University of Southern Queensland

Faculty of Engineering and Surveying

Investigation of the best percentage by weight of glass powder as fillers, in phenolic resins using flexural tests

A dissertation submitted by

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Courses ENG4111 and 4112 Research Project

Towards the degree of

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Abstract

This project is to find the best percentage by weight of glass powder, as fillers, in phenolic resins using flexural tests. Emphasis is placed on reducing the costs in industry while meeting needs. For this reason strategies have been developed for determining the beat percentage by weight of glass powder. Increasing the amount of glass powder into phenolic resins will ensure cost savings and a decrease in weight of the specimens without sacrificing the mechanical properties of the composites.

Commercial Phenol Formaldehyde based resole thermosetting resin was mixed with an acid catalyst Phencat 15 at a ratio of 30:1 along with varying percentage of glass powder. Flexural tests were performed on the produced composites to determine flexural strength, flexural strain and flexural modulus. These tests were used to determine the optimum level of glass powder to the samples. Once composites were removed from the moulds post-curing was conducted in an oven. Composite samples ranged of glass powder were produced from 0% to 35%, in increments of 5%, hence eight types of composites were produced.

There were six specimens for each type of composite. At 15% by weight of glass powder, the flexural strength was highest (45.9MPa). The highest flexural strain (0.017 mm/mm) was obtained for composites with 15% by weight of glass powder. However, the highest flexural modulus (2544MPa) was achieved when the percentage of glass powder is 15%.

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Date

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Contents

1 – Introduction

1.1– Introduction

This chapter will outline the purpose of this research study, demonstrating the need for the solutions that will be obtained. The optimum percentage of glass powder filler required will be determined based on the flexural properties of composites post-cured in an oven.

1.2– Project Aims and Objectives of Research Project

This project is to find the bench-mark percentage by weight of glass powder, as fillers, in phenolic resins using flexural tests to reduce costs of the composites but at the same time maintain the flexural properties. Phenolic materials were the first major plastic material used by industry. They are still among the most widely used phenolic because they are some of the lowest-cost engineering material on a cost-per-volume basis. The composite samples ranged from a percentage of filler added to the composite from 0% to 35%, in increments of 5%, hence eight types of samples in total were produce. Each type of composites has six samples.

1.3 –Publication

Ku, H, Trada, M and Zong, X

Flexural properties of phenolic composites reinforced with glass powder: Preliminary results, Journal of reinforced plastic and composites, 2008.

1.4–Concluding remarks

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

Chapter 2 – Literature Review

The literature review has been divided into areas covering phenol formaldehyde resins, their material properties and applications, fillers and their uses, the three point bending test, beam loading equations safety and the consequences, and effects of this research.

2.1 –**Introduction to Phenolics Resins**

Phenolic resin was synthesized by Leo Bakeland in 1907; phenolic resins were the first thermosetting plastics and were considered to be the first commercially available plastic resins. They are also the second most widely used thermosetting plastic on the market today (Goodman, 1998). Due to their low cost and ease of formation, phenolics are among the most common thermosets used. They are formed when the combination of phenol and formaldehyde react together under heat and pressure. Generally a filler of some type is added to the resin in order to lower the cost and improve mechanical properties of the resins. Phenolics are formed from the condensation polymerization reaction between phenol, an aromatic molecule, and formaldehyde; a small organic compound often used as a solvent or as a preservative (Strong, 1996)

Phenolic resin (Hexion J2027L) is commercial phenol formaldehyde based resole thermosetting resin. It was one of the first major plastic materials used by industry, and is still one of the most widely used thermosetting resins to date due to its excellent properties. Phenolics are formed by the polymerization reaction between the phenol and formaldehyde; this is shown in figure 2.1. However two types of reactions can occur depending upon the type of catalyst used. This will produce two different intermediate materials, being novolacs and resoles.

The resole process is a condensation polymerization reaction which takes place with

excess formaldehyde and is a carefully controlled linear, non-cross linked polymer liquid. Cross linking can be obtained by heating the viscous liquid. Alternatively an acid catalyst can be added to allow curing via room temperature known as stage one resins; this demonstrates the purpose of adding the acid catalyst ‘Phencat 15’ (Smith and Hashemir, 1993)

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

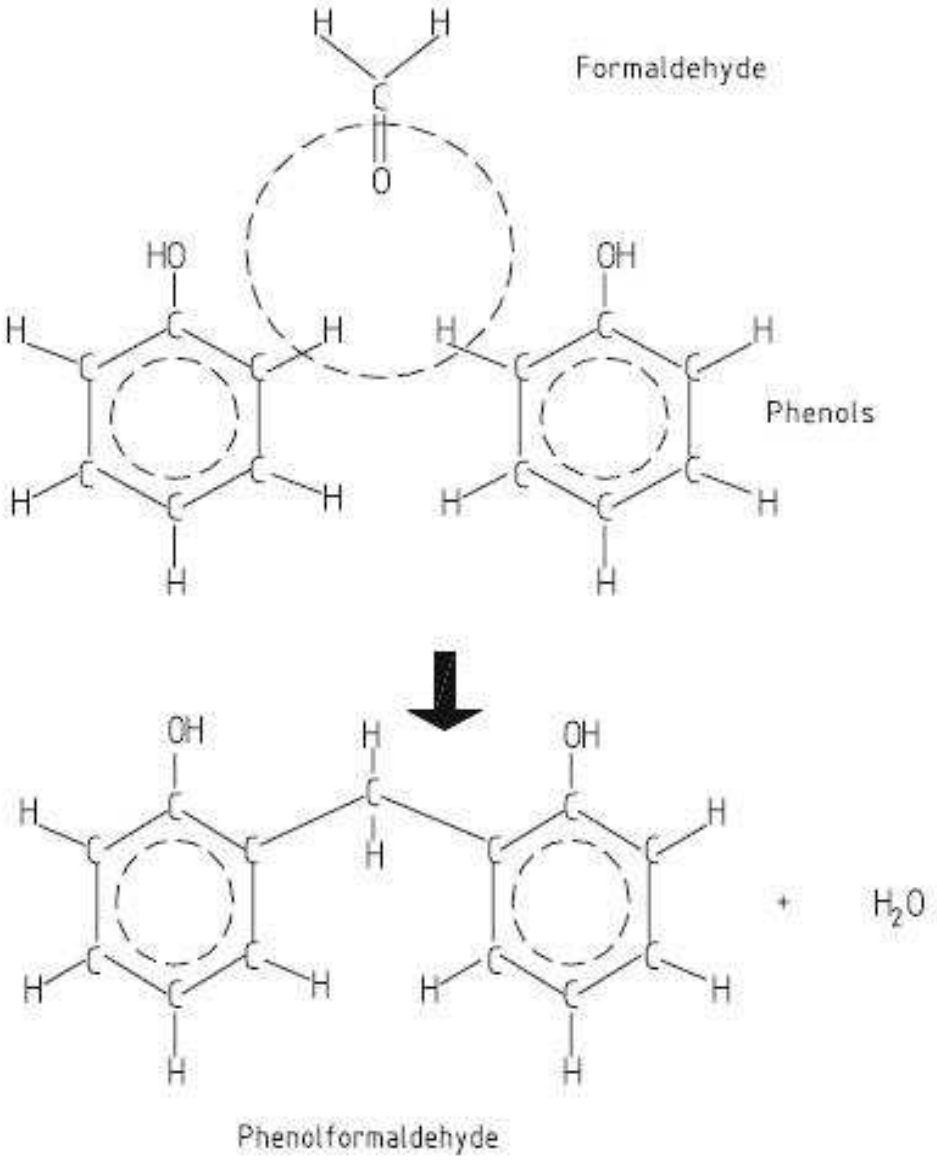

Figure 2.1 Formation of phenol formaldehyde

2.2 – **Resin and Catalyst**

The commercial resole phenolic resin used in study was J2027L manufactured by Hexion Specialty Chemicals Pty Ltd; officially called Hexion Cellobond J2027L (Chemwatch, 2005). Phencat 15, an acid catalyst which allows cross linking to occurs at room temperature. With reference to phenolic molecule of in figure 2.2, there are five 5 hydrogen atoms in the benzene ring however, because of limited space, there are only three possible sites for reaction and the phenolic molecule is said to have a functionality

of three (Ku, et al, 2006). The resin and catalyst form a strong cross linking 3-D network and with the addition of filler; mechanical properties will increase while costs decrease. The catalyst used to crosslink the resin is phenolic resin hardener cttalyst produced by the same company. The official name of the catalyst is Hexion Phencat 15 (Chemwatch, 2005b). The ratio by weight of the resin to hardener is 30:1.

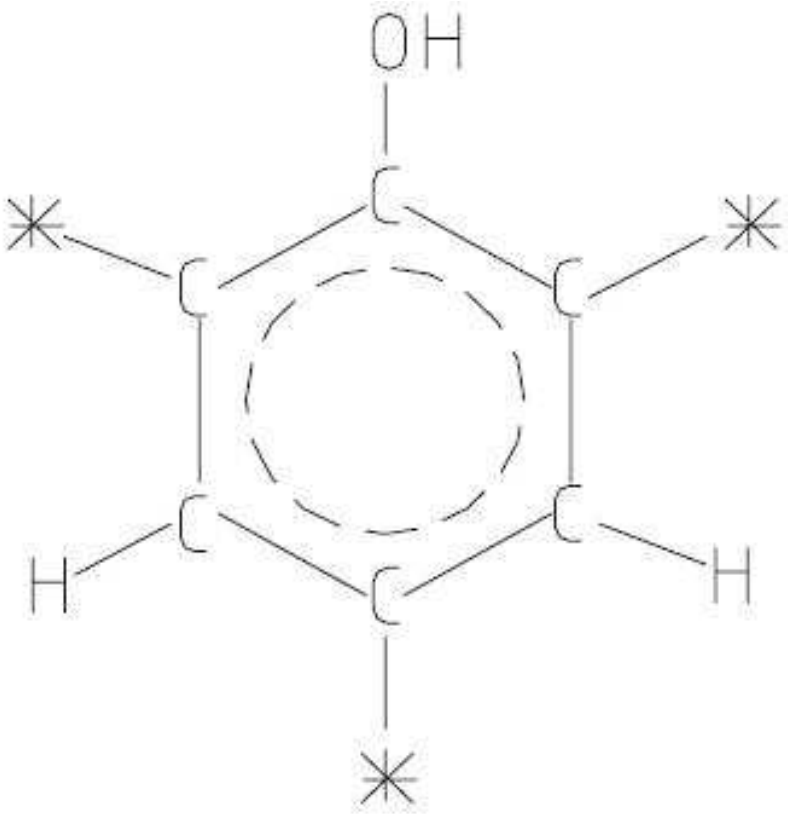

Figure 2.2 Phenol with active sites marked

2.3 – **Glass powder**

Glass powders are spheres of glass, technically manufactured with a diameter in the range 1 to 1000 micrometres, although the term is also used for a wider range of 100 nanometres to 5 millimetres. Glass powders are used in composites to fill polymer resins for specific characteristics such as weight, sand ability and sealing surfaces.

2.4 – **Specimen**

Six specimens are produced per mould, shown in Figure 2.3. Each specimen was made to

the following dimensions, 64mm in length, 9.6mm in width and a thickness of 5.6mm. Once specimens have been poured into the mould, a curing time of 72 hours is allowed to ensure specimens were fully cured. To assist the removal of the specimens, the mould is pre-greased to allow for easy release. The viscosity of liquid when all three materials are mixed is an important consideration. Included in this research study was the composite made up of 35% of filler by weight. This was the maximum amount of filler used as higher percentages of filler would become too difficult to mix and cost into moulds.

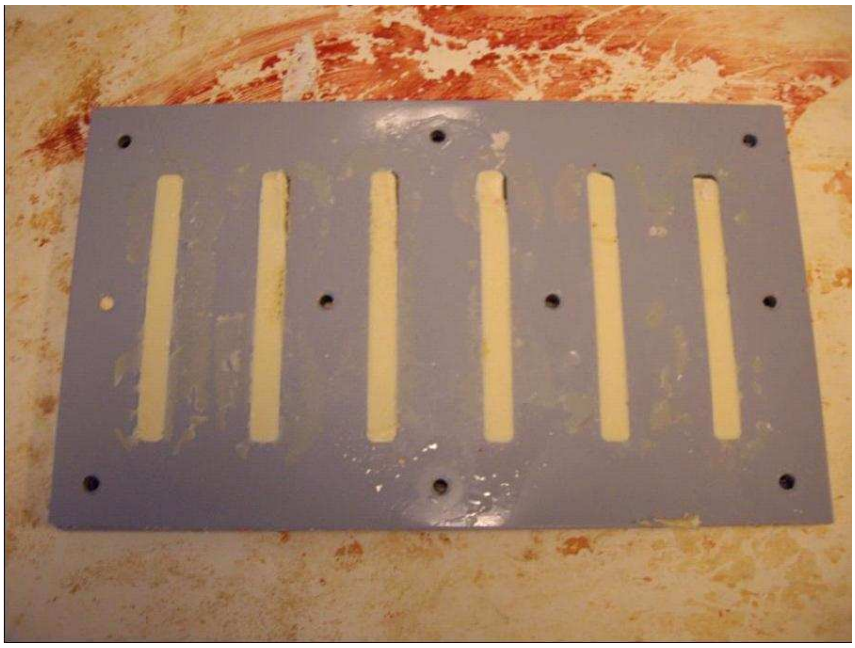

Figure 2.3 Specimen after initial curing in mould

2.5 Viscosity

According to Fox et al, (2003), when a solid is deformed, stresses arise due to the object being deformed or put under strain. Similarly in a liquid, shear stresses arise due to the solid being viscous (able to flow). Therefore, the viscosity of a fluid is a measure of the resistance of the fluid to deform when subject to a shear stress (Fox 2003). As an example, water has a very low viscosity (and therefore low resistance to shear) and flows very easily. Some oils have a high viscosity and will therefore take more force to flow. The viscosity of a liquid, or pertaining to this research, a resin,

can have an effect on moulding procedures. If a liquid has a low viscosity, then it will be able to be poured easily. On the other hand, if the viscosity is high then problems can arise with the fluid not permeating to the edges of the mould. In these cases other moulding methods may have to be utilized, such as the use of positive pressure.

2.6 - Testing

The testing was conducted by t The MTS 810 Material Testing System, located at the Faculty of Engineering and Surveying, at the University of Southern Queensland (USQ), as shown in Figure 2.4 The test is relatively inexpensive to perform and the information gained is extremely valuable. By performing a flexural test unknown such as Young's modulus, flexural strength and flexural strain are able to be found.

2.6.1 –Flexural tests (Three-point bending test)

The three-point (3-point) bending test is a test that is useful for finding the flexural properties of a material, such as un/reinforced plastic composites. The results of such tests are useful for quality control purposes and specification analysis. The test is carried out on a simple bar-shaped element. This research has been carried out as per International Standard ISO14125: Fiber reinforced plastic composites – Determination of flexural properties, details of which are set out by the International Organization for Standardization. (ISO, 1998)

The test was conducted on a beam-type test specimen, supported at both ends and was deflected up to a pre-determined point, complete fracture. Deflection was carried out at a constant rate and was transferred to the beam midway along its length for the 3-point test. This test has been designed to determine flexural stress-strain information and properties of the test specimen material.

The requirements of the test machine were that it had to be able to maintain the speed of testing as the load increases (ISO, 1998). The loading rate was set out in ISO14125

as were the full dimensions for the support points and loading point for the beam.

Figure 2.4 Three-Point bending test machine

2.6.2 Specimen/Beam loading calculations

During the test, the upper support contacted the top surface of the test specimen, applying a load, which forced the piece to bend. This force was increased until the test specimen failed, at which point the maximum load (Peak Load (N)) that the specimen supported was recorded and the deflection at the mid point was noted.

From this peak load, the flexural strength (or flexural stress) of the material can be

found using the equation (1) and was measured in mega Pascals (MPa). From this, calculations of flexural strain and then Young's modulus of Elasticity in Bending (E) were carried out. Please note it is possible to use other values of load at different points of deflection to find the stress at a given point, though this research only dealt with load at failure.

2.6.2.1 Flexural strength and strain

The flexural strength of a material is defined as its ability to resist deformation under load. For materials that deform significantly but do not break, the load at yield, typically measured at 5% deformation/strain of the outer surface, is reported as the flexural strength or flexural yield strength. The test beam is under compressive stress at the concave surface and tensile stress at the convex surface.

Stress is a method of defining the load on a certain object and is expressed in mega Pascals (MPa) (Beer, et al, 2002). Simple compression is defined as being equal to the force or load, divided by the area on which that loads is applied. In SI units the force is expressed in Newtons (N) and the area are expressed in square meters (m^2).

Strain is defined as the deformation of the member per unit length (Beer, et al, 2002). It is also a dimensionless value due to being a percentage. In the case of a tensile load, and in light of the above statement.

Where δ (delta) is the change in length and L is the original length (Beer, et al, 2002).

The relationship that strain provides is a percentage change that can be compared with stress to give a value of E, or flexural modulus.

Formulae for calculating the properties are given below:

$$\text{Flexural Stress (MPa)} \quad \sigma_f = \frac{3PL}{2bh^2} \quad (1) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{Flexural Strain } \varepsilon = \frac{6Dh}{L^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$\sigma = \frac{F}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$\varepsilon = \frac{\delta}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where: σf: stress in outer fibre at midpoint, MPa;

P: load at a given point on the load deflection curve, N;

L: support span, mm;

b: width of test beam, mm;

h: depth of test beam, mm;

D: maximum deflection of the centre of the beam, mm;

M: slope of the tangent to the initial straight line portion of the load deflection curve, N/mm.

2.6.2.2 – Flexural Modulus

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

$$\text{Flexural Modulus, E (MPa)} = \frac{L^3 m}{4bh^3} = \frac{\sigma_f}{\varepsilon_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where: E: modulus of elasticity in bending, MPa;

ε_f : strain in the outer surface, %.

2.7 – **Preliminary curing**

Allowing a minimum time of 72 hours for preliminary curing at room temperature, the six specimens were then removed and prepared for post curing. Post-curing to light-cured resin composite will lead to a decrease in the negative effects of polymerization shrinkage and an increase in the hardness and wear resistance of the material (Marais, et al, 1999).All specimens would be post-cured in an oven.

2.8 – Conventional oven

Post-curing by way of conventional oven (figure 2.5) is very effective. An advantage of the conventional oven is that heating will be constant and even throughout the entire space. As the heat builds up over many hours, less damage is likely to be inflicted upon the specimens. Disadvantage that is found by using conventional oven, the much greater time required to achieve the desired effects, and the excessive consumption of electricity.

Figure 2.5 Conventional oven

2.9 – Risk

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

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

Phenolic resin: - toxic by inhalation

- Toxic in contact with skin and if swallowed

- Limited evidence of a carcinogenic effect

- Serious damage to eyes

- Sensitization by skin contact

- Serious damage by prolonged exposure through inhalation, in contact with skin and if swallowed

- Possible risks of irreversible effects [Chemwatch 4601-85]
-

Catalyst: - harmful by inhalation and if swallowed

- causes burns

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

- Similar circumstances apply for the catalyst.

Glass powder: -dust in excess of recommended exposure limits may result in irritation to the respiratory tract

- Inhalation

- Not listed under NTP, IARC Monographs, or OSHA.

- Chronic lung conditions may be aggravated by exposure to high concentration of dust.

Control: Various controls have been implemented to ensure the user is aware of all hazards. Booklets of Phenolic Resin and Catalyst are provided for the user and consent of understanding is signed to ensure their awareness. Regulations have also

been put in place. Whilst handling the material a respirator, safety glasses and surgical gloves must be worn. When casting the moulds, they must stay inside a designated area containing a large exhaust fan to remove harmful fumes and heat. When using the microwave or conventional ovens and the tensile testing machine, an instructor was present during the first use to explain the working procedures, and warning signs were to be aware of.

2.10 – Equipment

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

Equipment required: - Molds (each can made six specimens)

-Screws (to hold the molds together)

- Sheet of glass (cover the mold top)

- The three materials (phenolic resin, catalyst & glass powder)

- Safety equipment (safety glasses, surgical glove, gas mask, etc)

- Cooking oil (lubricate the mold before casting)

Facilities that are required: - Laboratory Z106 (molds are cast)

- Z113 (post-curing)

- Z105 (testing machine)

Chapter 3 – Research design and methodology

3.1 Introduction

The methodology for this research has been divided into sections relating to the mould and test specimen, the three point bending test and the collection of data. Each section has been discussed in detail and covers mould design and its manufacture and relevant detail.

3.2 Mould design

Two major options were available when deciding what type of mould system to use when casting the test pieces.

The first was a mould that could be disassembled fully to enable easy removing of the resin test piece. This consisted of multiple pieces of 6mm plastic sheeting bolted together in such a way as to leave a space in the correct shape of the test piece. After disassembling the mould, the test pieces would be left free with no manual removal required after this.

This option was not used in this research, due to the larger amount of components in the mould and the fact that the mould needed to be reconstructed every time that a new test piece was moulded. Having to rebuild the mould so many times may have lead to inaccuracies in dimensions and deterioration of the surface finish.

The second option consisted of three sheets of 6mm plastic sheet bolted together on top of each other with the middle sheet containing cut outs of the test pieces. After the bolts were removed the mould could be split into the three parts, with the middle containing the cast resin pieces. These would then have to be removed manually from

the sheet. This method yields a higher dimensional accuracy and surface finish while retaining very good.

The mould as depicted in Figure 3.1 was fastened together with 10 x M5 bolts with wing type nuts to allow quick fastening without the need for tools. These were spaced evenly around the surface of the plastic, with three bolts on the top, four in the middle and three along the bottom

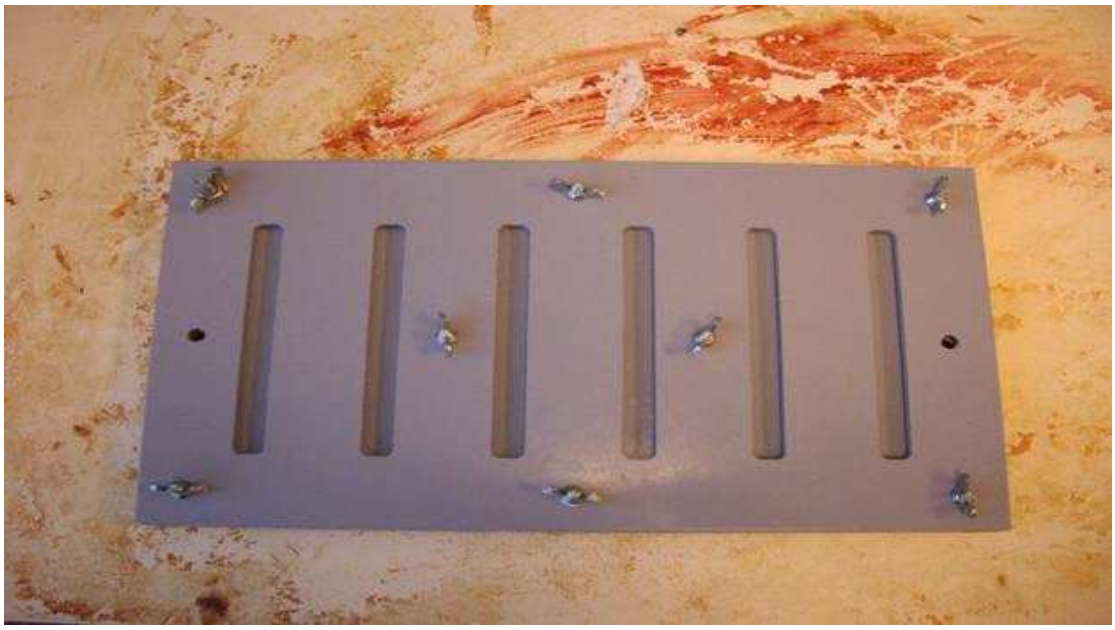

Figure 3.1 Manufactured mould

3.3 Test pieces and porosity

Porosity is a phenomenon that occurs when pouring and drying resin pieces. As the hardener combines with the resin, the chemical reaction that takes place produces gas, which is usually forced to the surface of the piece and appears as bubbles and gas just under the surface and as indentations on the surface.

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

The design of the mould was required to take the possible creation of porosity into account. Therefore the use of 6mm sheet plastic added 2mm to the top of the required 4mm test piece to allow for the removal of material containing porosity on the upper surface of the test piece.

3.4 Mould preparation

No cleaning or preparation was required to make the mould ready for use, as the finish on the mould was adequate after receipt from the USQ Engineering Workshop.
The only change that was required was to the centerline of bolt holes. On the top sheet, the outer two holes had to be increased in size due to permanent fastening of the bottom two sheets together using an M5 nut. When these were bolted together prior to pouring, a larger hole had to be allowed so that the upper sheet mated to the middle without these nuts holding it clear of the surface.
After the mould was used, it was cleaned and prepared for the next batch of parts. This involved cleaning any excess resin off surfaces and wiping them with a thin layer of oil (cooking oil in a spray can was appropriate) to facilitate removal of the resin pieces.

3.5 Preparation of mould

Before the resin can be poured, the mould was cleaned and checked for traces of previous resin mixture or dirt. The presence of any surface contaminants or old resin disrupted the strength characteristics if dried into the test piece as this would introduce sections into the piece that had different flexural strengths, leading to either less space for the material to fail or areas of stronger or weaker material.

After being cleaned, the mould was sprayed with cooking oil (aerosol type spray can). After coating all surfaces of the mould, most excess oil was wiped away with a piece

of absorbent paper towel to reduce the amount that could interfere or mix with the resin.

Oil was applied to reduce the surface friction when removing the test pieces from the mould. This made pieces easier to remove while avoiding breaking them in the process.

3.6 Manufacturing of test pieces

Cost plays a significant role in decision making today, as there are an increasing number of different research areas becoming available for institutions to support. The cheaper one area of research is the more funds can be placed in other areas of study. Therefore, as the resin Hexion Cellobond J2027L and catalyst Hexion Phencat 15 are the most expensive part of this research study, the need to reduce its cost is high and any gains would be desirable. Table 3.1 shows the Weight of materials required to make 1000g/ glass-powder

Table 3.1 Weight of materials required to make 1000g/ glass-powder

%	R:C	Resin (g)	Catalyst (g)	Glass powder
0	30:1	967.7	32.3	0
5	30:1	919.4	30.6	50
10	30:1	871	29	100
15	20:1	809.5	40.5	150
20	20:1	762	38	200
25	15:1	703.1	46.9	250
30	15:1	656.3	43.7	300
35	15:1	609.4	40.6	350

The resin was first measured into a container then the catalyst was measured out

separately and added to the resin. After measured glass powder and added to the mixture.

Once the mixture had reached an even consistency, it was poured into the mould through the use of a plastic spoon. Excessive mixture is poured in to eliminate the likelihood and affects of porosity and air bubbles.

3.7 Test pieces

3.7.1 Size and Dimensions of test pieces

Creating the test specimens using the ISO14125 standard yielded results that could be used and compared with other future studies into fillers and their effects on strength in phenolic resins.

3.7.2 Curing of test pieces

After initial curing when the test pieces were removed from the mould, they needed to be post cured. This was achieved by baking the pieces in an oven.
Oven temperatures and times were as follows:

• 4 hours at 50˚C

• 4 hours at 80˚C

• 2 hours at 100˚C

During the initial baking process of 4 hours at 50˚C, it was observed that a number of test pieces were developing a bow in middle. This bowing was between 1mm and 4mm in the middle of the piece and seemed to be exacerbated by the higher temperature baking processes. It was also noted that bowing was all in the same orientation; bowed around the “upper” (in relation to moulding) face of the test piece.

To counteract this, after the test pieces were removed from each baking session, all pieces were subject to an approximate 2kg load while between two pieces of toughened glass. The time for this weighting was approximately 16 hours as they cured overnight. Figure 3.2 shows the phenolic resin post-cured for 4 h at 80 _C at a magnification of 3500 times.

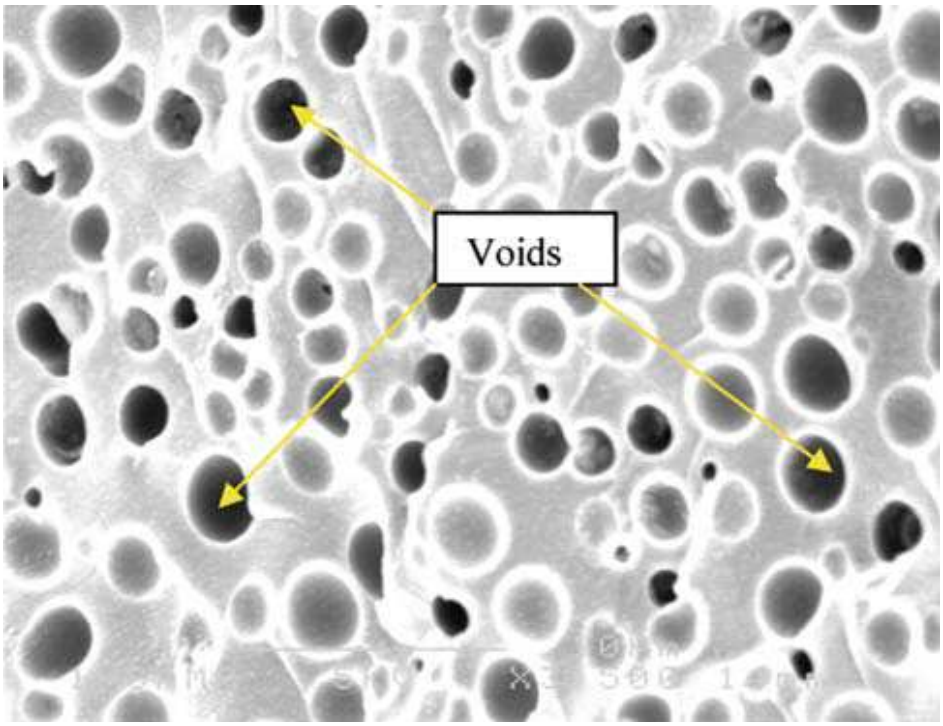

Figure 3.2 Phenolic resin post-cured for 4 h at 80 _C at a magnification of 3500 times

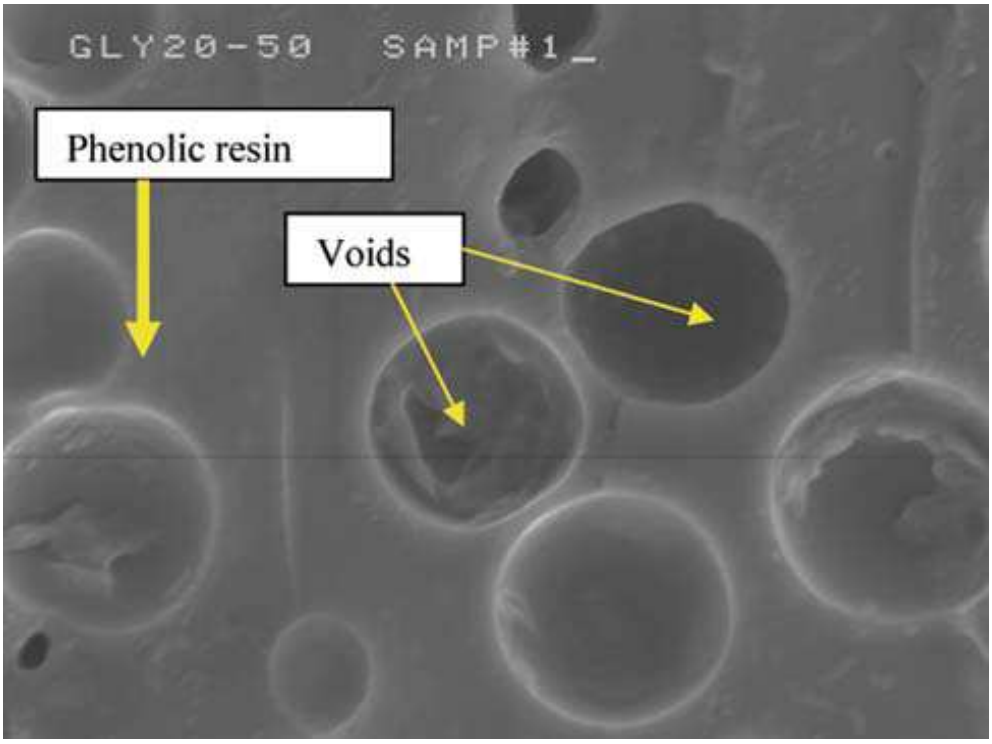

Figure 3.3 Phenolic resin post-cured for 4 h at 80 _C at a magnification of 10,000 times

The figure 3.3 shows the phenolic resin post-cured for 4 h at 80 _C at a magnification of 10,000 times. The reason for this bowing is not immediately apparent. A number of possibilities are feasible though this is more suited to further study. Some supposed possibilities are as follows:

• When the test pieces were oven cured, the resin expanded. With porosity in the top surface, there was less material to support this expansion, therefore the top face contracted, pulling the ends of the pieces up.

• An internal stress was developed while drying in the mould.

• During removal from the mould, the upper surface of the test specimen became flawed.

3.8 Three–point bending test

The three-point bending test (Figure 3.4) is a test used to measure the flexural strength of a material or component. It uses a vertical force applied to a long thin member to

force the member to deflect and then finally fail, at which point the peak load sustained by the member is recorded and from this, material strength can be ascertained. It is suitable not only as a method of testing material qualities and properties but also as a quality control method.

Figure 3.4 Three-point bending test machine

Figure 3.5: Three-point bending test on flexural specimen

The three-point bending test machine used was a hydraulic type with vertical rams. For this particular (three-point) test, the bottom ram was actuated and allowed to move vertically, moving the test piece supported on the lower two points to contact the upper point, therefore acting on the centre of the specimen.

Using this machine allowed for the measurement of certain parameters while the test was taking place. For this research, the load and deflection were measured throughout the full extent of the test, allowing the values of flexural strength/stress and strain to be calculated.

The upper and lower supports were held in place by the jaws of the rams. These were a sliding chuck type that could be used to grip cylinders of different sizes.

The procedure for conducting this test is defined in ISO14125: 1998 Fibre-reinforced plastic composites – Determination of flexural properties. Firstly, test specimens were measured and ensured that they complied within the required dimensional accuracy. This was done immediately after specimen preparation with vernier calipers.

The test system was then set up for the appropriate loading rate of 2mm per minute on the control-center computer attached. Specimens were then placed central on the supporting cylinders and any details noticed regarding the test specimens was noted. The test was then commenced. At this time the computer attached to the test system recorded real time data about load, deflection and time. This is shown in Figure 3.5.

The data recording was stopped approximately 4 seconds after the specimens broke and a print out was acquired detailing peak load, deflection, deflection at failure, time and a graphical readout of these results

Chapter 4 – Test Results

4.1 Introduction

This part provides the results obtained from the three-point bending test outlined in chapter 3. It gives full explanations of peak load, material flexural stress/strength, strain and the modulus of elasticity for each percentage of glass powder filled phenol formaldehyde composite mixture.

4.2 Flexural stress/strength

Figure 4.1 illustrates the flexural strength of varying percentage by weight of glass powder reinforced phenolic resin. At 15 percent by weight of the glass powder, the flexural strength is highest at 45.9 MPa; at all other percentage by weight of glass powder, the flexural strengths were lower than that of neat resin. Except at 10 to 15 % by weight of glass powder, the higher the percentage by weight of the filler, the lower the flexural strength was. By having 15% of glass powder in the composite, the flexural strength was increased by 26%. Wang et al. (1997) found that the flexural strength of the neat resin was 71.3 MPa with a standard deviation of 13.5 MPa. It can be argued that the value obtained was not too reliable because of its high standard deviation.

Wang et al. (1997) found that the flexural strength of the 20% glass powder filled resin was 90.5 MPa with a standard deviation of 10.8 MPa. This is better than the value obtained for the neat resin. On the other hand, the flexural strength of the 20% glass powder filled resin in this project was 18.19 MPa with a standard deviation of 2.37 MPa. It was difficult to conclude who was correct because Wang et al. (1997) used ICI Fiberite resol-type CMXR-6055 phenolic formaldehyde resin; this research used Chemwatch Hexion Cellobond J2027L phenolic formaldehyde resin. On top of it, Wang el al. (1997) did not mention they way they cured the resin and its filler. The difference in flexural strength of the 20% glass powder reinforced phenolic formaldehyde composites for both studies is 400 %, which is a significant difference.

Wang et al. (1997) did not mention any information about the glass powder used. In this study, the diameters of the glass particles were from 6 to 32 microns with an average size of 20 microns. It can be argued that Wang et al. (1995) had used nano size glass powder (Pukanszky and Voros, 1993; Fu et al., 2008). Redjel (1995) claimed that the flexural strength of neat phenolic resin was 68 MPa. The material he used was a pure phenolic resin 84055 catalyzed by 3 percent of C 1650 and cured at 80^{o}C for 8 days. It was produced and prepared by CDF-Chimie, France. The curing time was excessively long and would not be industrially viable and the energy consumption was enormous.

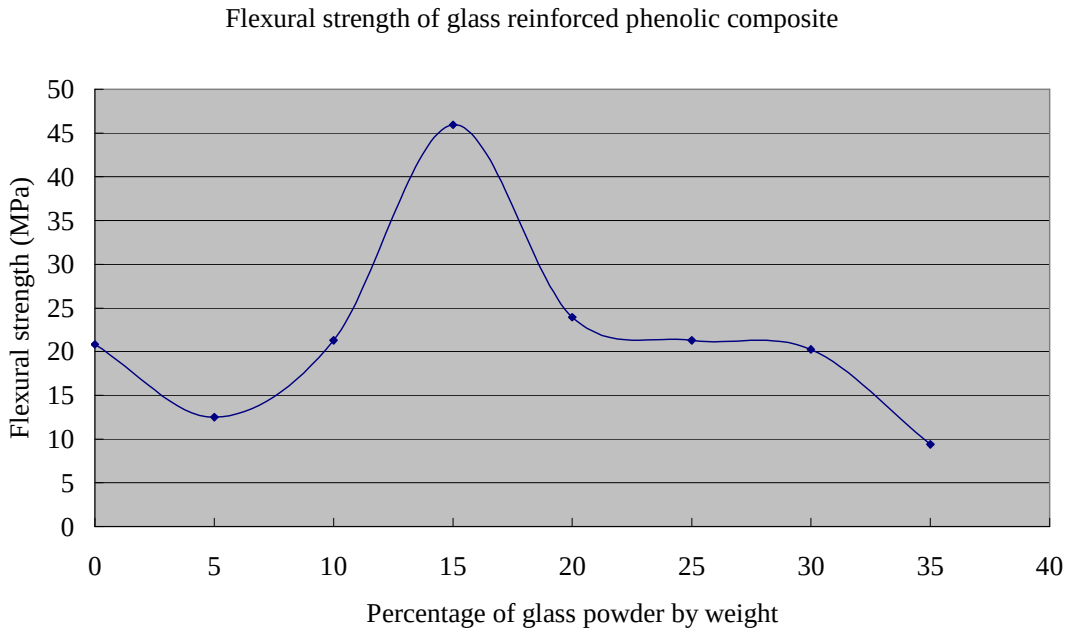

Figure 4.1: Flexural strength of varying percentage by weight of glass powder reinforced phenolic resin

Table 4.1: Values of flexural strength

Percentage	0	5	10	15	20	25	30	35
Flexural strength	20.83	12.52	21.29	45.95	23.93	21.28	20.27	9.39
std	3.75	1.24	2.17	3.72	2.57	3.09	3.08	0.74

Table 4.1 shows the values of flexural strength mentioned above with their standard deviation. It can be found that the maximum flexural strength, 49.01 MPa, was obtained when the percentage by weight of filler is 15 %. As the standard deviations flexural strengths obtained in this study were low, it can be argued that the values were valid for the resin used and the post-curing process employed.

4.3 Flexural strain

From Figure 4.2 it can be seen that the flexural strain varies from one percentage to the next, though it can be observed that there is a general downward trend from the lower values of filler (left hand side) to the higher values of filler (right hand side). The highest strain experienced was by the 15% filler data set with a value of 0.017, while the next highest was 0.016 from the 25% filler. 5% filler experienced a strain of 0.0095 while both 15% and 30% experienced a strain of 0.0115, while the lowest was 20% with a strain of 0.009.

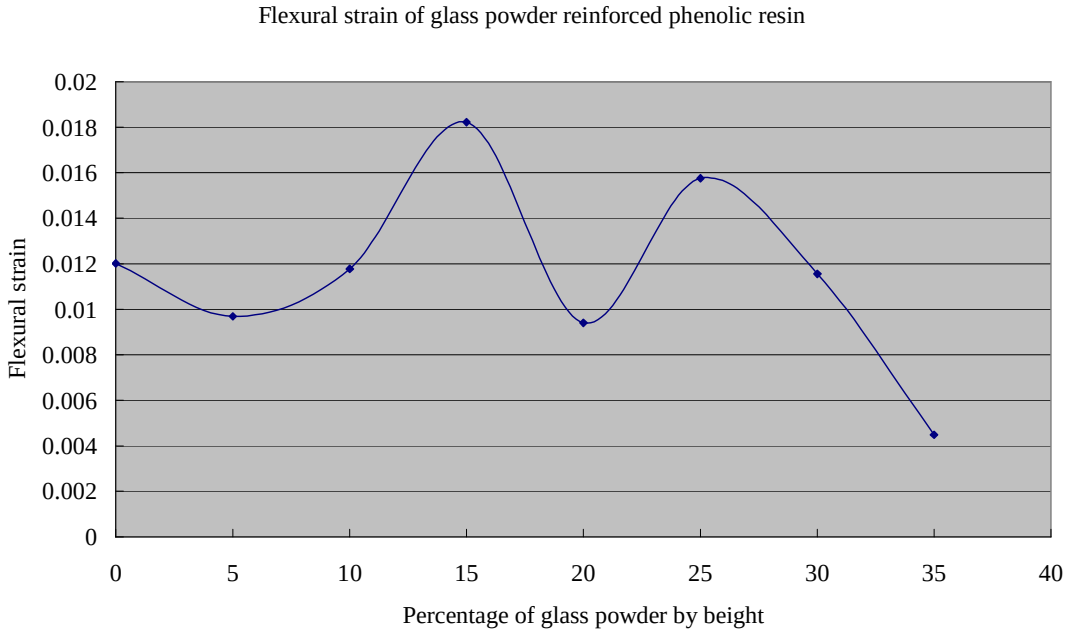

Figure 4.2: the flexural strain of varying percentage by weight of glass powder reinforced phenol formaldehyde matrix composite

Table 4.2 Values of flexural strain mentioned

Percentage	0	5	10	15	20	25	30	35
Flexural strain	0.012	0.010	0.012	0.018	0.009	0.016	0.012	0.005
std	0.002	0.003	0.004	0.002	0.001	0.003	0.002	0.0005

Table 4.2 illustrates the values of flexural strain mentioned above with their standard deviation. It appears that except for the peak value, the flexural strain from 0 – 30 percent is around 0.010. It can be observed that at the maximum flexural strength of 349.01 MPa, i.e.

4.4 Modulus of elasticity (bending)

Figure 4.3 shows the flexural modulus of varying by weight of glass powder reinforced phenol formaldehyde matrix composite. The flexural modulus increased from 1733 MPa (neat resin) to 2511 MPa (at 15 % by weight of filler) and 2544 MPa (at 20 % by weight of filler) then dropped back to 1351 MPa (at 25 % by weight of filler) and then increased again to 1755 MPa (at 30 % by weight of filler). The values found seemed to be a little bit low when they were compared with those of phenolic resins (2,760 – 4,830 MPa) (Callister, 2005). Wang el al. (1997) found that the flexural modulus of neat resin was 2,900 MPa and its standard deviation was 480 MPa; they also found that the flexural modulus with 20% by weight of glass powder was 4,300 MPa and its standard deviation was 620 MPa. The flexural modulus of neat resin found by Redjel (1995) was 4401 MPa.

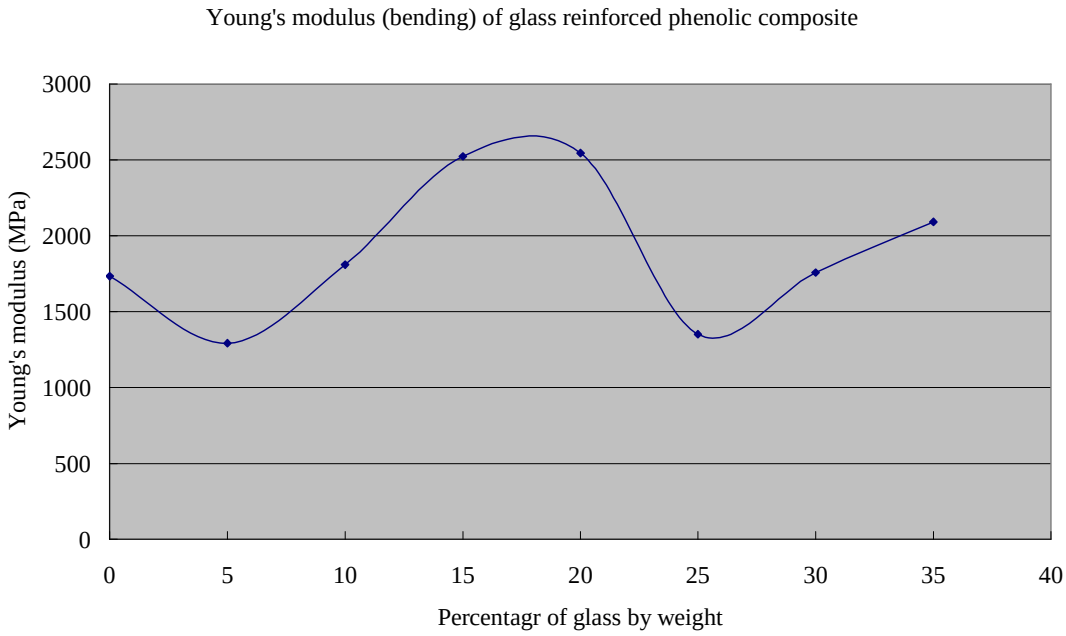

Figure4.3 flexural modulus of varying by weight of glass powder reinforced phenol formaldehyde matrix composite

Table 4.3 the values of flexural modulus mentioned above with their standard deviation.

Percentage	0	5	10	15	20	25	30	35
Flexural modulus	1741.3	1385.4	2026.4	2538.8	2560.2	1358.5	1953.4	2220.7
std	213.03	411.85	885.37	215.63	161.62	86.99	510.22	439.71

Table 4.3 illustrates the values of flexural modulus mentioned above with their standard deviation. It can be found that the maximum flexural modulus, 2544.898 MPa, was obtained when the percentage by weight of glass powder was 20 %. The maximum flexural strength of 45.9 MPa occurred at 15 % by weight of filler.

Chapter 5 – Conclusion

This study has evaluated the flexural strength, flexural strain and flexural modulus of varying percentage by weight of glass powder reinforced phenolic resin; in all cases, the fluidity of the slurry composite was good and could be cast easily into moulds. The optimum percentage by weight of glass powder was 15% for compromised flexural properties of the composite. The value with no filler had also been compared with those found by other studies but they did not agree with each other. However, it is difficult to argue that which is better than the other because much experimental information employed by other researchers were not available. The values of this study were generally lower but they were reliable because their standard deviations of the properties obtained were low. It can be argued that when the fusion between phenolic resin (matrix) and glass (reinforce) is improved by adding some other fillers and resins to the composite, its flexural properties will be improved.

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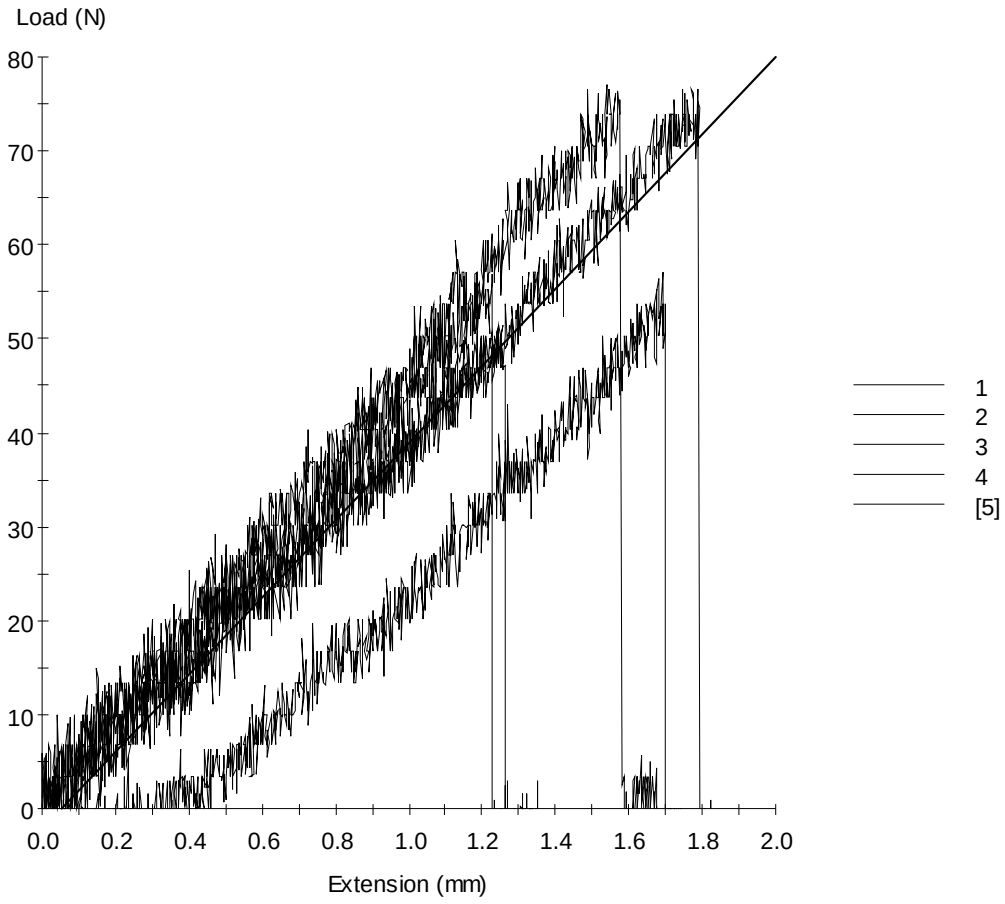
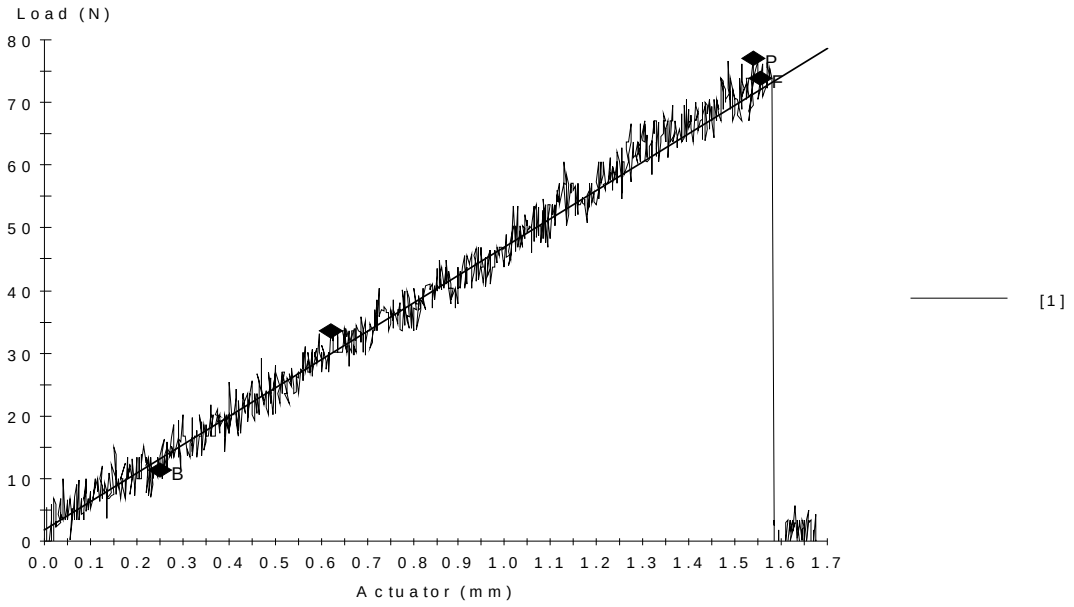
Appendix A - MTS 810 Testing System Data

0% by Weight of Filler



Stress vs Strain Plot

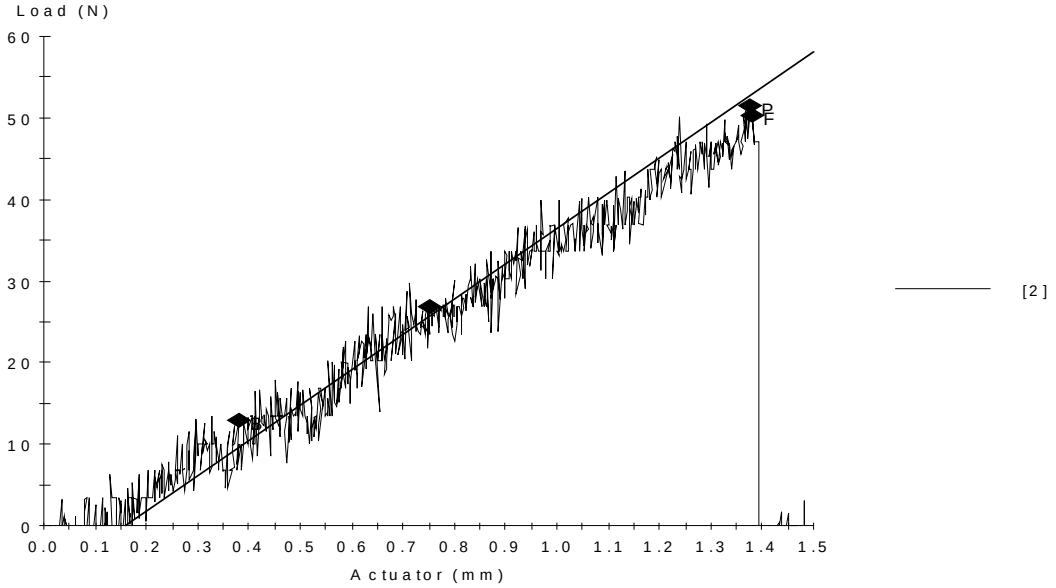
Sample ID: xue-0%G-1.mss
Specimen Number: 1
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.48	mm
Average Width	9.84	mm
Flexural Modulus	1833	MPa
Yield - Elongation	0.04	mm
Yield - Strain	0.03	%
Yield - Load	10	N
Yield - Stress	3.27	MPa
Peak - Elongation	1.54	mm
Peak - Strain	1.24	%
Peak - Load	77.0	N
Peak - Stress	25.04	MPa
Break - Elongation	1.55	mm
Break - Strain	1.25	%
Break - Load	74	N
Break - Stress	24.00	MPa

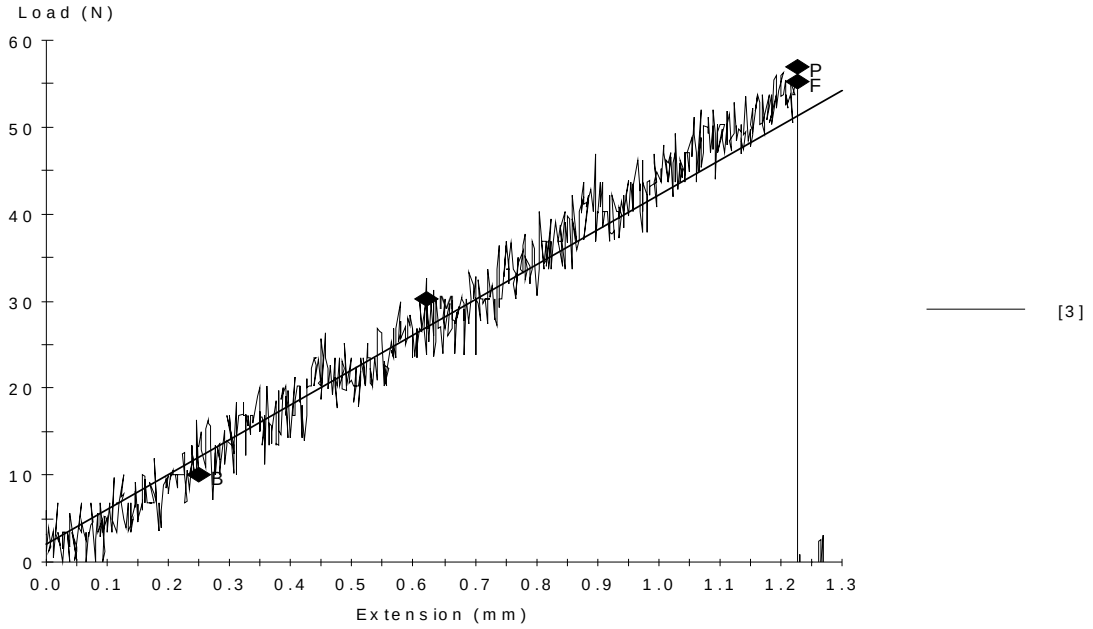
Sample ID: xue-0%G-2.mss
Specimen Number: 2
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.47	mm
Average Width	9.81	mm
Flexural Modulus	1774	MPa
Yield - Elongation	-0.10	mm
Yield - Strain	-0.08	%
Yield - Load	3	N
Yield - Stress	1.04	MPa
Peak - Elongation	1.25	mm
Peak - Strain	1.00	%
Peak - Load	51.5	N
Peak - Stress	16.86	MPa
Break - Elongation	1.25	mm
Break - Strain	1.00	%
Break - Load	50	N
Break - Stress	16.47	MPa

Sample ID: xue-0%G-3.mss
Specimen Number: 3
Tagged: False

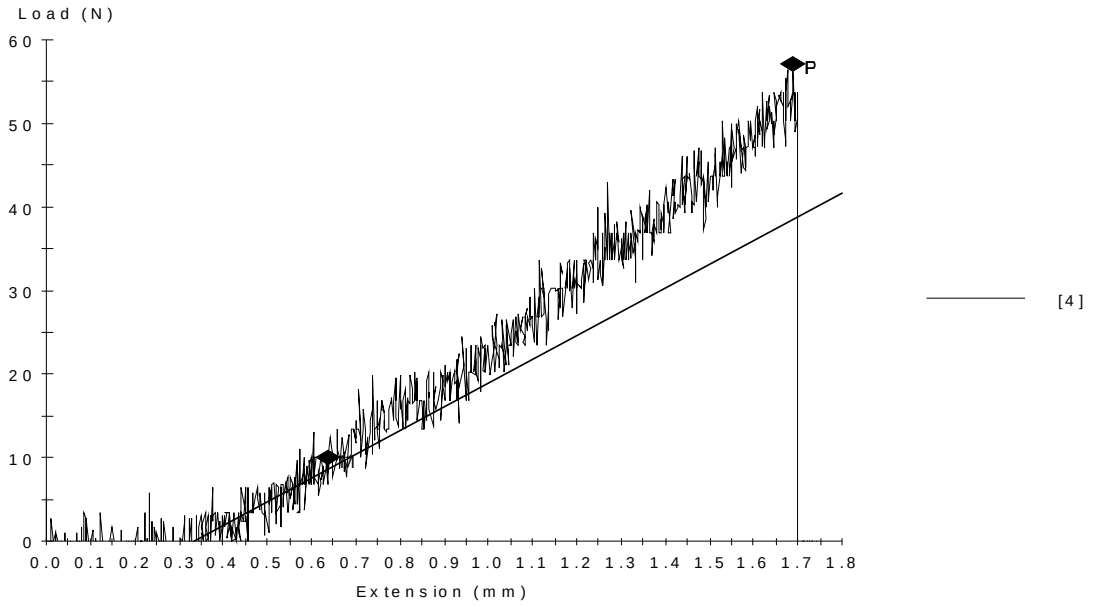


Specimen Results:

Name	Value	Units
Average Thickness	5.51	mm
Average Width	9.80	mm
Flexural Modulus	1611	MPa
Yield - Elongation	-0.49	mm
Yield - Strain	-0.39	%
Yield - Load	2	N
Yield - Stress	0.71	MPa
Peak - Elongation	1.23	mm
Peak - Strain	0.99	%
Peak - Load	56.9	N
Peak - Stress	18.39	MPa
Break - Elongation	1.23	mm
Break - Strain	0.99	%
Break - Load	55	N
Break - Stress	17.85	MPa

6/05/2008

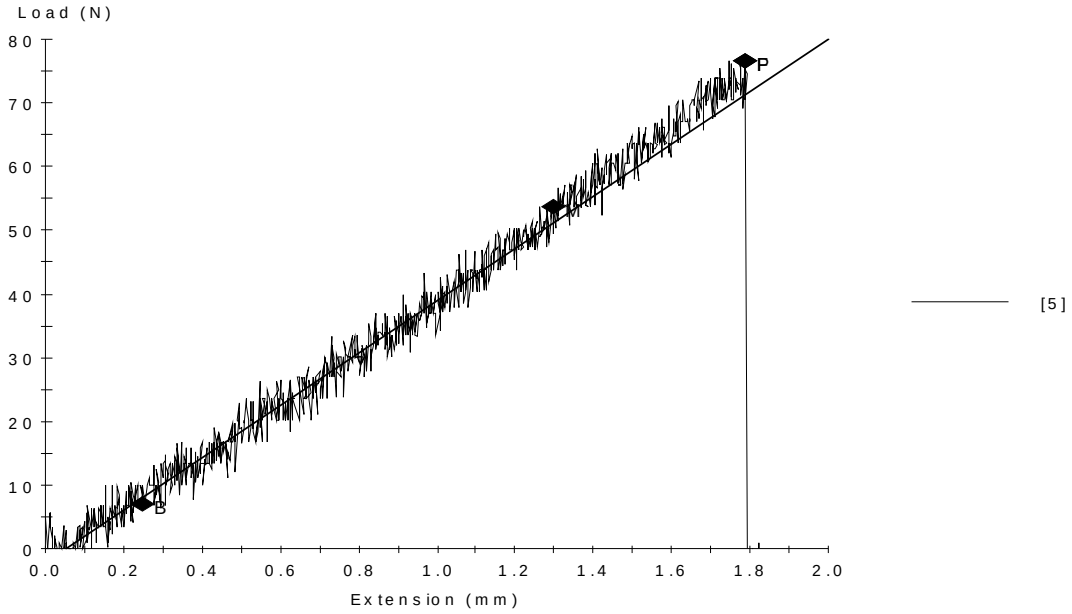
Sample ID: xue-0%G-4.mss
Specimen Number: 4
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.38	mm
Average Width	9.81	mm
Flexural Modulus	1223	MPa
Yield - Elongation	-0.30	mm
Yield - Strain	-0.24	%
Yield - Load	3	N
Yield - Stress	0.91	MPa
Peak - Elongation	1.69	mm
Peak - Strain	1.33	%
Peak - Load	57.1	N
Peak - Stress	19.31	MPa
Break - Elongation	1.69	mm
Break - Strain	1.33	%
Break - Load	57	N
Break - Stress	19.31	MPa

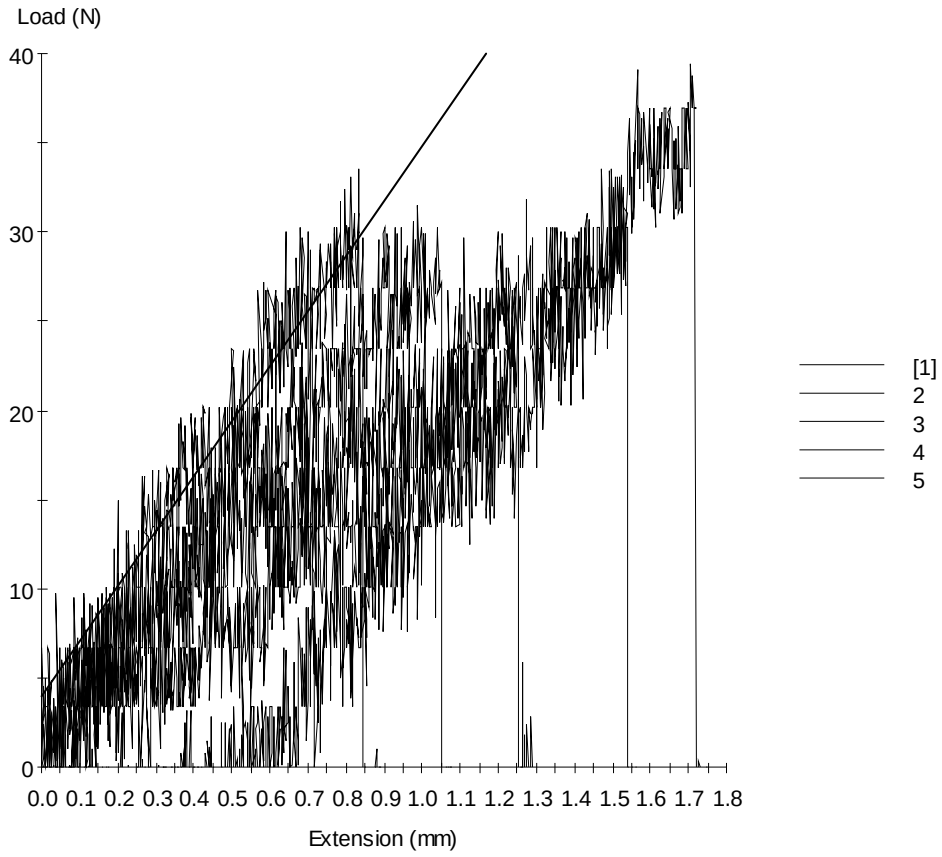
Sample ID: xue-0%G-5.mss
Specimen Number: 5
Tagged: False



Specimen Results:

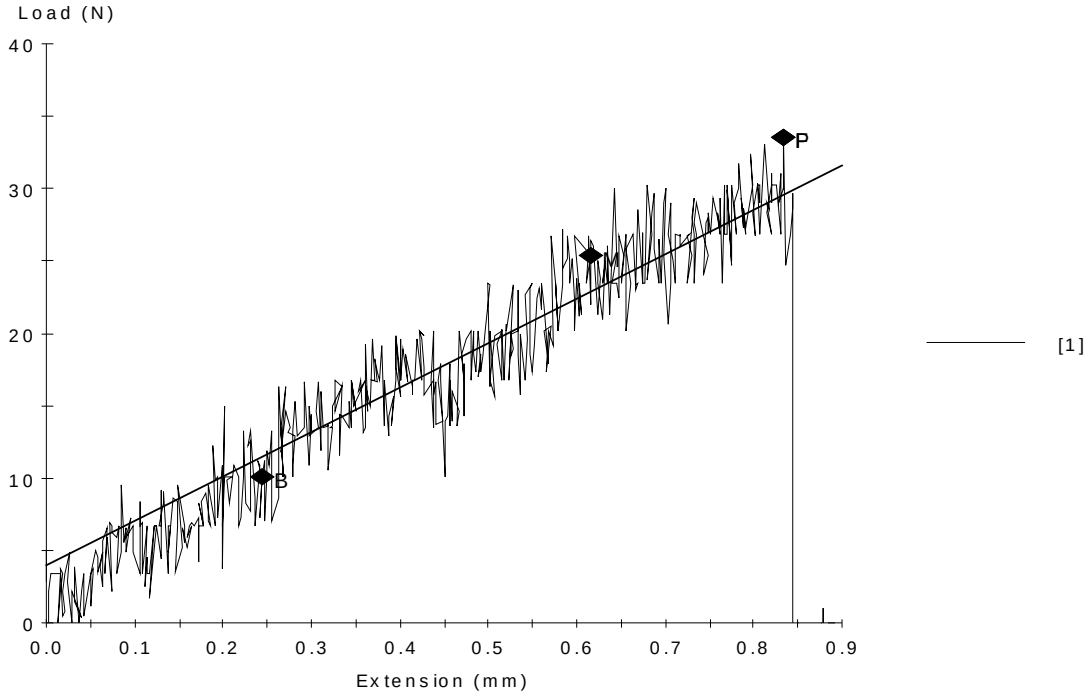
Name	Value	Units
Average Thickness	5.52	mm
Average Width	9.78	mm
Flexural Modulus	1639	MPa
Yield - Elongation	0.00	mm
Yield - Strain	0.00	%
Yield - Load	5	N
Yield - Stress	1.62	MPa
Peak - Elongation	1.79	mm
Peak - Strain	1.44	%
Peak - Load	76.5	N
Peak - Stress	24.68	MPa
Break - Elongation	1.79	mm
Break - Strain	1.44	%
Break - Load	77	N
Break - Stress	24.68	MPa

5% by Weight of Filler



Stress vs Strain Plot

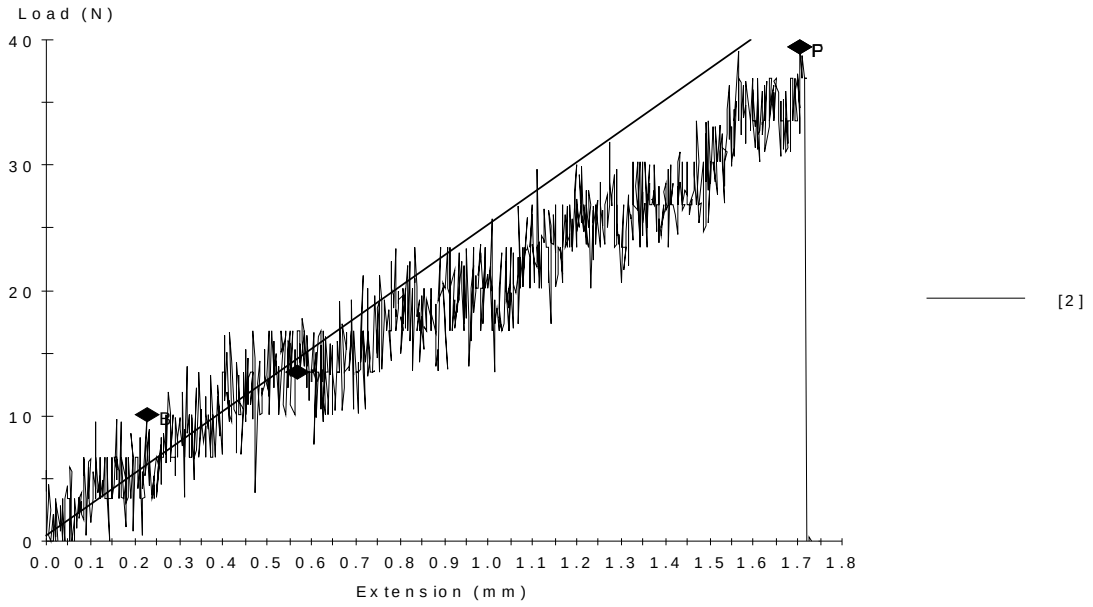
Sample ID: xue-5%G-1.mss
Specimen Number: 1
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.58	mm
Average Width	9.79	mm
Flexural Modulus	1184	MPa
Yield - Elongation	-0.13	mm
Yield - Strain	-0.10	%
Yield - Load	3	N
Yield - Stress	1.06	MPa
Peak - Elongation	0.83	mm
Peak - Strain	0.68	%
Peak - Load	33.6	N
Peak - Stress	10.56	MPa
Break - Elongation	0.83	mm
Break - Strain	0.68	%
Break - Load	34	N
Break - Stress	10.56	MPa

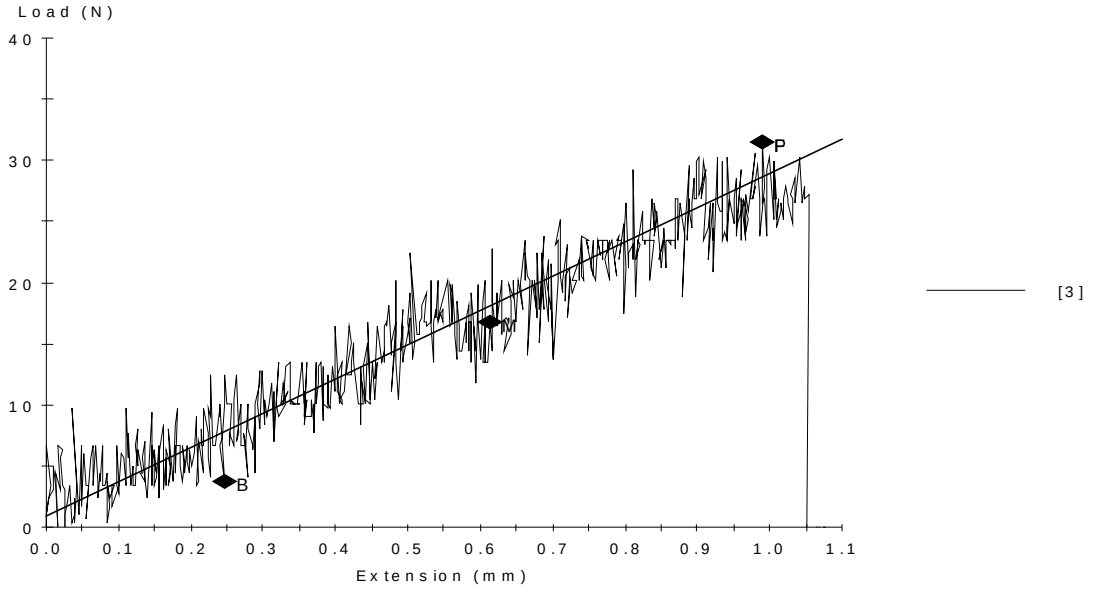
Sample ID: xue-5%G-2.mss
Specimen Number: 2
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.02	mm
Average Width	9.57	mm
Flexural Modulus	779	MPa
Yield - Elongation	-0.33	mm
Yield - Strain	-0.29	%
Yield - Load	3	N
Yield - Stress	0.93	MPa
Peak - Elongation	1.71	mm
Peak - Strain	1.50	%
Peak - Load	39.4	N
Peak - Stress	10.92	MPa
Break - Elongation	1.71	mm
Break - Strain	1.50	%
Break - Load	39	N
Break - Stress	10.92	MPa

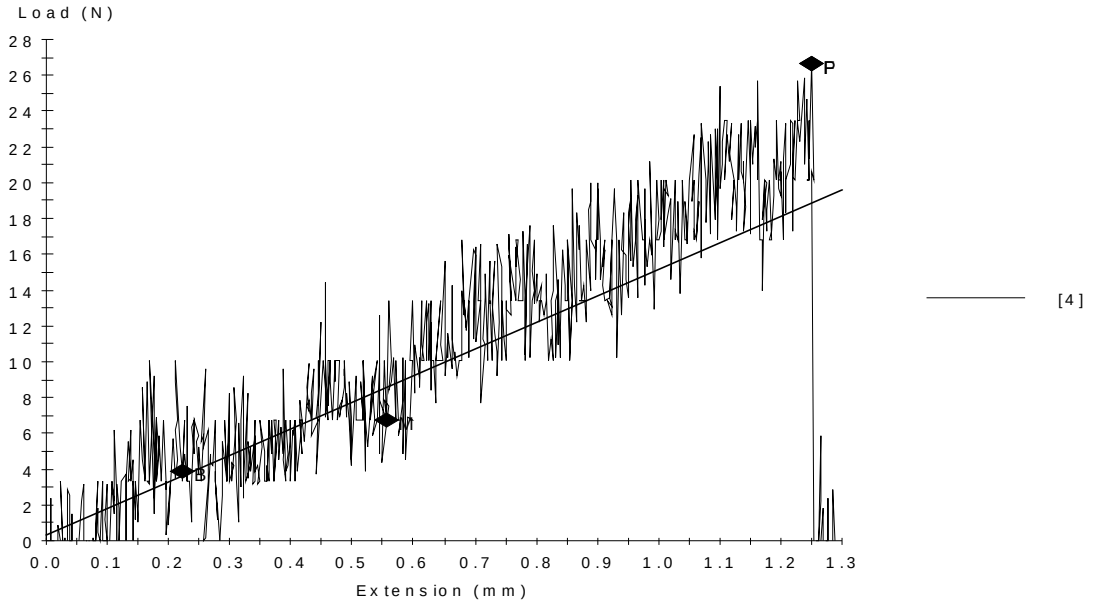
Sample ID: xue-5%G-3.mss
Specimen Number: 3
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.56	mm
Average Width	9.78	mm
Flexural Modulus	1093	MPa
Yield - Elongation	-0.13	mm
Yield - Strain	-0.10	%
Yield - Load	3	N
Yield - Stress	1.07	MPa
Peak - Elongation	0.99	mm
Peak - Strain	0.81	%
Peak - Load	31.6	N
Peak - Stress	10.02	MPa
Break - Elongation	0.99	mm
Break - Strain	0.81	%
Break - Load	32	N
Break - Stress	10.02	MPa

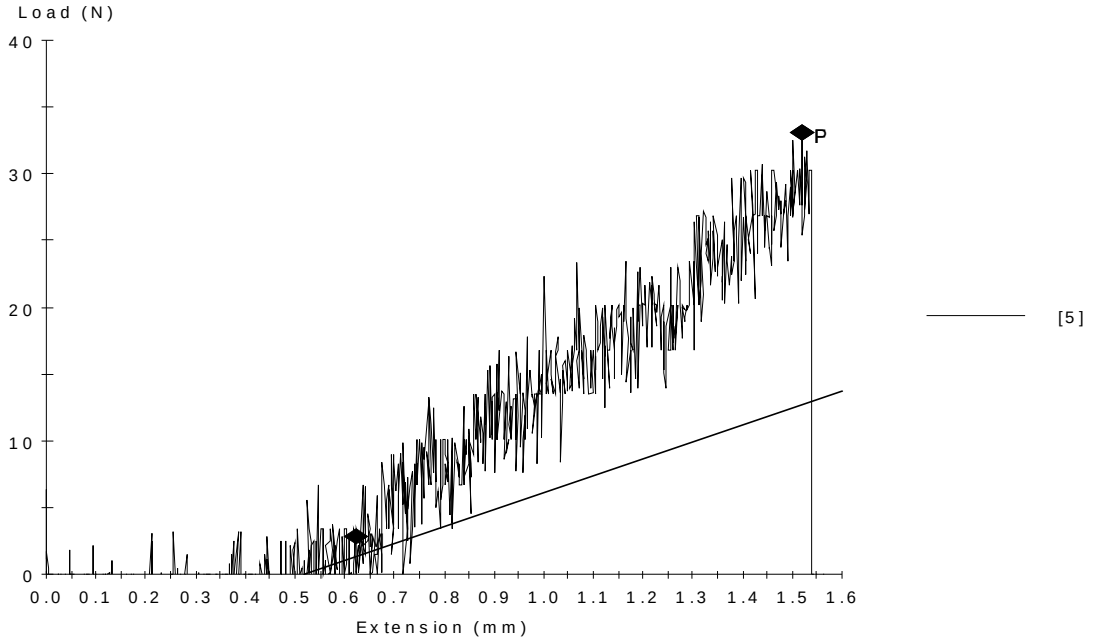
Sample ID: xue-5%G-4.mss
Specimen Number: 4
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.19	mm
Average Width	9.65	mm
Flexural Modulus	424	MPa
Yield - Elongation	0.00	mm
Yield - Strain	0.00	%
Yield - Load	5	N
Yield - Stress	1.31	MPa
Peak - Elongation	1.25	mm
Peak - Strain	1.13	%
Peak - Load	26.7	N
Peak - Stress	6.93	MPa
Break - Elongation	1.25	mm
Break - Strain	1.13	%
Break - Load	27	N
Break - Stress	6.93	MPa

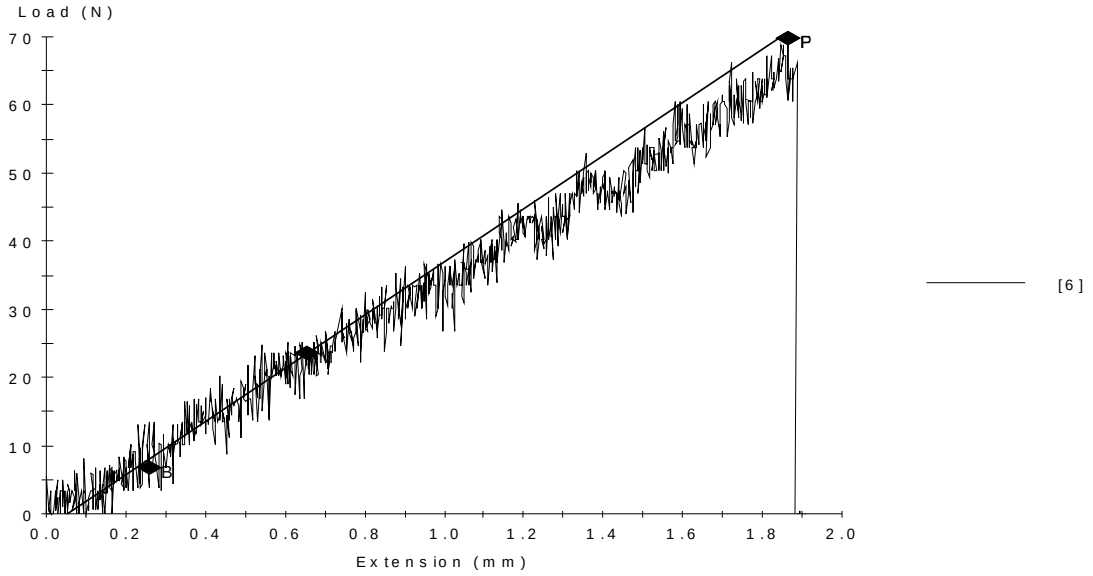
Sample ID: xue-5%G-5.mss
Specimen Number: 5
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.50	mm
Average Width	9.77	mm
Flexural Modulus	511	MPa
Yield - Elongation	-0.37	mm
Yield - Strain	-0.30	%
Yield - Load	3	N
Yield - Stress	1.04	MPa
Peak - Elongation	1.52	mm
Peak - Strain	1.23	%
Peak - Load	33.1	N
Peak - Stress	10.73	MPa
Break - Elongation	1.52	mm
Break - Strain	1.23	%
Break - Load	33	N
Break - Stress	10.73	MPa

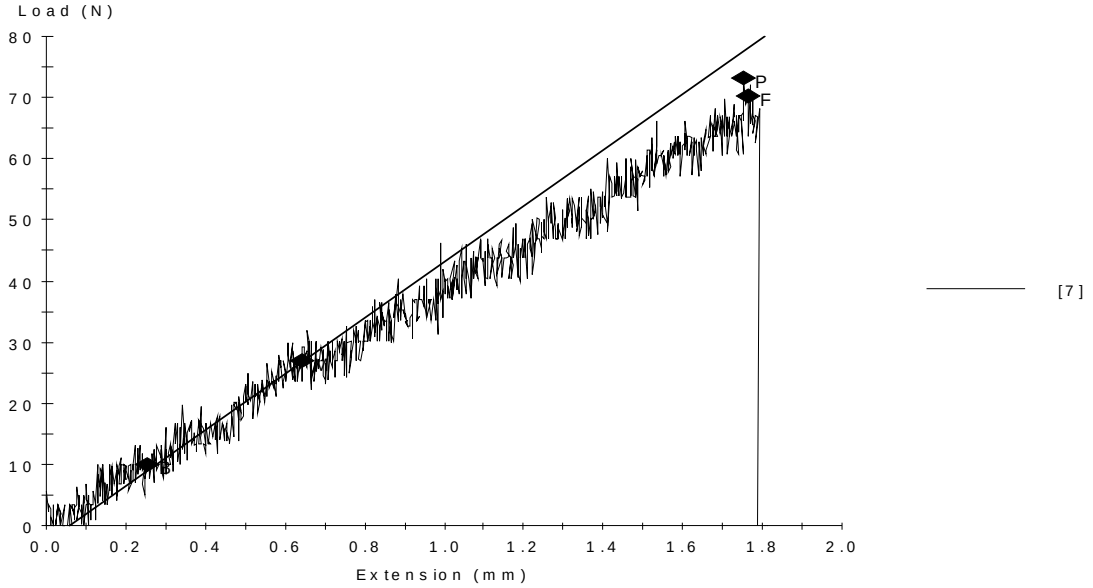
Sample ID: xue-10%G-1.mss
Specimen Number: 6
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.25	mm
Average Width	9.58	mm
Flexural Modulus	1848	MPa
Yield - Elongation	-0.09	mm
Yield - Strain	-0.07	%
Yield - Load	3	N
Yield - Stress	1.10	MPa
Peak - Elongation	1.87	mm
Peak - Strain	1.43	%
Peak - Load	69.8	N
Peak - Stress	25.42	MPa
Break - Elongation	1.87	mm
Break - Strain	1.43	%
Break - Load	70	N
Break - Stress	25.42	MPa

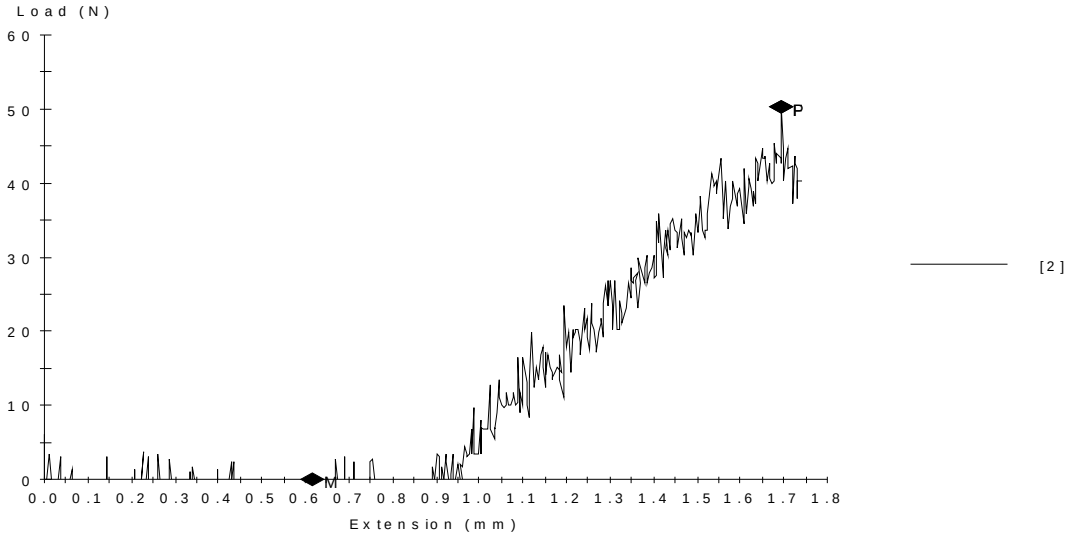
Sample ID: xue-10%G-2.mss
Specimen Number: 7
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.32	mm
Average Width	9.58	mm
Flexural Modulus	2077	MPa
Yield - Elongation	-0.03	mm
Yield - Strain	-0.02	%
Yield - Load	3	N
Yield - Stress	1.19	MPa
Peak - Elongation	1.75	mm
Peak - Strain	1.37	%
Peak - Load	73.2	N
Peak - Stress	25.87	MPa
Break - Elongation	1.76	mm
Break - Strain	1.38	%
Break - Load	70	N
Break - Stress	24.80	MPa

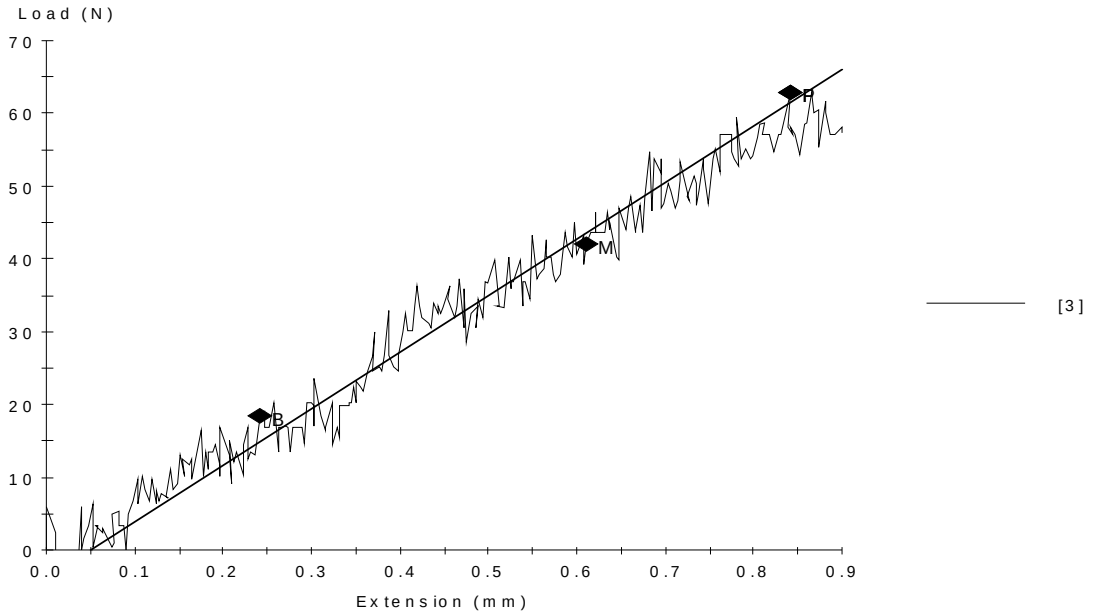
Sample ID: xue10%glass-2.mss
Specimen Number: 2
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.53	mm
Average Width	9.59	mm
Flexural Modulus	-227	MPa
Yield - Elongation	-0.30	mm
Yield - Strain	-0.24	%
Yield - Load	2	N
Yield - Stress	0.55	MPa
Peak - Elongation	1.70	mm
Peak - Strain	1.37	%
Peak - Load	50.4	N
Peak - Stress	16.46	MPa
Break - Elongation	1.70	mm
Break - Strain	1.37	%
Break - Load	50	N
Break - Stress	16.46	MPa

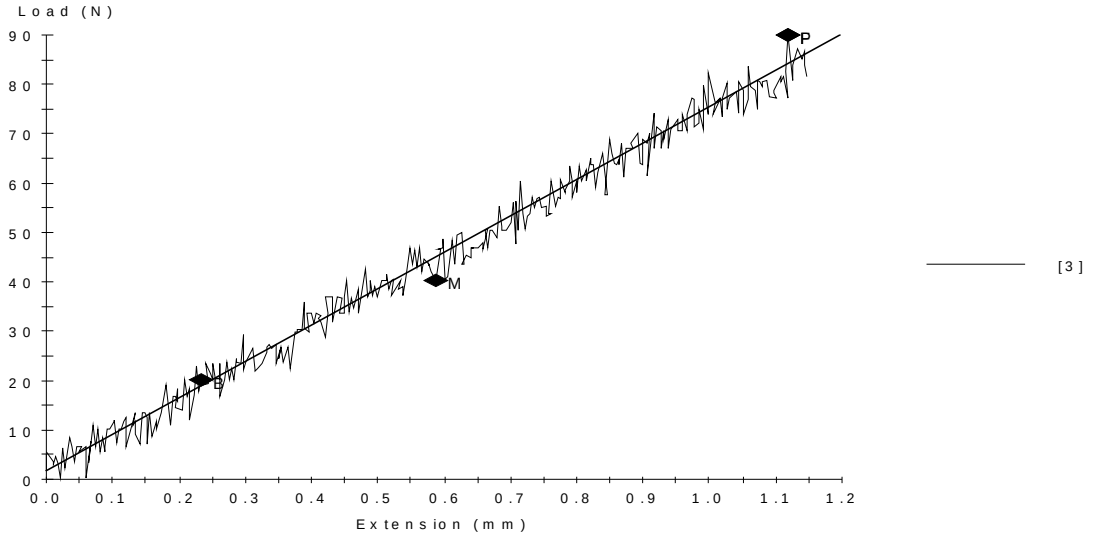
Sample ID: xue10%glass-3.mss
Specimen Number: 3
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.59	mm
Average Width	9.74	mm
Flexural Modulus	2990	MPa
Yield - Elongation	-1.26	mm
Yield - Strain	-1.03	%
Yield - Load	3	N
Yield - Stress	0.85	MPa
Peak - Elongation	0.84	mm
Peak - Strain	0.69	%
Peak - Load	62.8	N
Peak - Stress	19.79	MPa
Break - Elongation	0.84	mm
Break - Strain	0.69	%
Break - Load	63	N
Break - Stress	19.79	MPa

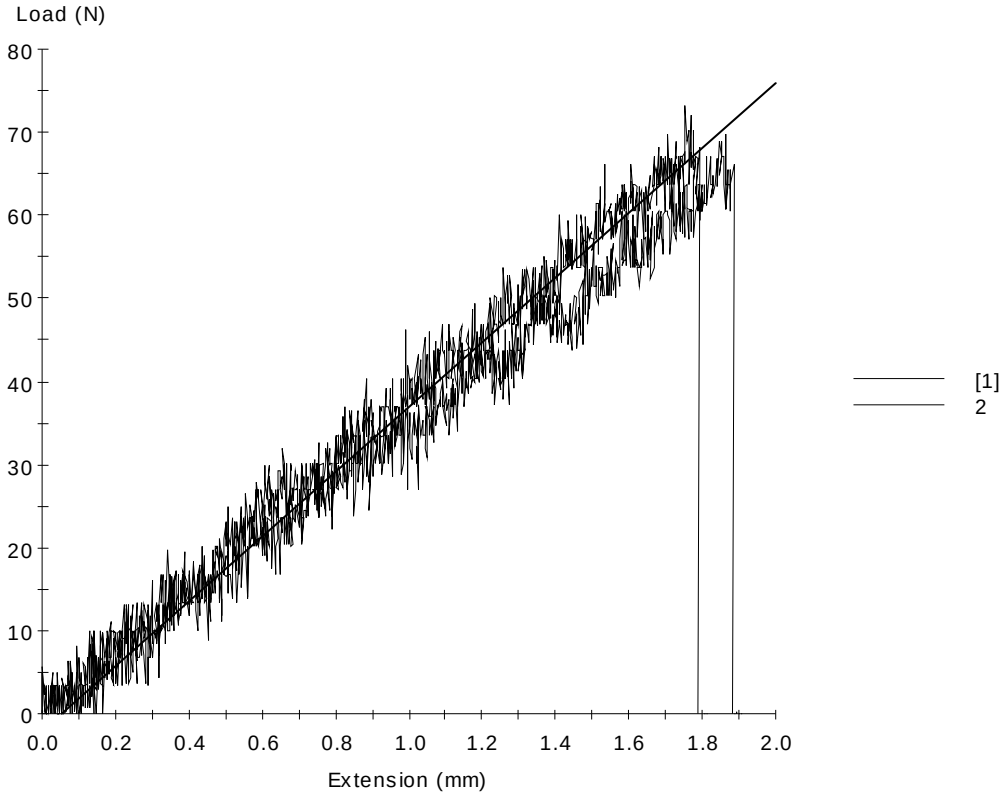
Sample ID: xue10%glass-4.mss
Specimen Number: 3
Tagged: False



Specimen Results:

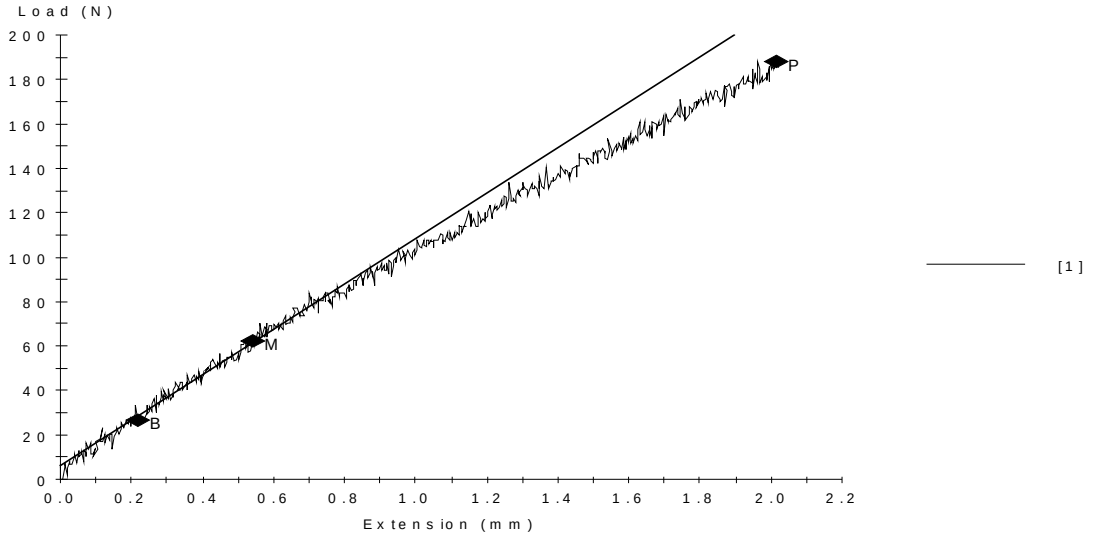
Name	Value	Units
Average Thickness	5.81	mm
Average Width	9.72	mm
Flexural Modulus	2531	MPa
Yield - Elongation	-0.86	mm
Yield - Strain	-0.74	%
Yield - Load	2	N
Yield - Stress	0.69	MPa
Peak - Elongation	1.12	mm
Peak - Strain	0.95	%
Peak - Load	90.0	N
Peak - Stress	26.30	MPa
Break - Elongation	1.12	mm
Break - Strain	0.95	%
Break - Load	90	N
Break - Stress	26.30	MPa

10% by Weight of Filler



Stress vs Strain Plot

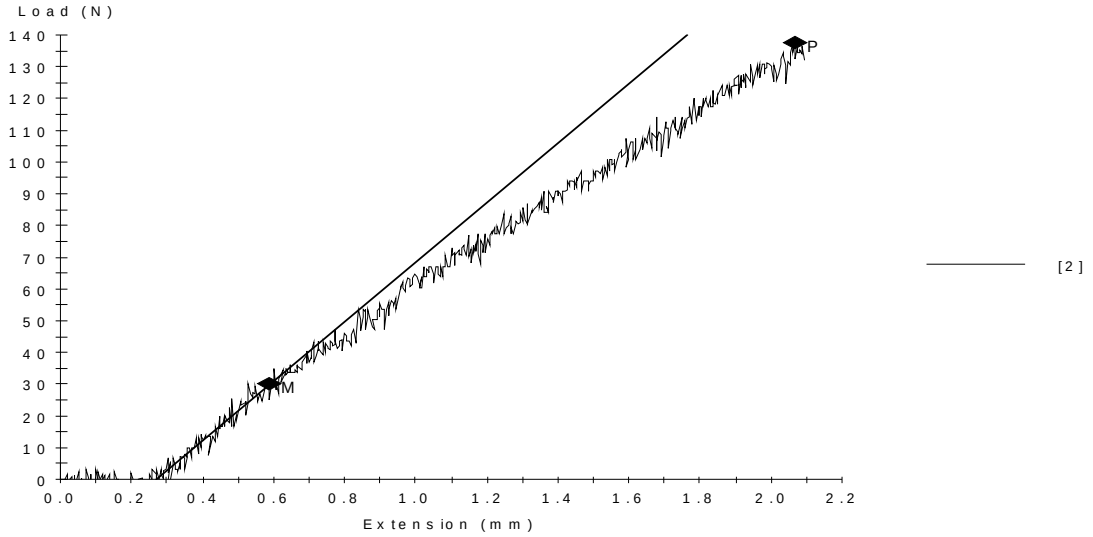
Sample ID: xue15%glass-1.mss
Specimen Number: 1
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.29	mm
Average Width	9.47	mm
Flexural Modulus	2844	MPa
Yield - Elongation	0.12	mm
Yield - Strain	0.11	%
Yield - Load	23	N
Yield - Stress	5.90	MPa
Peak - Elongation	2.02	mm
Peak - Strain	1.86	%
Peak - Load	188.2	N
Peak - Stress	48.26	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

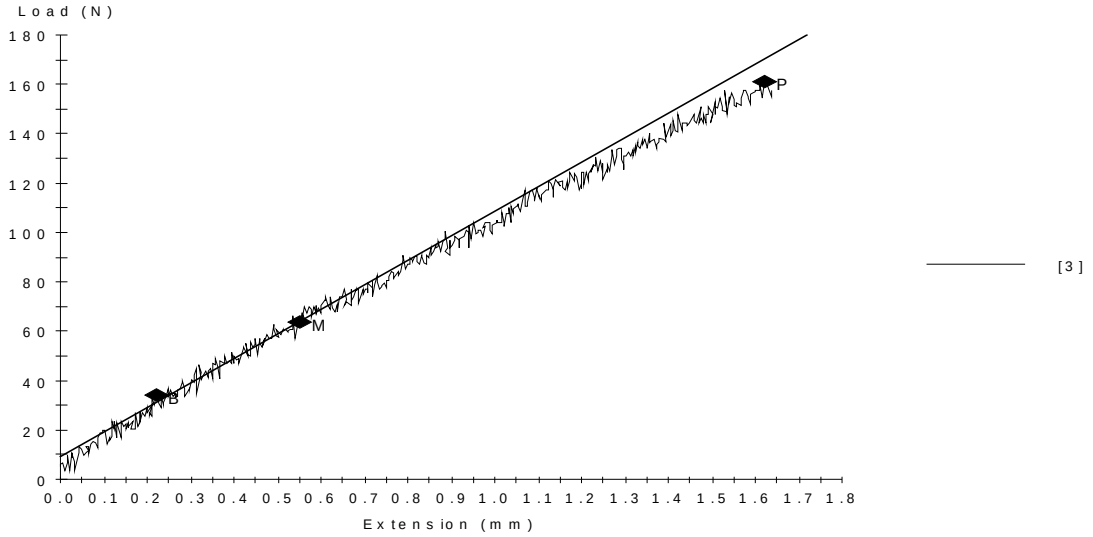
Sample ID: xue15%glass-2.mss
Specimen Number: 2
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.80	mm
Average Width	9.50	mm
Flexural Modulus	3309	MPa
Yield - Elongation	-0.10	mm
Yield - Strain	-0.08	%
Yield - Load	3	N
Yield - Stress	1.01	MPa
Peak - Elongation	2.06	mm
Peak - Strain	1.75	%
Peak - Load	137.6	N
Peak - Stress	41.33	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

Sample ID: xue15%glass-3.mss
Specimen Number: 3
Tagged: False

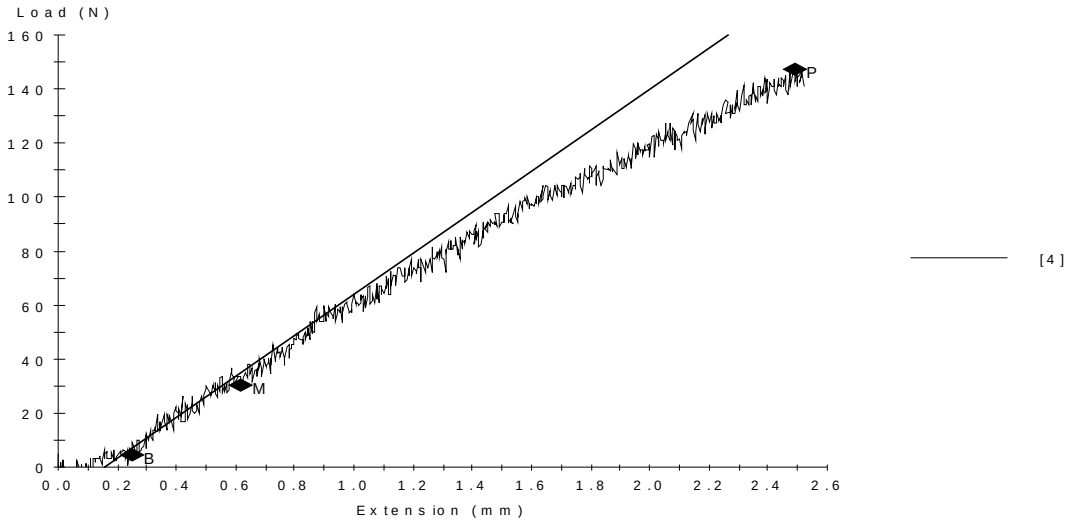


Specimen Results:

Name	Value	Units
Average Thickness	6.19	mm
Average Width	9.50	mm
Flexural Modulus	2882	MPa
Yield - Elongation	0.49	mm
Yield - Strain	0.45	%
Yield - Load	63	N
Yield - Stress	16.59	MPa
Peak - Elongation	1.62	mm
Peak - Strain	1.47	%
Peak - Load	161.1	N
Peak - Stress	42.48	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

Sample ID: xue15%glass-4.mss

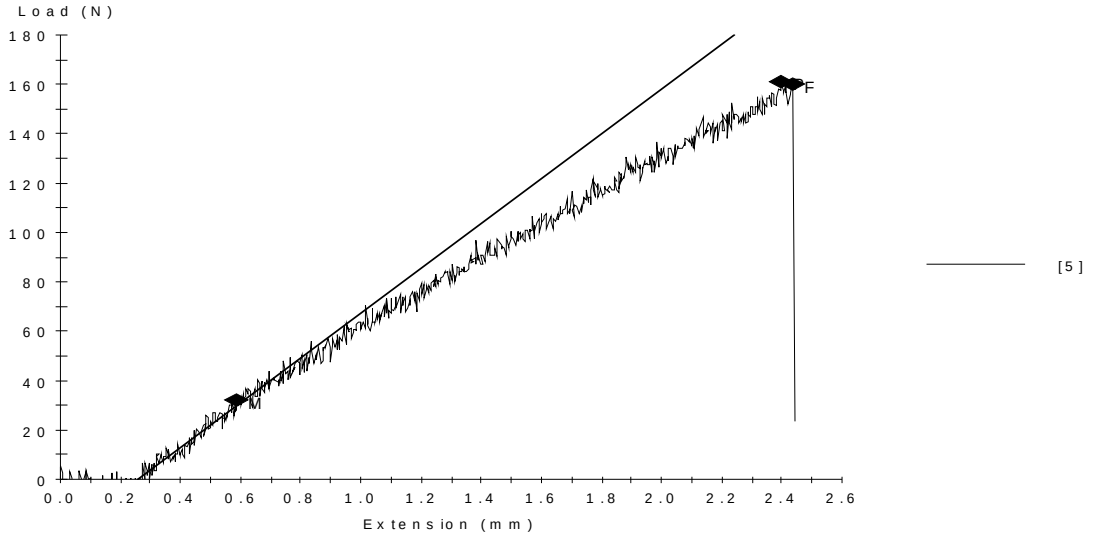
Specimen Number: 4
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.50	mm
Average Width	9.53	mm
Flexural Modulus	3138	MPa
Yield - Elongation	-0.37	mm
Yield - Strain	-0.30	%
Yield - Load	3	N
Yield - Stress	1.01	MPa
Peak - Elongation	2.49	mm
Peak - Strain	2.00	%
Peak - Load	147.2	N
Peak - Stress	49.00	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

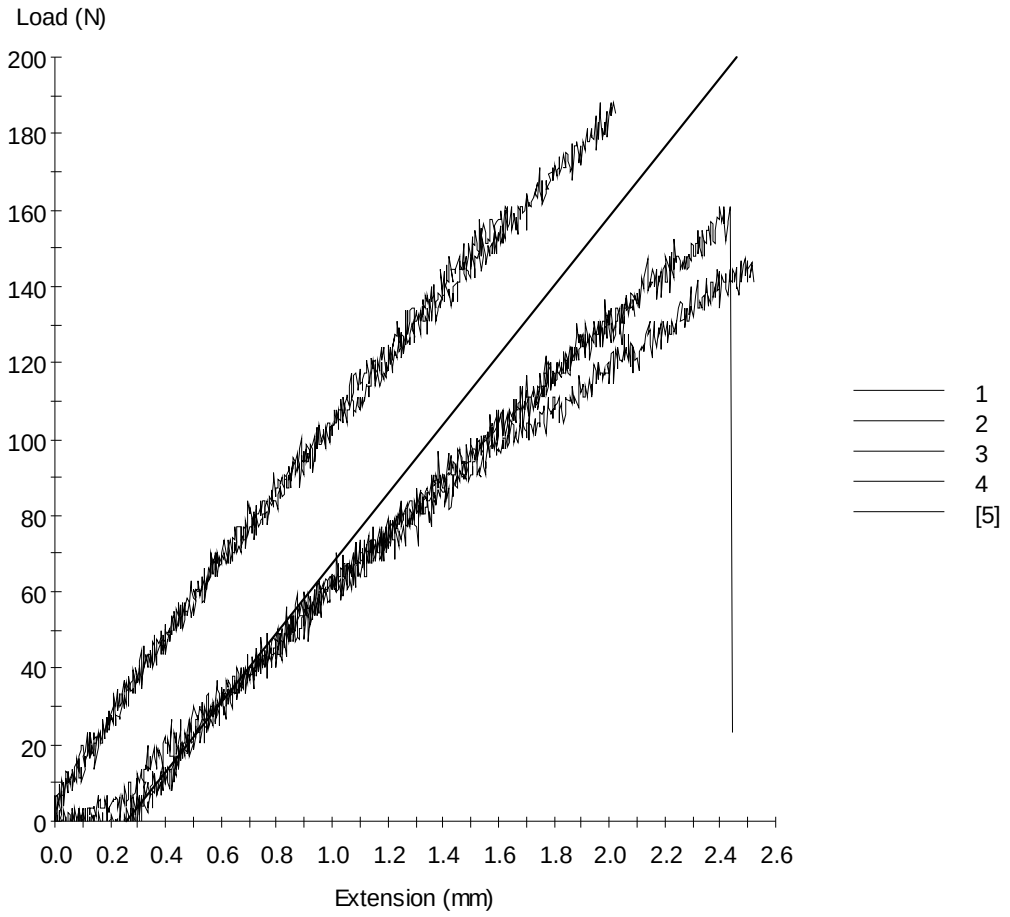
Sample ID: xue15%glass-5.mss
Specimen Number: 5
Tagged: False



Specimen Results:

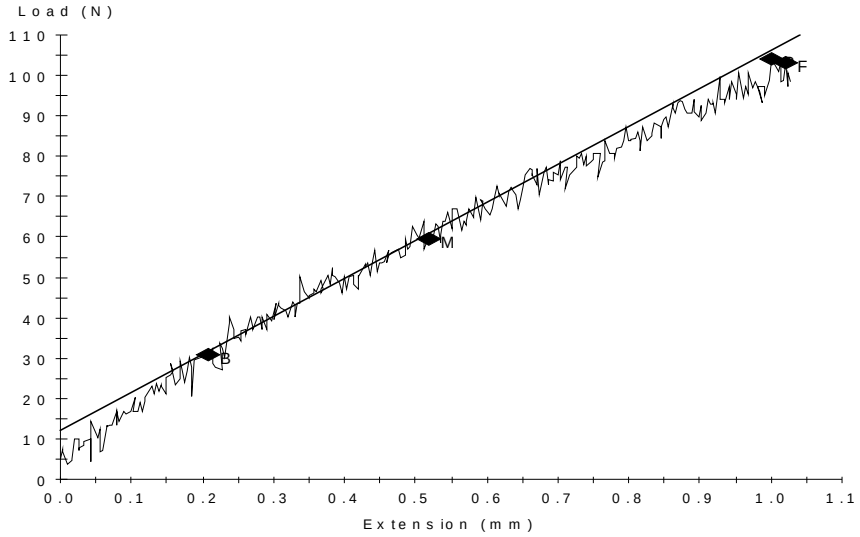
Name	Value	Units
Average Thickness	5.78	mm
Average Width	9.51	mm
Flexural Modulus	3252	MPa
Yield - Elongation	0.00	mm
Yield - Strain	0.00	%
Yield - Load	6	N
Yield - Stress	1.93	MPa
Peak - Elongation	2.39	mm
Peak - Strain	2.03	%
Peak - Load	161.1	N
Peak - Stress	48.73	MPa
Break - Elongation	2.44	mm
Break - Strain	2.06	%
Break - Load	160	N
Break - Stress	48.42	MPa

15% by Weight of Filler



Stress vs Strain Plot

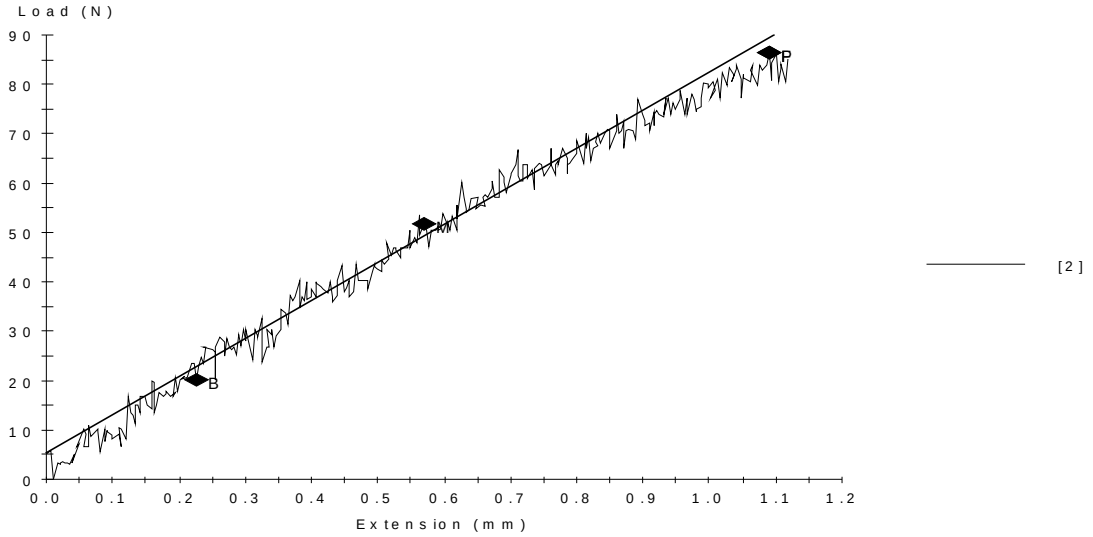
Sample ID: xue20%glass-1.mss
Specimen Number: 1
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.56	mm
Average Width	9.61	mm
Flexural Modulus	2273	MPa
Yield - Elongation	-0.18	mm
Yield - Strain	-0.17	%
Yield - Load	2	N
Yield - Stress	0.55	MPa
Peak - Elongation	1.00	mm
Peak - Strain	0.96	%
Peak - Load	104.1	N
Peak - Stress	24.19	MPa
Break - Elongation	1.02	mm
Break - Strain	0.98	%
Break - Load	103	N
Break - Stress	24.00	MPa

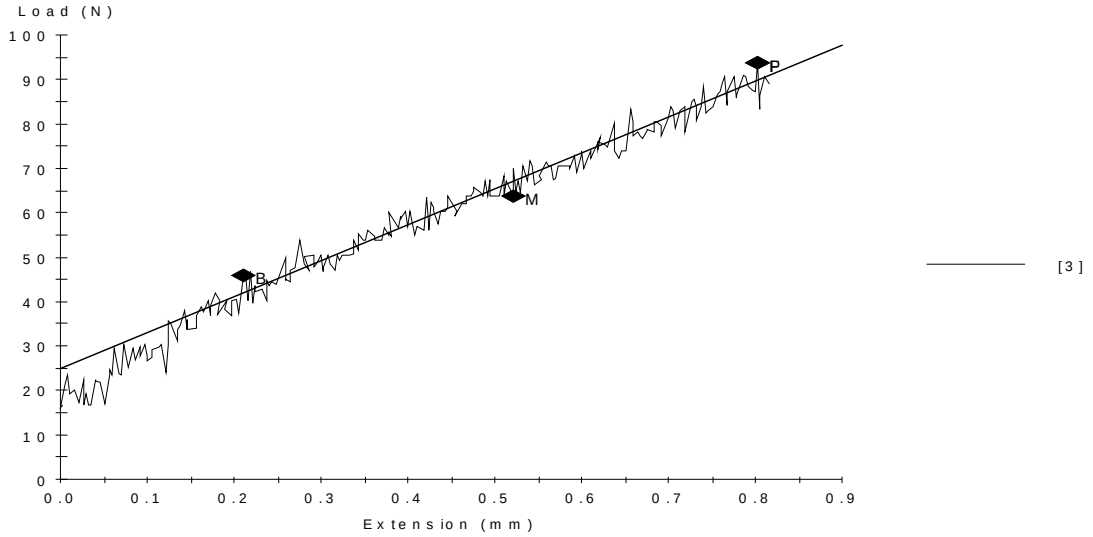
Sample ID: xue20%glass-2.mss
Specimen Number: 2
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.00	mm
Average Width	9.61	mm
Flexural Modulus	2436	MPa
Yield - Elongation	-0.48	mm
Yield - Strain	-0.42	%
Yield - Load	3	N
Yield - Stress	0.88	MPa
Peak - Elongation	1.09	mm
Peak - Strain	0.96	%
Peak - Load	86.4	N
Peak - Stress	23.96	MPa
Break - Elongation	1.09	mm
Break - Strain	0.96	%
Break - Load	86	N
Break - Stress	23.96	MPa

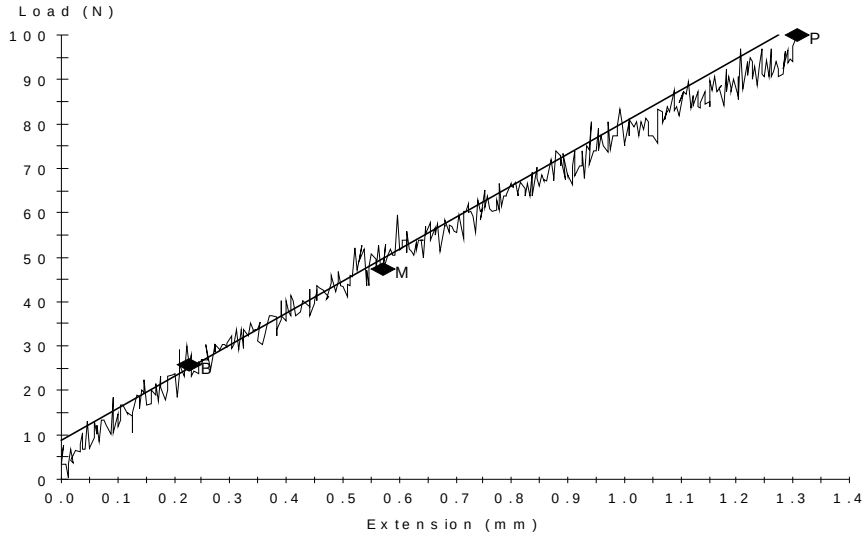
Sample ID: xue20%glass-3.mss
Specimen Number: 3
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.56	mm
Average Width	9.56	mm
Flexural Modulus	1962	MPa
Yield - Elongation	0.01	mm
Yield - Strain	0.01	%
Yield - Load	23	N
Yield - Stress	5.49	MPa
Peak - Elongation	0.80	mm
Peak - Strain	0.77	%
Peak - Load	93.7	N
Peak - Stress	21.87	MPa
Break - Elongation	0.80	mm
Break - Strain	0.77	%
Break - Load	94	N
Break - Stress	21.87	MPa

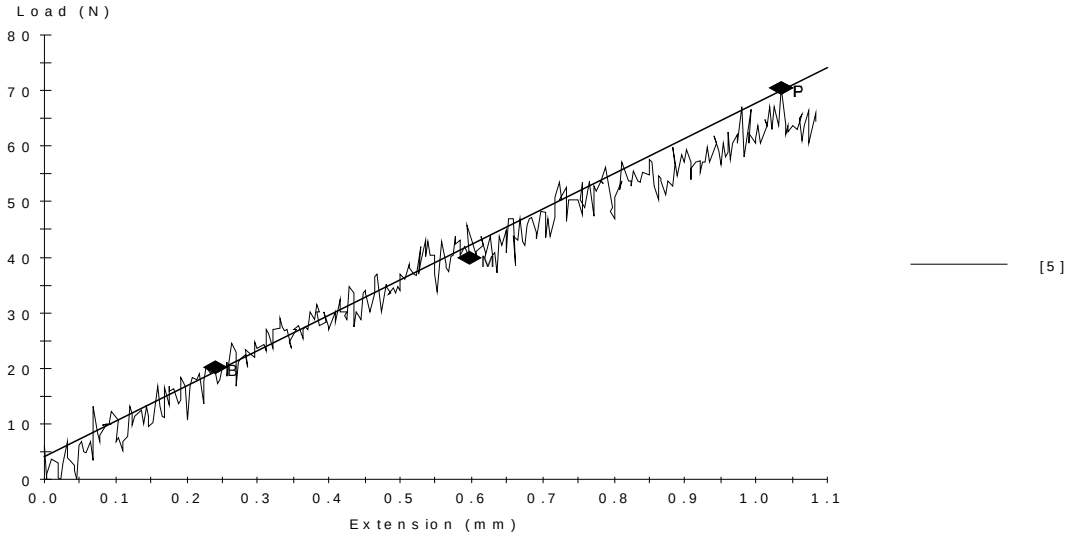
Sample ID: xue20%glass-4.mss
Specimen Number: 4
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.99	mm
Average Width	9.54	mm
Flexural Modulus	2286	MPa
Yield - Elongation	-0.04	mm
Yield - Strain	-0.03	%
Yield - Load	3	N
Yield - Stress	0.94	MPa
Peak - Elongation	1.31	mm
Peak - Strain	1.15	%
Peak - Load	99.9	N
Peak - Stress	27.98	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

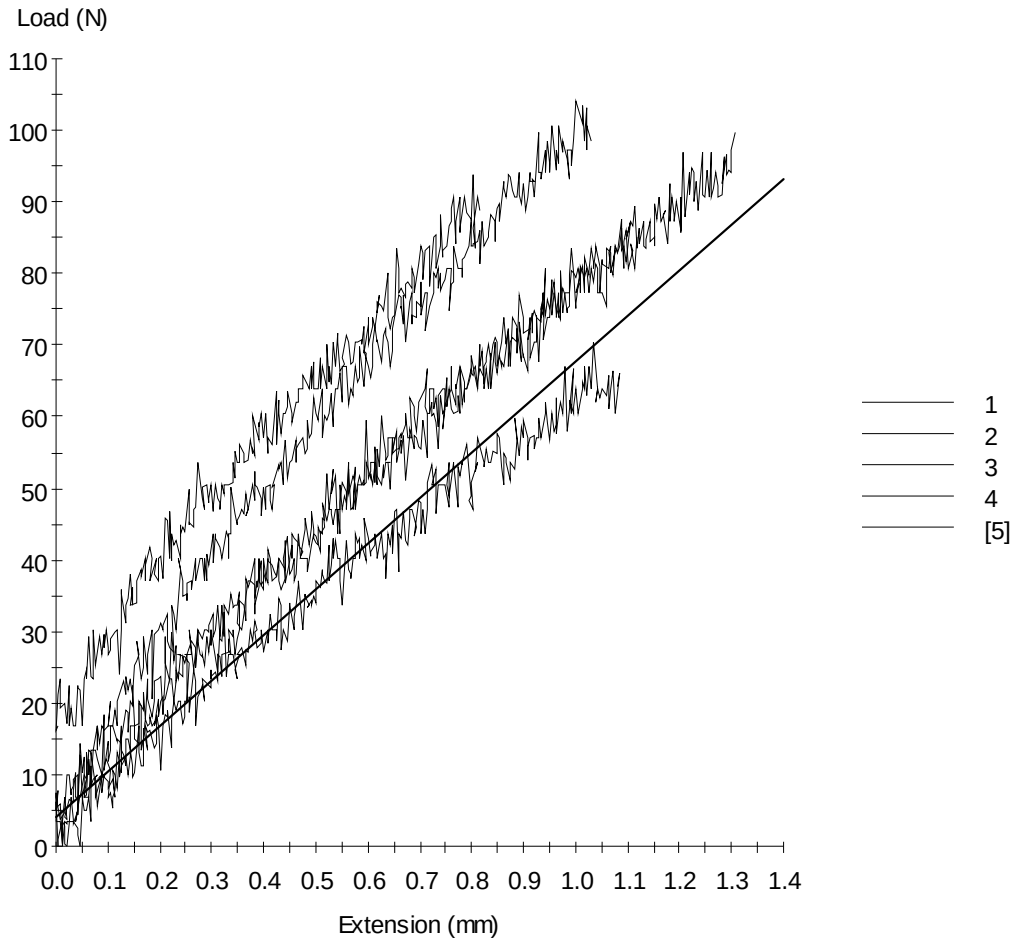
Sample ID: xue20%glass-5.mss
Specimen Number: 5
Tagged: False



Specimen Results:

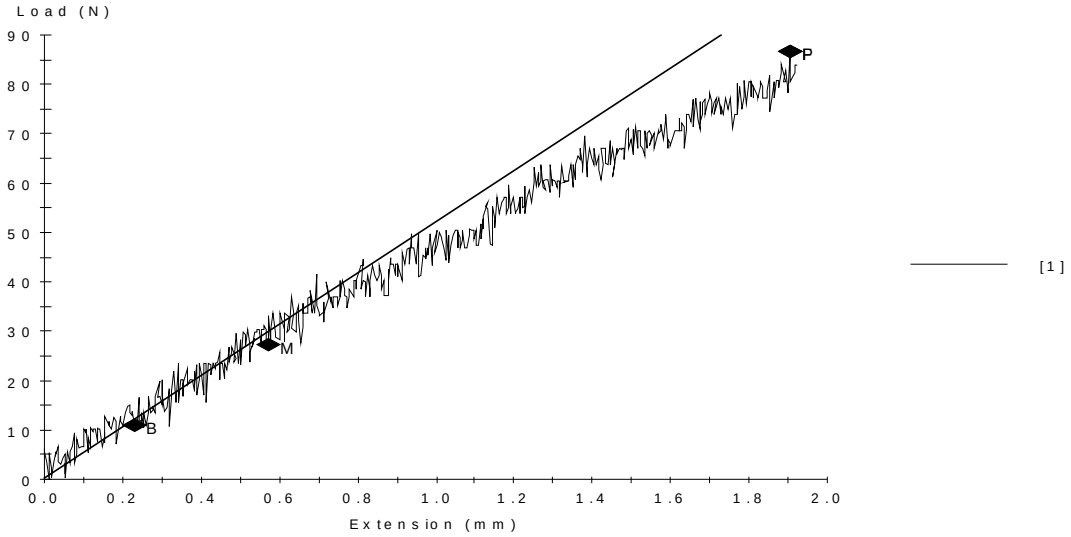
Name	Value	Units
Average Thickness	5.73	mm
Average Width	9.53	mm
Flexural Modulus	2329	MPa
Yield - Elongation	-0.03	mm
Yield - Strain	-0.03	%
Yield - Load	4	N
Yield - Stress	1.08	MPa
Peak - Elongation	1.03	mm
Peak - Strain	0.87	%
Peak - Load	70.5	N
Peak - Stress	21.65	MPa
Break - Elongation	1.03	mm
Break - Strain	0.87	%
Break - Load	70	N
Break - Stress	21.65	MPa

20% by Weight of Filler



Stress vs Strain Plot

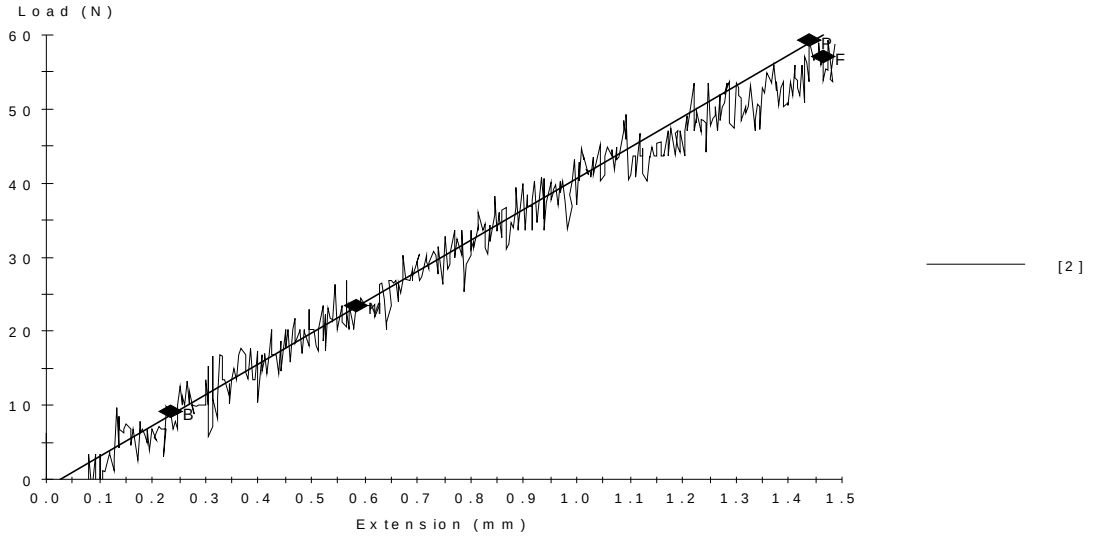
Sample ID: xue25%glass-1.mss
Specimen Number: 1
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.00	mm
Average Width	9.74	mm
Flexural Modulus	1620	MPa
Yield - Elongation	-0.33	mm
Yield - Strain	-0.29	%
Yield - Load	3	N
Yield - Stress	0.74	MPa
Peak - Elongation	1.90	mm
Peak - Strain	1.67	%
Peak - Load	86.6	N
Peak - Stress	23.70	MPa
Break - Elongation	1.90	mm
Break - Strain	1.67	%
Break - Load	87	N
Break - Stress	23.70	MPa

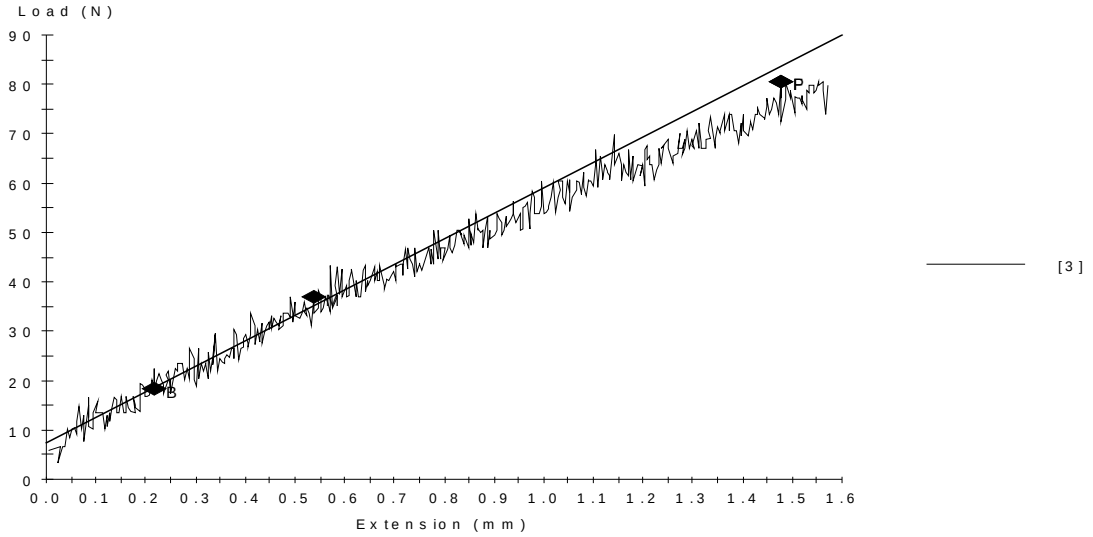
Sample ID: xue25%glass-2.mss
Specimen Number: 2
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.84	mm
Average Width	9.74	mm
Flexural Modulus	1408	MPa
Yield - Elongation	-0.16	mm
Yield - Strain	-0.14	%
Yield - Load	3	N
Yield - Stress	0.97	MPa
Peak - Elongation	1.44	mm
Peak - Strain	1.23	%
Peak - Load	59.3	N
Peak - Stress	17.12	MPa
Break - Elongation	1.46	mm
Break - Strain	1.25	%
Break - Load	57	N
Break - Stress	16.49	MPa

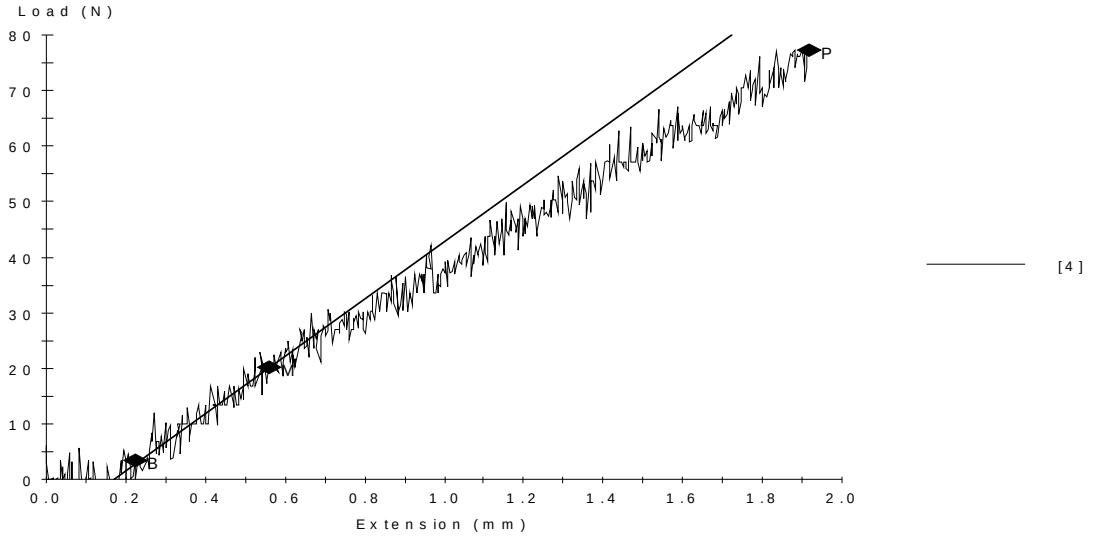
Sample ID: xue25%glass-3.mss
Specimen Number: 3
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.34	mm
Average Width	9.72	mm
Flexural Modulus	1365	MPa
Yield - Elongation	0.09	mm
Yield - Strain	0.08	%
Yield - Load	16	N
Yield - Stress	4.04	MPa
Peak - Elongation	1.48	mm
Peak - Strain	1.37	%
Peak - Load	80.6	N
Peak - Stress	19.80	MPa
Break - Elongation	1.48	mm
Break - Strain	1.37	%
Break - Load	81	N
Break - Stress	19.80	MPa

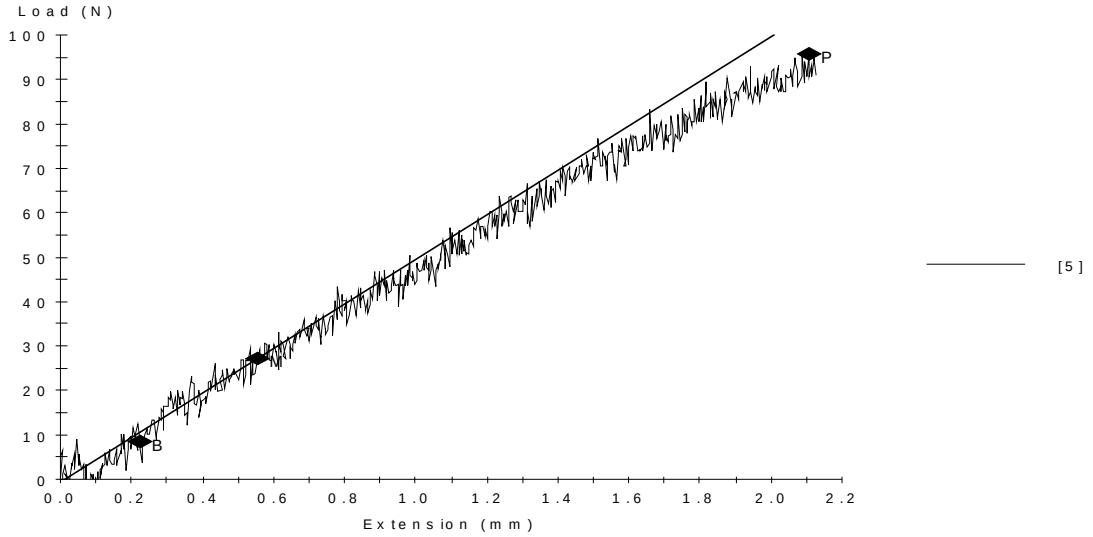
Sample ID: xue25%glass-4.mss
Specimen Number: 4
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.04	mm
Average Width	9.74	mm
Flexural Modulus	1575	MPa
Yield - Elongation	-0.13	mm
Yield - Strain	-0.12	%
Yield - Load	3	N
Yield - Stress	0.91	MPa
Peak - Elongation	1.92	mm
Peak - Strain	1.70	%
Peak - Load	77.4	N
Peak - Stress	20.89	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

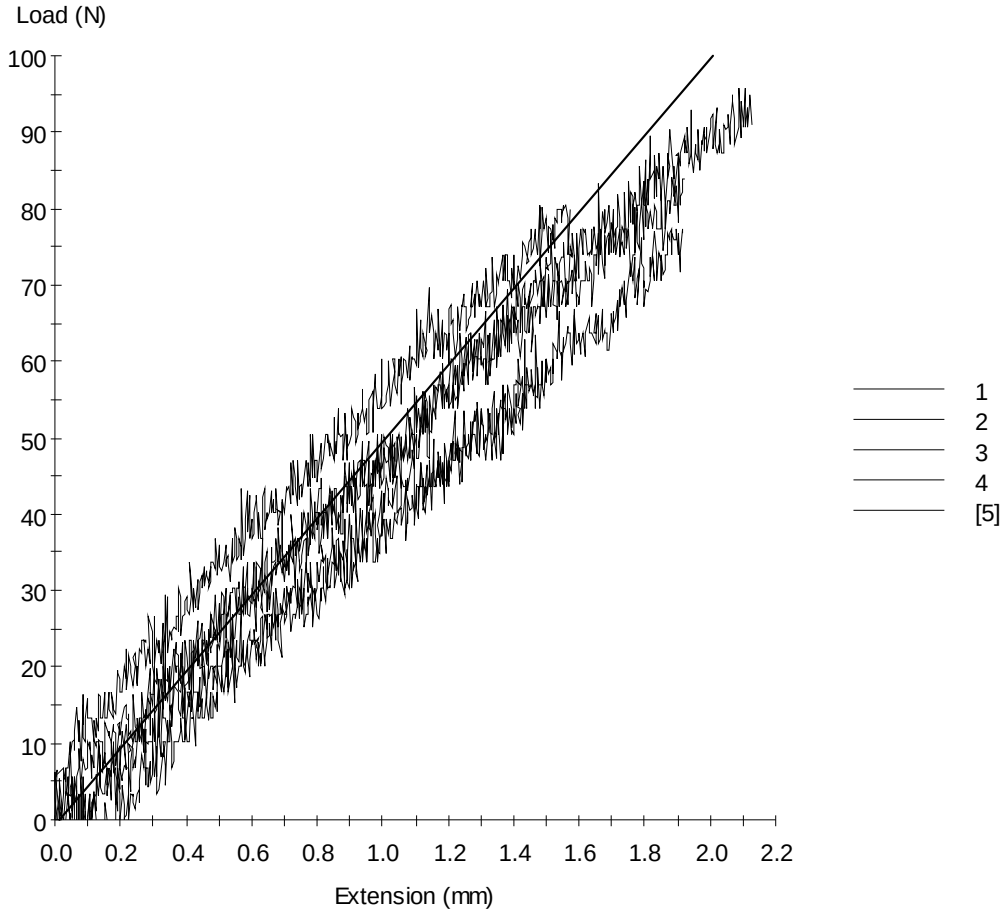
Sample ID: xue25%glass-5.mss
Specimen Number: 5
Tagged: False



Specimen Results:

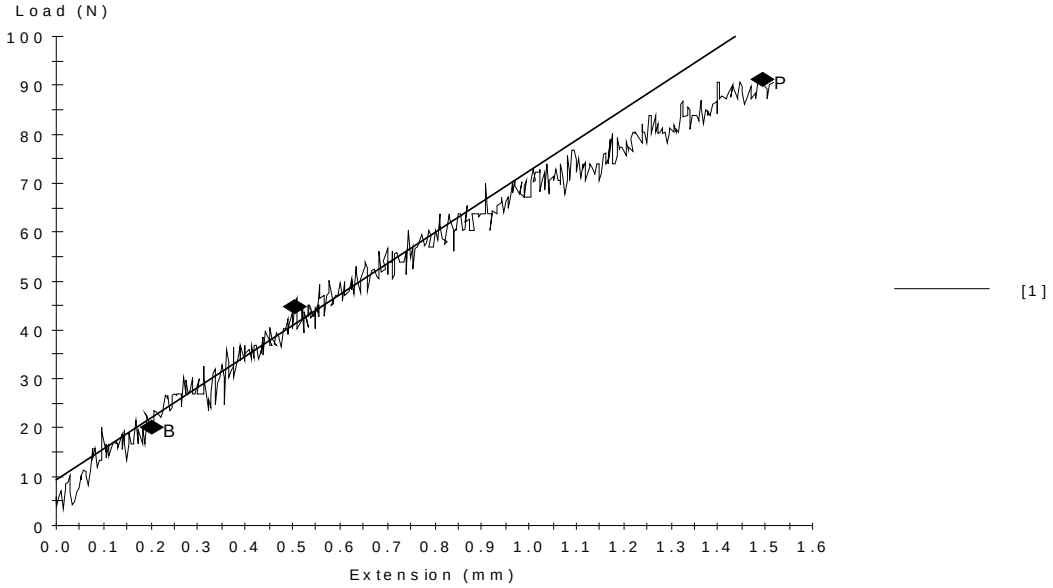
Name	Value	Units
Average Thickness	6.17	mm
Average Width	9.71	mm
Flexural Modulus	1436	MPa
Yield - Elongation	0.05	mm
Yield - Strain	0.04	%
Yield - Load	9	N
Yield - Stress	2.35	MPa
Peak - Elongation	2.10	mm
Peak - Strain	1.90	%
Peak - Load	95.7	N
Peak - Stress	24.81	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

25% by Weight of Filler



Stress vs Strain Plot

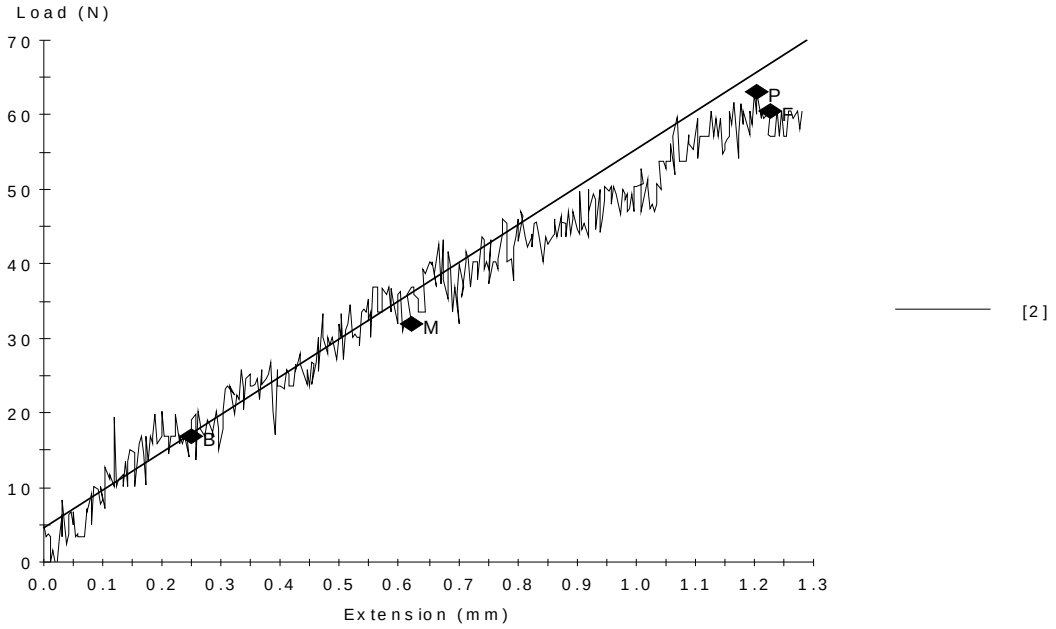
Sample ID: xue30%glass-1.mss
Specimen Number: 1
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.76	mm
Average Width	9.80	mm
Flexural Modulus	1371	MPa
Yield - Elongation	-0.11	mm
Yield - Strain	-0.11	%
Yield - Load	3	N
Yield - Stress	0.61	MPa
Peak - Elongation	1.49	mm
Peak - Strain	1.48	%
Peak - Load	91.1	N
Peak - Stress	19.56	MPa
Break - Elongation	****	mm
Break - Strain	****	%
Break - Load	****	N
Break - Stress	****	MPa

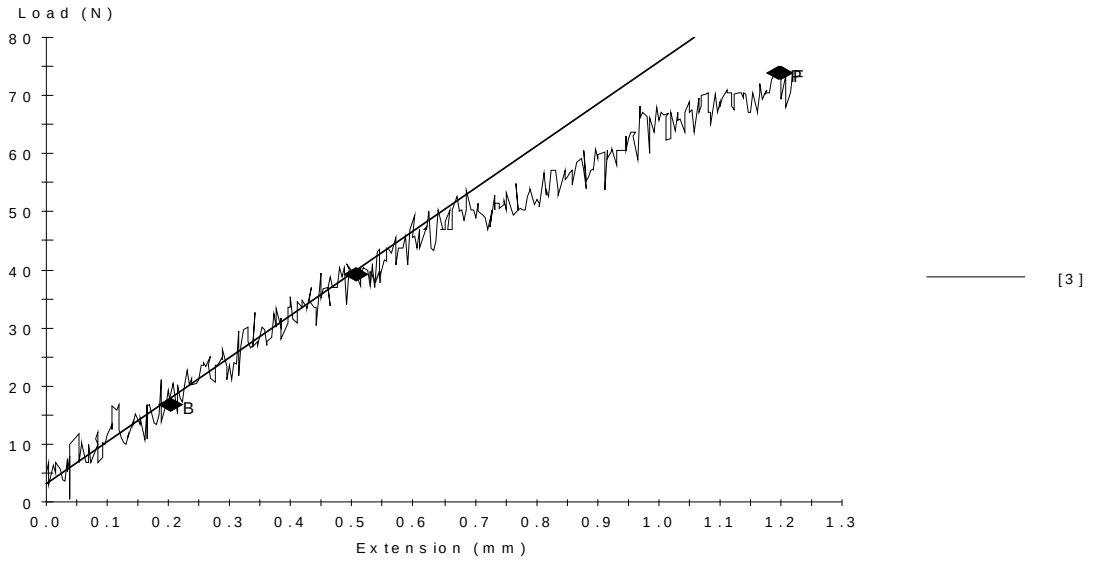
Sample ID: xue30%glass-2.mss
Specimen Number: 2
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.53	mm
Average Width	9.71	mm
Flexural Modulus	2028	MPa
Yield - Elongation	0.03	mm
Yield - Strain	0.02	%
Yield - Load	8	N
Yield - Stress	2.71	MPa
Peak - Elongation	1.21	mm
Peak - Strain	0.98	%
Peak - Load	63.1	N
Peak - Stress	20.41	MPa
Break - Elongation	1.23	mm
Break - Strain	0.99	%
Break - Load	60	N
Break - Stress	19.54	MPa

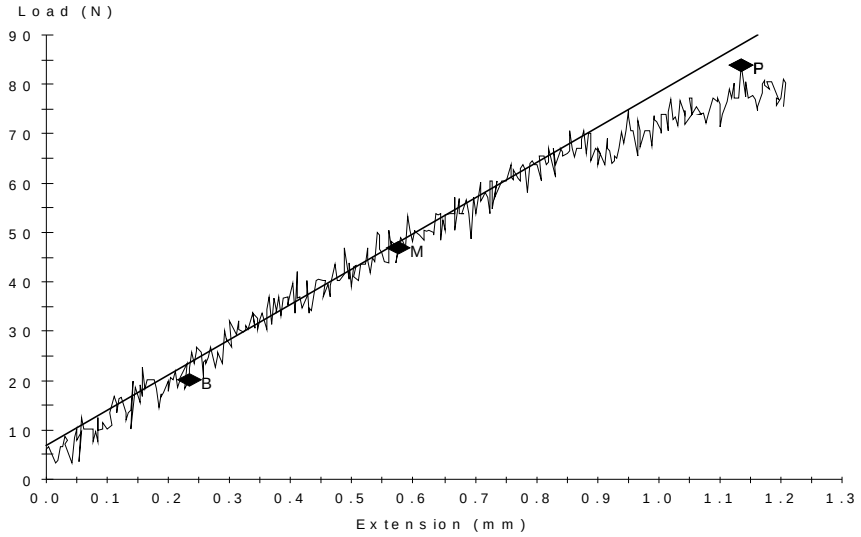
Sample ID: xue30%glass-3.mss
Specimen Number: 3
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	6.72	mm
Average Width	9.68	mm
Flexural Modulus	1619	MPa
Yield - Elongation	0.05	mm
Yield - Strain	0.05	%
Yield - Load	12	N
Yield - Stress	2.58	MPa
Peak - Elongation	1.20	mm
Peak - Strain	1.18	%
Peak - Load	73.9	N
Peak - Stress	16.20	MPa
Break - Elongation	1.20	mm
Break - Strain	1.18	%
Break - Load	74	N
Break - Stress	16.20	MPa

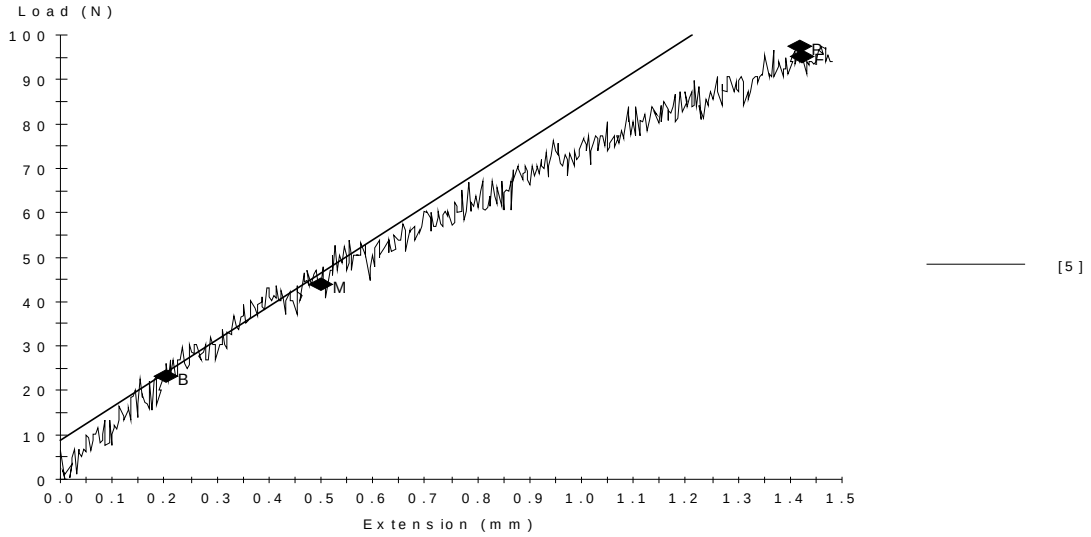
Sample ID: xue30%glass-4.mss
Specimen Number: 4
Tagged: False



Specimen Results:

Name	Value	Units
Average Thickness	5.94	mm
Average Width	9.63	mm
Flexural Modulus	2318	MPa
Yield - Elongation	0.06	mm
Yield - Strain	0.05	%
Yield - Load	13	N
Yield - Stress	3.55	MPa
Peak - Elongation	1.13	mm
Peak - Strain	0.99	%
Peak - Load	83.9	N
Peak - Stress	23.68	MPa
Break - Elongation	1.13	mm
Break - Strain	0.99	%
Break - Load	84	N
Break - Stress	23.68	MPa

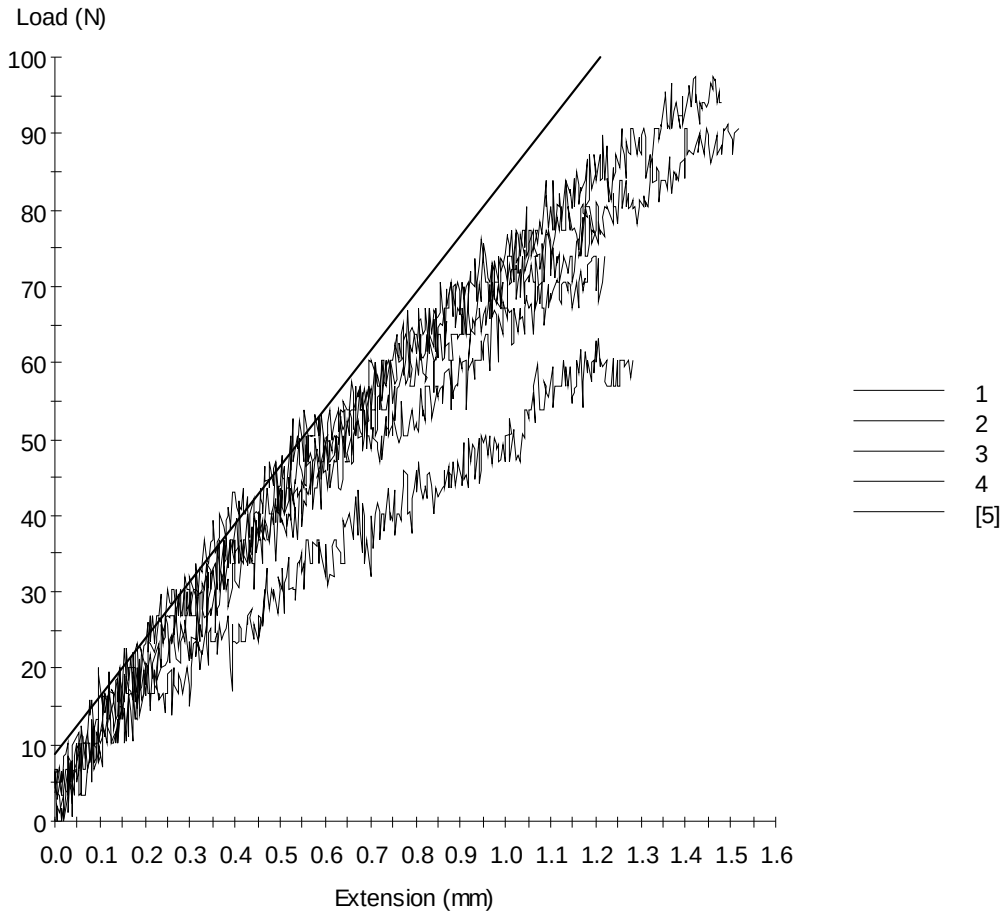
Sample ID: xue30%glass-5.mss
Specimen Number: 5
Tagged: False



Specimen Results:

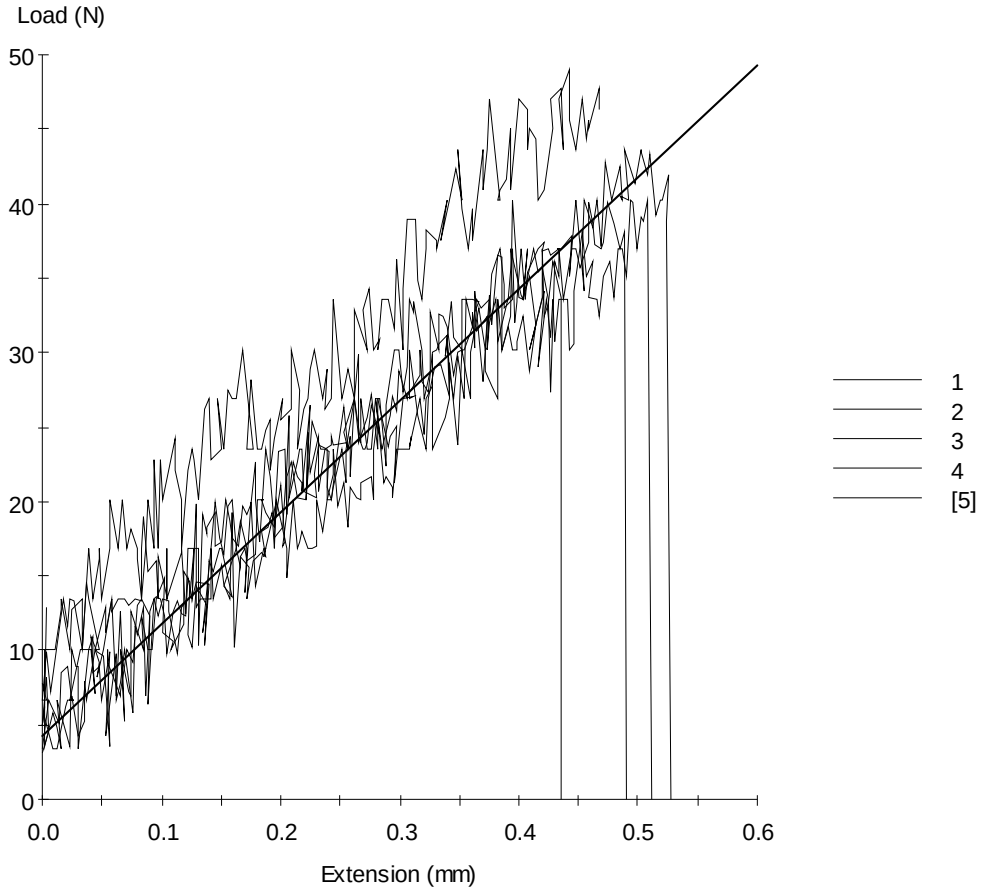
Name	Value	Units
Average Thickness	6.83	mm
Average Width	9.66	mm
Flexural Modulus	1600	MPa
Yield - Elongation	0.42	mm
Yield - Strain	0.42	%
Yield - Load	44	N
Yield - Stress	9.28	MPa
Peak - Elongation	1.42	mm
Peak - Strain	1.42	%
Peak - Load	97.4	N
Peak - Stress	20.71	MPa
Break - Elongation	1.42	mm
Break - Strain	1.42	%
Break - Load	95	N
Break - Stress	20.25	MPa

30% by Weight of Filler



Stress vs Strain Plot

35% by Weight of Filler



Stress vs Strain Plot