value	Units
Thickness	5.520	mm
Width	14.410	mm
Area	80	mm^2
Peak Load	133	N
Peak Stress	1.67	MPa
Break Load	133	N
Break Stress	1.67	MPa
Elongation At Break	0.469	mm
Stress At Offset Yield	0.865	MPa
Load At Offset Yield	68.819	N

11/09/2008

Sample ID: shashi-sd118-5%-2.mss
Specimen Number: 2
Tagged: False

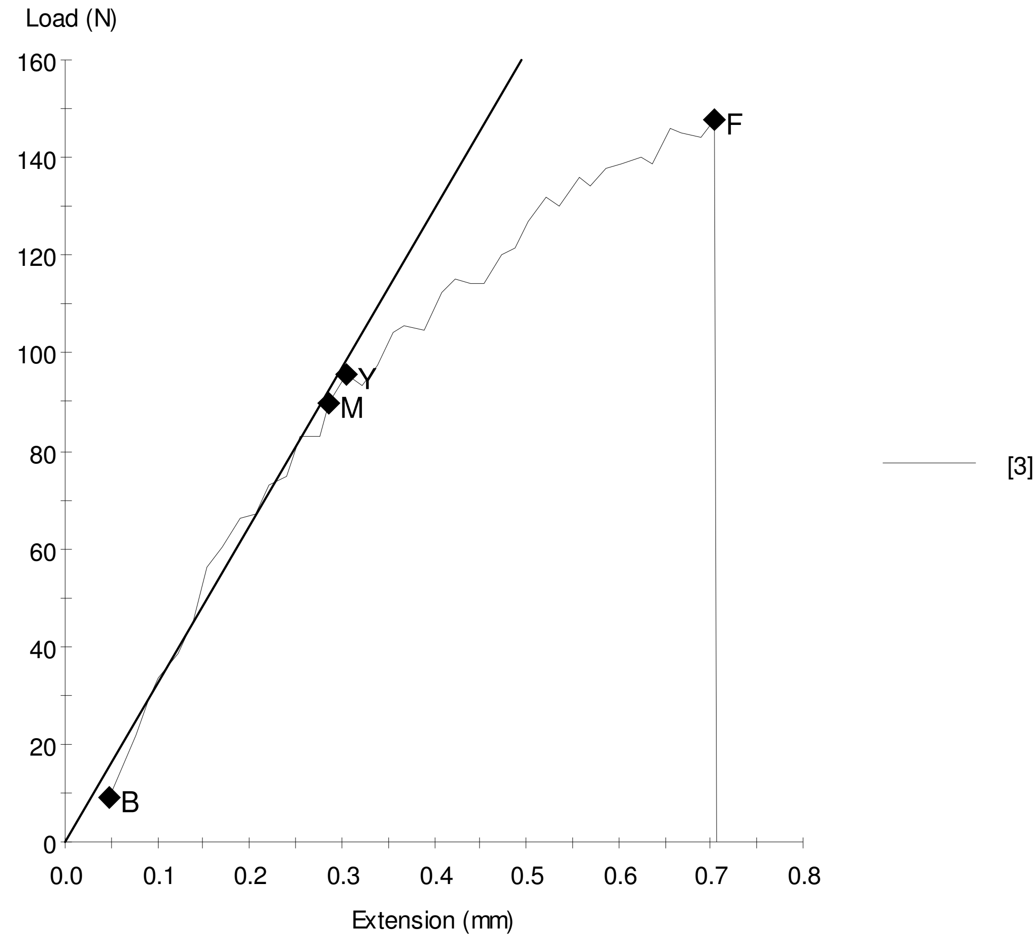


Specimen Results:

Name	Value	Units
Thickness	5.350	mm
Width	14.550	mm
Area	78	mm^2
Peak Load	128	N
Peak Stress	1.64	MPa
Break Load	128	N
Break Stress	1.64	MPa
Elongation At Break	0.405	mm
Stress At Offset Yield	1.143	MPa
Load At Offset Yield	88.961	N

11/09/2008

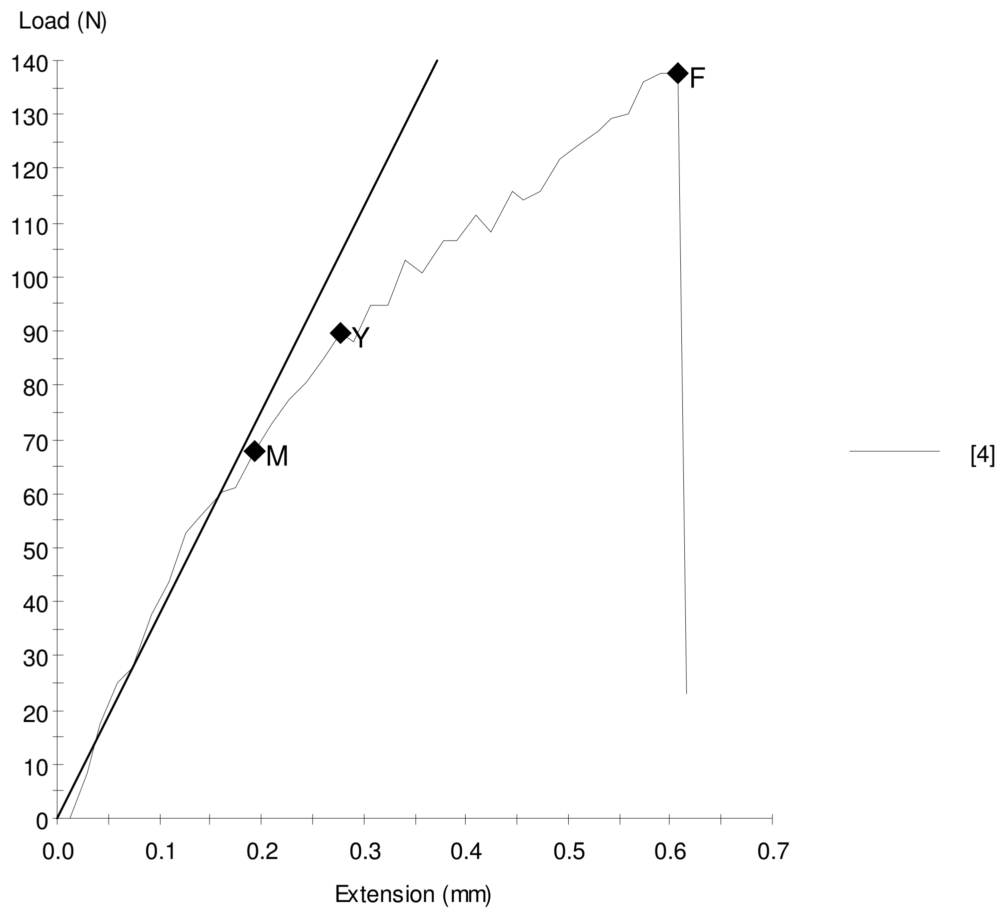
Sample ID: shashi-sd118-5%-3.mss
Specimen Number: 3
Tagged: False



Specimen Results:

Name Value Units
Thickness 5.560 mm
Width 14.700 mm
Area 82 mm^2
Peak Load 148 N
Peak Stress 1.81 MPa
Break Load 148 N
Break Stress 1.81 MPa
Elongation At Break 0.704 mm
Stress At Offset Yield 1.140 MPa
Load At Offset Yield 93.158 N

Sample ID: shashi-sd118-5%-4.mss
Specimen Number: 4
Tagged: False

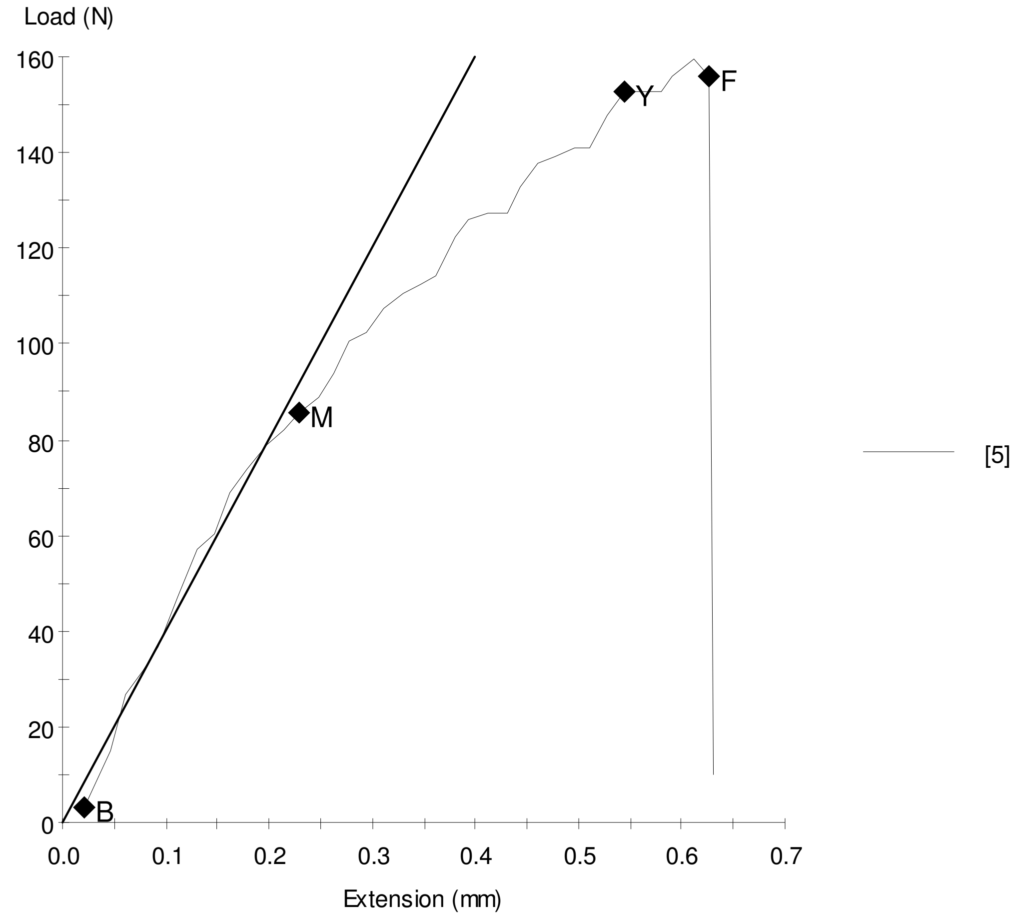


Specimen Results:

Name	Value	Units
Thickness	5.620	mm
Width	14.800	mm
Area	83	mm^2
Peak Load	138	N
Peak Stress	1.65	MPa
Break Load	138	N
Break Stress	1.65	MPa
Elongation At Break	0.607	mm
Stress At Offset Yield	0.817	MPa
Load At Offset Yield	67.980	N

11/09/2008

Sample ID: shashi-sd118-5%-5.mss
Specimen Number: 5
Tagged: False

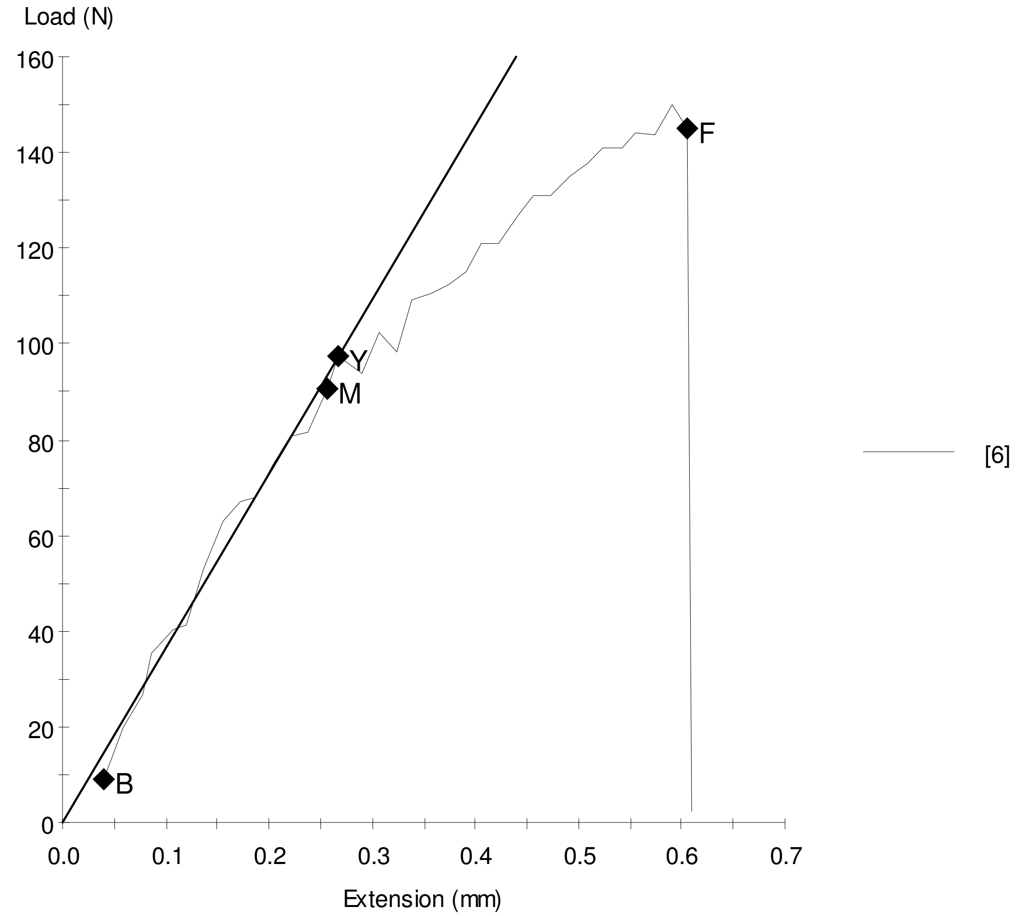


Specimen Results:

Name	Value	Units	
Thickness		5.650	mm
Width	14.580	mm	
Area	82	mm^2	
Peak Load		159	N
Peak Stress		1.94	MPa
Break Load		156	N
Break Stress		1.89	MPa
Elongation At Break		0.626	mm
Stress At Offset Yield		1.039	MPa
Load At Offset Yield		85.604	N

11/09/2008

Sample ID: shashi-sd118-5%-6.mss
Specimen Number: 6
Tagged: False



Specimen Results:

Name	Value	Units	
Thickness		5.520	mm
Width	14.720	mm	
Area	81	mm^2	
Peak Load		150	N
Peak Stress		1.85	MPa
Break Load		145	N
Break Stress		1.79	MPa
Elongation At Break			0.606 mm
Stress At Offset Yield			1.157 MPa
Load At Offset Yield			93.997 N

Appendix E: Viscosity Measurements

Viscosity was measured using the **Brookfield Programmable DV-II+ viscosity testing machine** at the Centre of Excellence in Engineered Fibre Composites (CEEFC), USQ.

Figure E. 1: Brookfield Programmable DV-II+ viscosity testing machine

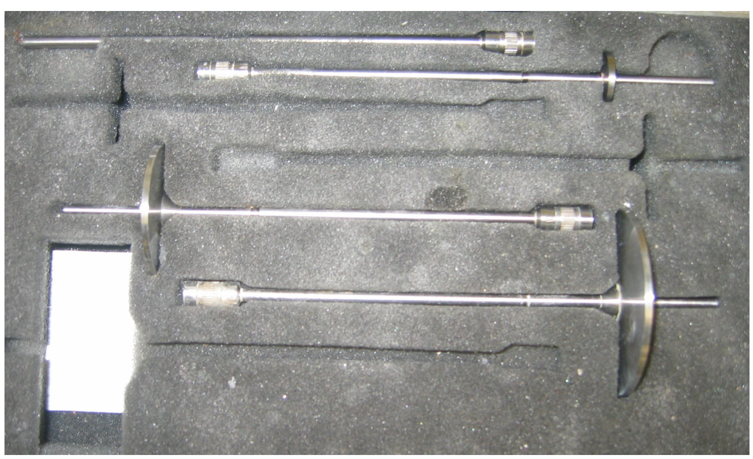


Figure E. 2: Spindles for Brookfield Programmable DV-II+ Viscometer

The figure above show the Viscometer used to test the viscosity of the samples. The second figure above shows the various spindles used. It is a practice to use smaller diameter spindles to measure liquids of higher viscosity whereas larger diameter spindles are used for non-viscous/ less viscous liquids. This is critical for the accuracy of the measurements. The spindle number varies from 1-7.

% of Saw dust by weight (1.18 mm)	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 E. 1: Viscosity reading for resin and 1.18 mm grain size sawdust (0-25%) taken using Brookfield Programmable DV-II + Viscometer

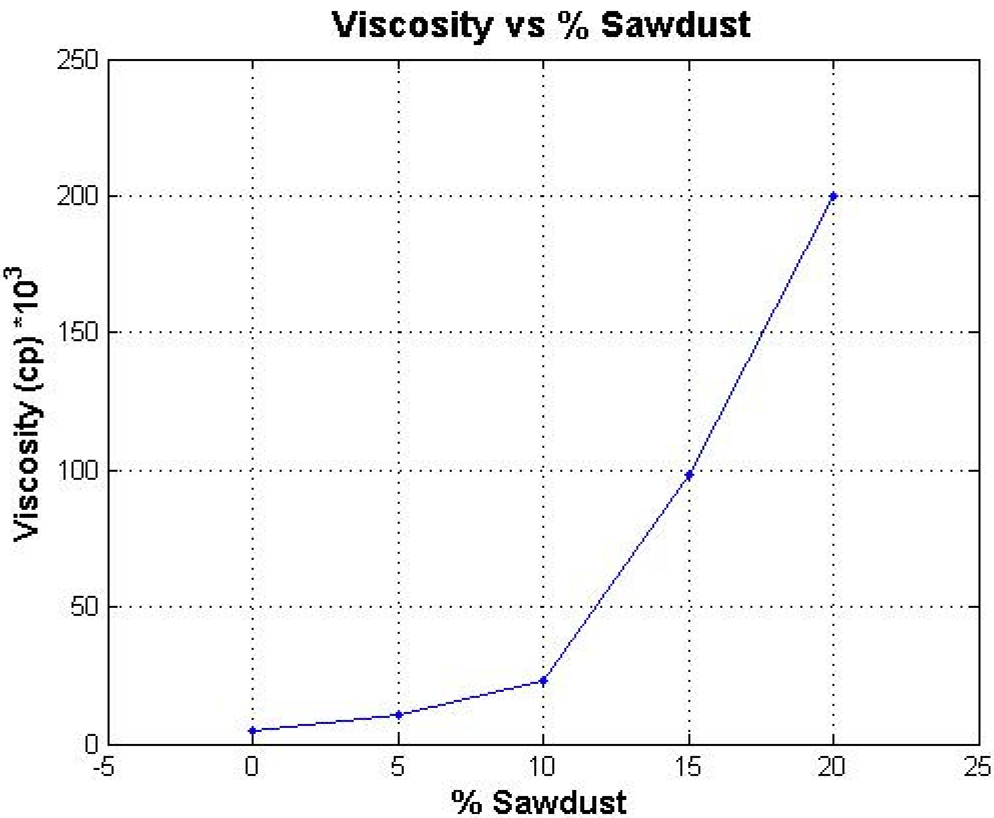


Figure E. 3: Viscosity reading trend

The above figure shows that the viscosity keeps on increasing as the filler (saw dust) is added to the phenolic resin. As seen from the above table, at 20% by weight of sawdust, the viscosity increases to a very high value thus making molding impossible.

Figure E. 4: A very high viscous resin mixture

This value is much higher than the optimum filler content in resin which is required to achieve maximum tensile strength. The value of viscosity for 5% w/w is found to be 10800 cp.

In order to take viscosity reading, we needed to have the density values for sawdust. The various reading for densities is shown in the table below. These readings are manually inputted in the program while calculating viscosity.

% Ratio of Resin– Sawdust	Density Readings (g/cm^3)			Temperature (^{0}C)	Mean Density (g/cm^3)
	Reading 1	Reading 2	Reading 3		
95 R: 5 S/D	1.2535	1.2528	1.2525	24.4	1.25
90 R:10 S/D	1.2601	1.2596	1.2592	24.4	1.26
80 R:15 S/D	1.2666	1.2666	1.2660	24.4	1.27
85 R:20 S/D	1.2682	1.2679	1.2673	26.4	1.27
75 R: 25 S/D	1.2929	1.2908	1.2878	25.7	1.29

Table E. 2: Density of the 1.18mm grain size mixed with the resin of different ratio of percentage by weight

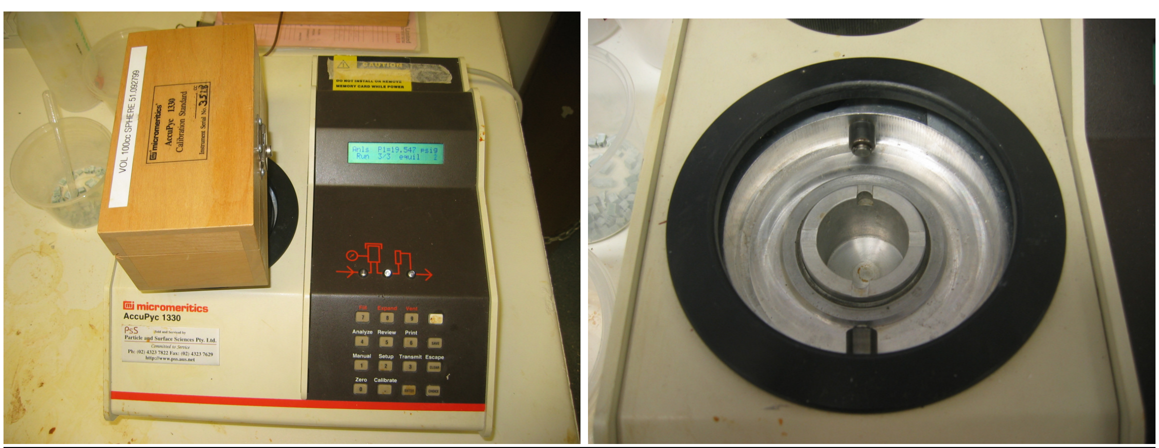


Figure E. 5: Density measuring machine

Appendix F: Calculations of Tensile Strength from Raw Data

Sample ID: shashi-sd425-5%-4.mss
Specimen Number: 4

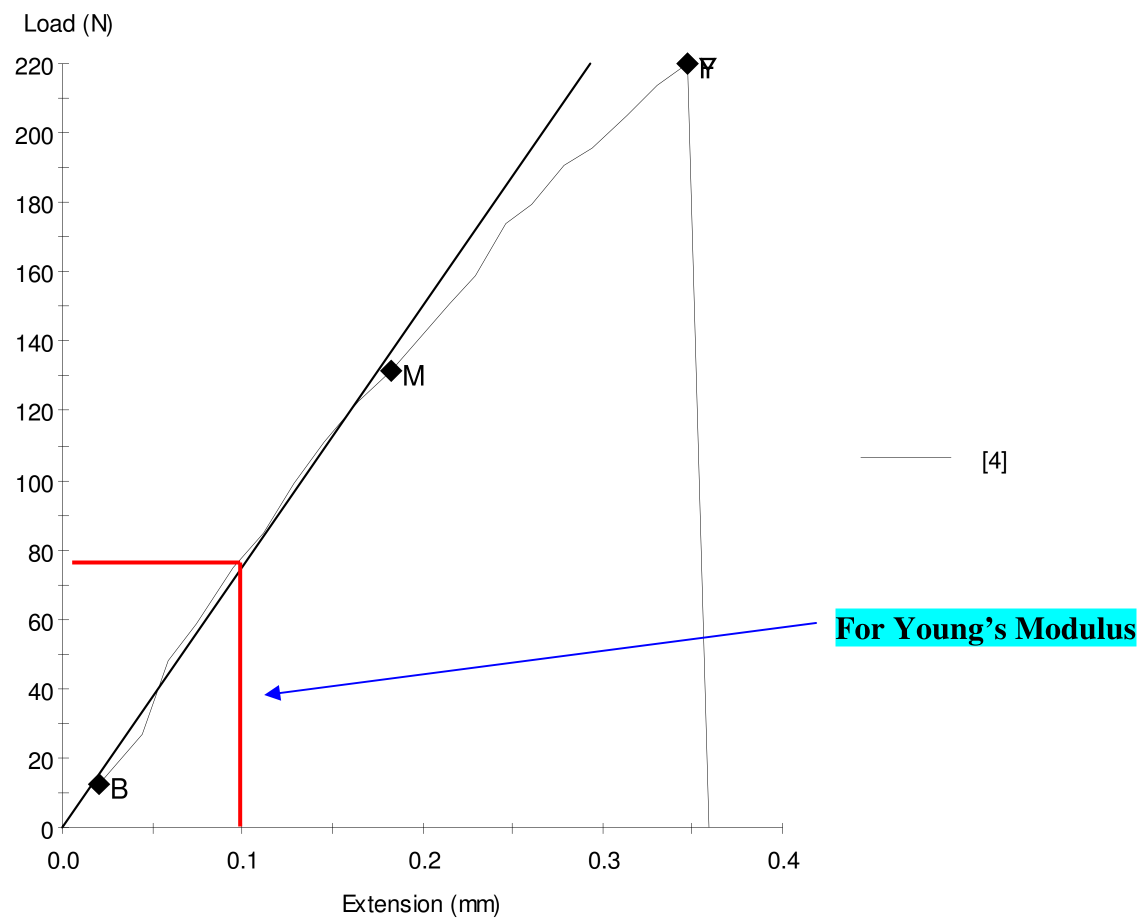


Figure F. 1: Load vs extension plot from Tensile testing machine

Specimen Results:
Name Value Units
Thickness 5.410 mm
Width 14.560 mm
Area 79 mm^2
Peak Load 220 N
Peak Stress 2.79 MPa ← Peak stress = Tensile stress
Break Load 220 N
Break Stress 2.79 MPa
Elongation At Break 0.347 mm
Stress At Offset Yield 1.918 MPa
Load At Offset Yield 151.067 N

The calculations of strengths for the plot shown above can be done as described below:

Young's Modulus

Young's modulus is obtained from the data obtained for the straight part of the plot.

$$E = \frac{Stress}{Strain}$$

$$= \frac{\sigma}{\varepsilon}$$

$$= \frac{F}{A} \div \frac{l}{L}$$

$$= \frac{70-0}{79} \div \frac{0.1-0}{105}$$

$$= 930.38 \text{ MPa}$$

Tensile Strength

Tensile strength is the same as peak stress. For the plot shown above it is equal to 2.79 MPa.

Appendix G: Composite Mixture Table

The tables on the following pages give the percentage by weight of the various components in the composite material.

<u>Composite = Resin + Catalyst + Filler</u>

Where,

Filler (Sawdust)

- 1.18 mm
- 425 microns
- 300 microns

Resin : Catalyst = 30:01 (by weight)

Filler : (Resin + Catalyst) = 00 : 100 (by weight)
05 : 95 (by weight)
10 : 90 (by weight)
15 : 85 (by weight)

Parameters	Materials	Resin (R)	Catalyst (C)	R + C	Sawdust	Composite
Percentage by weight		30	1			
Percentage by weight				95 %	5 %	100 %
Weight of materials in 1000g		919.4 (g)	30.6 (g)	950 (g)	50 (g)	1000 (g)

Table G. 1: Composition by weight of various materials in 1000g composite with 5% filler

Parameters	Material	Resin (R)	Catalyst (C)	R + C	Sawdust	Composite
Percentage by weight		30	1			
Percentage by weight				90 %	10 %	100 %
Weight of material in 1000g		871.0 (g)	29.0 (g)	900 (g)	100 (g)	1000 (g)

Table G. 2: Composition by weight of various materials in 1000g composite with 10% filler

Parameters	Materials	Resin (R)	Catalyst (C)	R + C	Sawdust	Composite
Percentage by weight		30	1			
Percentage by weight				85 %	15 %	100 %
Weight of materials in 1000g		822.6 (g)	27.4 (g)	850 (g)	150 (g)	1000 (g)

Table G. 3: Composition by weight of various materials in 1000g composite with 15% filler

Parameters	Materials	Resin (R)	Catalyst (C)	R + C	Sawdust	Composite
Percentage by weight		30	1			
Percentage by weight				100 %	0 %	100 %
Weight of materials in 1000g		967.7 (g)	32.3 (g)	1000 (g)	0 (g)	1000 (g)

Table G. 4: Composition by weight of various materials in 1000g composite with 0% filler

Appendix H: Calculations of Material Costs

Resin:

1 Litre = 1.225 kg = 1225 g

Or, 1 g $= \frac{1000}{1225}$ ml = 0.8163 ml

Also, 1 Litre = $ 3.50 [CEEFC]

Or, 1 ml = $ 0.0035

Catalyst:

1 Litre = 1.056 kg = 1056 g

Or, 1 g $= \frac{1000}{1056}$ ml = 0.9470 ml

Also, 1 Litre = $ 8.00 [CEEFC]

Or, 1 ml = $ 0.0080

Composite with 0% w/w of Sawdust:

Per 1000 ml sample $= \frac{(30\times1225)+(1\times1056)}{31}$

= 1219.5 g

Resin (30:31)

$= \frac{30}{31} \times 1219.5 = 1180.16$ g

$= 1180.16 \times 0.8163$ ml

= 963.4 ml

$= 963.36 \times \$0.0035$

= $ 3.37 / 1000 ml

Catalyst (1:31)

$= \frac{1}{31} \times 1219.5 = 39.34$ g

$= 39.34 \times 0.9470$ ml

= 36.6 ml (approx. 1000-963.4 ml)

$= 36.6 \times \$0.0080$

= $ 0.29 / 1000 ml

Further calculations can be done in similar manner. Since we are only using catalyst in minimal amount (Resin: Catalyst = 30:1), we can ignore the cost of catalyst.

Appendix I: Plots for Tensile Strength of Various Specimen

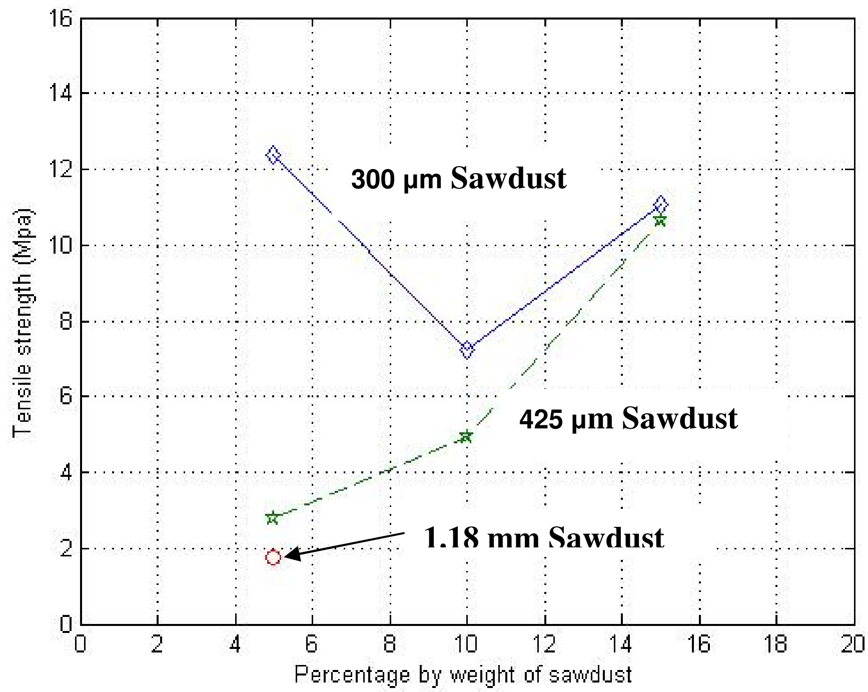


Figure I. 1: Tensile strength of various phenolic resin composite

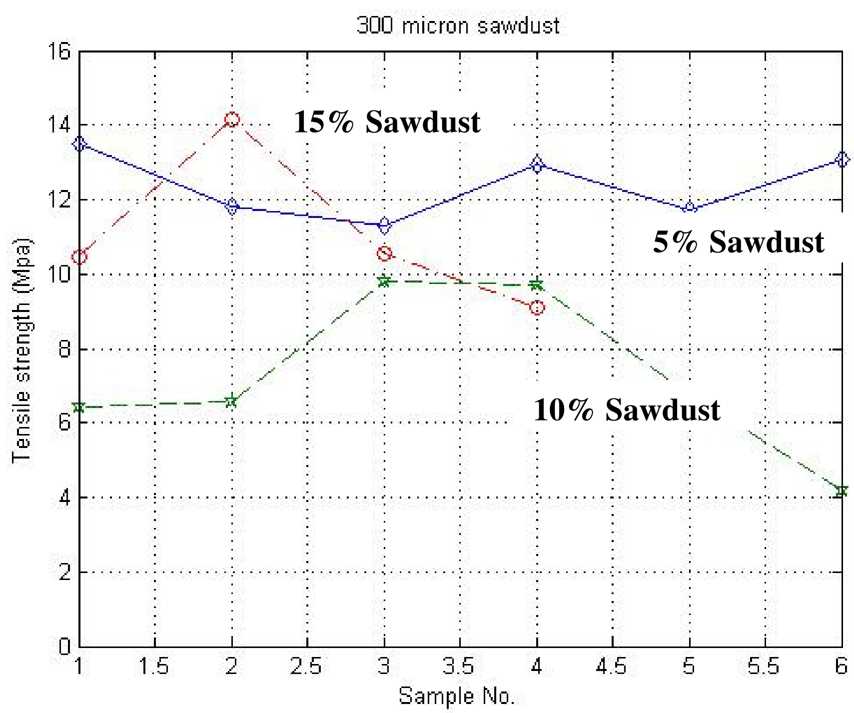


Figure I. 2: Tensile strength of composite specimen with 300µm sawdust

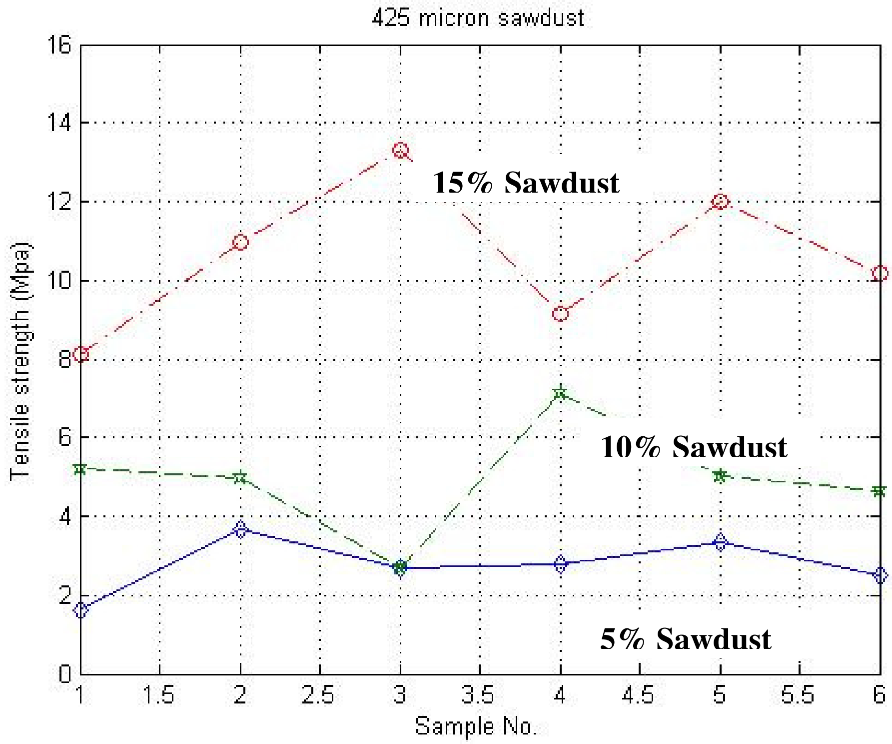


Figure I. 3: Tensile strength of composite specimen with 425µm sawdust

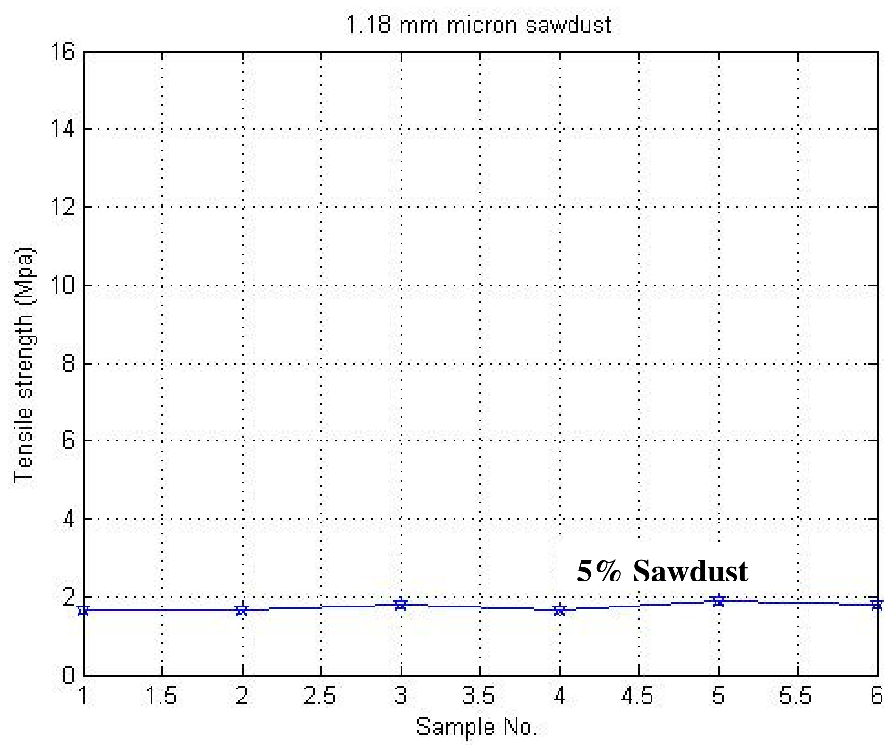


Figure I. 4: Tensile strength of composite specimen with 1.18mm sawdust

Appendix J: MATLAB Scripts

Script A: MATLAB Script- Plot for the Variation in Tensile Strength among Specimen (BAR Graph)

```
% research2_plot1.m
% peak stress in MPa
%
% sawdust_percent
clear all;close all;clc;
%
%
========================================================================
% 300 micron size sawdust
s300_5_1b=13.5; s300_5_2b=11.79; s300_5_3b=11.3; s300_5_4b=12.94;
s300_5_5b=11.70; s300_5_6b= 13.06;
s300_10_1b=6.42; s300_10_2b=6.59; s300_10_3b=9.78; s300_10_4b=9.70;
s300_10_5b=6.74; s300_10_6b=4.21;
s300_15_1b=10.46; s300_15_2b=14.16; s300_15_3b=10.56; s300_15_4b=9.10;
% 300 micron size sawdust average values
s300_5_avgb=(s300_5_1b+s300_5_2b+s300_5_3b+s300_5_4b+s300_5_5b+s300_5_6b
)/6;
s300_10_avgb=(s300_10_1b+s300_10_2b+s300_10_3b+s300_10_4b+s300_10_5b+s30
0_10_6b)/6;
s300_15_avgb=(s300_15_1b+s300_15_2b+s300_15_3b+s300_15_4b)/4;
%
%
========================================================================
% 425 micron size sawdust
s425_5_1b=1.63; s425_5_2b=3.69; s425_5_3b=2.68; s425_5_4b=2.79;
s425_5_5b=3.33; s425_5_6b=2.52;
s425_10_1b=5.23; s425_10_2b=4.99; s425_10_3b=2.67; s425_10_4b=7.14;
s425_10_5b=5.02; s425_10_6b=4.65;
s425_15_1b=8.11; s425_15_2b=10.98; s425_15_3b=13.31; s425_15_4b=9.16;
s425_15_5b=12.02; s425_15_6b=10.18;
% 425 micron size sawdust average values
s425_5_avgb=(s425_5_1b+s425_5_2b+s425_5_3b+s425_5_4b+s425_5_5b+s425_5_6b
)/6;
s425_10_avgb=(s425_10_1b+s425_10_2b+s425_10_3b+s425_10_4b+s425_10_5b+s42
5_10_6b)/6;
s425_15_avgb=(s425_15_1b+s425_15_2b+s425_15_3b+s425_15_4b+s425_15_5b+s42
5_15_6b)/6;
%
% % Plot for the variation among specimen for Mpa
% M = [1:6];
% N = [8.11 10.98 13.31 9.16 12.02 10.18];
% plot(M,N,M,N,'*');
% xlabel('Specimen No.')
% ylabel('Tensile Strength (MPa)')
% axis([1 6 0 14])
```

```
==============================================================================
% 1.18 mm size sawdust
s118_5_1b=1.67; s118_5_2b=1.64; s118_5_3b=1.81; s118_5_4b=1.65;
s118_5_5b=1.89; s118_5_6b=1.79;
% %
s118_5_avgb=(s118_5_1b+s118_5_2b+s118_5_3b+s118_5_4b+s118_5_5b+s118_5_6b
)/6;
% %
% %
==============================================================================
% % No sawdust
s0_1b=1.07; s0_2b=0.98; s0_3b=1.4;
% %
s0_avgb=(s0_1b + s0_2b + s0_3b)/3;
% %
% %
==============================================================================
%
%
bar(1,s0_avgb,'b')
hold on
bar(3,s300_5_avgb,'y')
bar(4,s300_10_avgb,'r')
bar(5,s300_15_avgb,'g')
hold off
%
hold on
bar(7,s425_5_avgb,'y')
bar(8,s425_10_avgb,'r')
bar(9,s425_15_avgb,'g')
hold off
%
hold on
bar(11,s118_5_avgb,'y')
ylabel('Strength (MPa)')
title('Tensile Strength of Phenolic Resin Composites')
hold off
% eof
%
==============================================================================
% X=[0 5 10 15];
% Y_300=[s0_avgb s300_5_avgb  s300_10_avgb  s300_15_avgb];
% Y_425=[s0_avgb s425_5_avgb  s425_10_avgb  s425_15_avgb];
% X_118=[0 5];
% Y_118=[s0_avgb s118_5_avgb];
% plot(X,Y_300,'-d',X,Y_425,'--p',X_118,Y_118,'-o')
% axis([0 20 0 16])
% grid on
% xlabel('Percentage by weight of sawdust')
% ylabel('Tensile strength (Mpa)');
% % eof
```

Script B: MATLAB Script- Plot for the Variation in Tensile Strength among Specimen (Line Graph)

```
% Variation in the readings among 6 samples across 5,10,15% sawdust
samples
% Take figure(2) 425 microns as demonstration
clear all;close all;clc;
%
%
% 300 micron size sawdust
s300_5_b=[13.5 11.79 11.3 12.94 11.70 13.06];
s300_10_b=[6.42 6.59 9.78 9.70 6.74 4.21];
s300_15_b=[10.46 14.16 10.56 9.10];
X_300=[1 2 3 4 5 6];
X_300_15=[1 2 3 4];
figure(1)
plot(X_300,s300_5_b,'-d',X_300,s300_10_b,'--p',X_300_15,s300_15_b,'-
.o');
hold on;
axis([1 6 0 16]);
grid on;
xlabel('Sample No.');
ylabel('Tensile strength (Mpa)');
title('300 micron sawdust');
%
% 425 micron size sawdust
s425_5_b=[1.63 3.69 2.68 2.79 3.33 2.52];
s425_10_b=[5.23 4.99 2.67 7.14 5.02 4.65];
s425_15_b=[8.11 10.98 13.31 9.16 12.02 10.18];
X_425=[1 2 3 4 5 6];
figure(2)
plot(X_425,s425_5_b,'-d',X_425,s425_10_b,'--p',X_425,s425_15_b,'-.o');
axis([1 6 0 16]);
grid on;
xlabel('Sample No.');
ylabel('Tensile strength (Mpa)');
title('425 micron sawdust');
%
% 1.18 mm size sawdust
s118_5_b=[1.67 1.64 1.81 1.65 1.89 1.79];
X_118=[1 2 3 4 5 6];
figure(3)
plot(X_118,s118_5_b,'-p');
axis([1 6 0 16]);
grid on;
xlabel('Sample No.');
ylabel('Tensile strength (Mpa)');
title('1.18 mm micron sawdust');
%
%eof
```

Script C: MATLAB Script- Plot for Tensile Strength

```
% research2_plot1.m
% peak stress in MPa
clear all;close all;clc;
%
% 300 micron size sawdust
s300_5_1b=13.5; s300_5_2b=11.79; s300_5_3b=11.3; s300_5_4b=12.94;
s300_5_5b=11.70; s300_5_6b= 13.06;
s300_10_1b=6.42; s300_10_2b=6.59; s300_10_3b=9.78; s300_10_4b=9.70;
s300_10_5b=6.74; s300_10_6b=4.21;
s300_15_1b=10.46; s300_15_2b=14.16; s300_15_3b=10.56; s300_15_4b=9.10;
% 300 micron size sawdust average values
s300_5_avgb=(s300_5_1b+s300_5_2b+s300_5_3b+s300_5_4b+s300_5_5b+s300_5_6b
)/6;
s300_10_avgb=(s300_10_1b+s300_10_2b+s300_10_3b+s300_10_4b+s300_10_5b+s30
0_10_6b)/6;
s300_15_avgb=(s300_15_1b+s300_15_2b+s300_15_3b+s300_15_4b)/4;
%
% 425 micron size sawdust
s425_5_1b=1.63; s425_5_2b=3.69; s425_5_3b=2.68; s425_5_4b=2.79;
s425_5_5b=3.33; s425_5_6b=2.52;
s425_10_1b=5.23; s425_10_2b=4.99; s425_10_3b=2.67; s425_10_4b=7.14;
s425_10_5b=5.02; s425_10_6b=4.65;
s425_15_1b=8.11; s425_15_2b=10.98; s425_15_3b=13.31; s425_15_4b=9.16;
s425_15_5b=12.02; s425_15_6b=10.18;
% 425 micron size sawdust average values
s425_5_avgb=(s425_5_1b+s425_5_2b+s425_5_3b+s425_5_4b+s425_5_5b+s425_5_6b
)/6;
s425_10_avgb=(s425_10_1b+s425_10_2b+s425_10_3b+s425_10_4b+s425_10_5b+s42
5_10_6b)/6;
s425_15_avgb=(s425_15_1b+s425_15_2b+s425_15_3b+s425_15_4b+s425_15_5b+s42
5_15_6b)/6;
%
% 1.18 mm size sawdust
s118_5_1b=1.67; s118_5_2b=1.64; s118_5_3b=1.81; s118_5_4b=1.65;
s118_5_5b=1.89; s118_5_6b=1.79;
%
s118_5_avgb=(s118_5_1b+s118_5_2b+s118_5_3b+s118_5_4b+s118_5_5b+s118_5_6b
)/6;
%
X=[5 10 15];
Y_300=[s300_5_avgb  s300_10_avgb  s300_15_avgb];
Y_425=[s425_5_avgb  s425_10_avgb  s425_15_avgb];
X_118=5;
Y_118=s118_5_avgb;
plot(X,Y_300,'-d',X,Y_425,'--p',X_118,Y_118,'o')
axis([0 20 0 16])
grid on
xlabel('Percentage by weight of sawdust')
ylabel('Tensile strength (Mpa)');
% eof
```

Script D: MATLAB Script- Viscosity Plots

```
x=[0 5 10 15 20];
y=[4.4 10.8 23.3 98.5 200];
plot(x,y,'LineStyle','-','Marker','.','MarkerSize',12);
    %hold on
    axis([-5 25 0 250])
    title('Viscosity vs % Sawdust','FontWeight','Bold','Fontsize',14);
    xlabel('% Sawdust', 'FontWeight', 'Bold', 'Fontsize', 12);
    ylabel('Viscosity (cp) *10^3', 'FontWeight', 'Bold', 'Fontsize',
12);
    grid on
```