University of Southern Queensland
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COMPARATIVE PROPERTIES OF EPOXY/SAWDUST COMPOSITES WITH PALM OIL CURED BY MICROWAVE AND THERMAL TREATMENT

A dissertation submitted by

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Abstract

This project looks at the flexural and thermal properties of composites that have renewable resources as fillers and additives, there is also a comparison between different post curing techniques. The renewable resources that have been analysed are palm oil and sawdust and the post curing techniques are conventionally and with a microwave.

Increasing pressure from environmental groups and the government have encouraged companies to investigate using renewable resources in all areas of their industry. This project investigates the relationships which renewable resources produce as a result of different amounts and sizes of fillers and additives.

The three point loading test was used to measure the flexural properties, the Dynamic Mechanical Analysis (DMA) testing machine tested the thermal properties and the microscope was used to analyse the level of adhesion between fillers and epoxy.

The results indicated that the plasticizing effect of the palm oil reduced the flexural stress and flexural modulus of the samples, while the strain increased with increasing amounts of palm oil. The flexural stress and flexural strain decreased with the increasing size of the sawdust particles, although the size of the sawdust particles had a minimal effect on the flexural modulus. The amount of sawdust added marginally reduced the peak flexural stress of the samples, and the strain and flexural modulus was not affected by increasing amounts of sawdust. The amount and size of sawdust particles, as well as amount of palm oil does not affect the thermal properties of the epoxy composite. The only significant difference between samples is the affect the post curing technique: conventional post cured samples exhibited a higher glass transition temperature.

In terms of flexural and thermal properties, natural fillers and additives represent an alternative to traditional fillers and additives, although there is a large amount of study that can be done to further improve the results. This research provides the basis for future study into the manufacturing and use of renewable fillers and additives in composites.

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Nomenclature

CEEFC = Centre of Excellence in Engineering Fibre Composites

DMA = Dynamic Mechanical Analysis

MSDS = Material Safety Data Sheet

OH = Hydroxide

PO = Palm Oil

PPE = Personal Protective Equipment

SD = Sawdust

Tg = Glass Transition Temperature

USQ = University of Southern Queensland

1 Introduction

This chapter will outline the purpose of the research study, and the research objectives of the project. The purpose of this project is to research the effect sawdust (SD) and palm oil (PO) have on the flexural and thermal properties of epoxy composites. The project also compares the effectiveness of different post curing techniques.

1.1 Project Topic

Comparative properties of epoxy/sawdust composites with palm oil cured by microwave and thermal treatment.

1.2 Project Background

Due to environmental and economic advantages, research and commercial applications of composites from renewable resources have been increasing over the last decade (Mosiewicki, Borrajo & Aranguren 2005).

A major area of mechanical engineering is developing new composites and understanding how they interact with different fillers. Studies have analysed how different sizes and volumes of fillers interact in a polymer; and by measuring and comparing the composites mechanical properties, the effect of the composite constituents has been able to be accurately gauged. Previous studies have been concerned with the use of synthetic fillers in composites; however this study looks at using renewable resources as fillers for composite materials.

1.3 Research Aims

The aim of this project is to develop composites from sawdust and palm oil post cured by microwave and thermal treatment and to evaluate and compare their thermal and flexural properties. Findings will be analysed in detail in order to establish behavioural trends can be used for theoretical prediction of filler polymer behaviour.

The experimentation and analysis part of this project will develop composite samples from palm oil and sawdust which will be post cured conventionally and by microwave. The composite sample will then evaluate and compare their flexural and thermal properties. The parameters that will be compared and evaluated to the flexural and thermal properties include:

- Size of the sawdust particles;
- Percentage by weight of sawdust;
- Percentage by weight of palm oil; and
- Post curing treatment.

Findings will be analysed in detail in order to establish behavioural trends that can be used for theoretical prediction of filled polymer behaviour. Literature research will support the experimentation and analysis.

1.4 Objectives of the Research and Development

The Project Objectives are to:

- Understand the mechanisms and benefits of making the composites;
- Prepare composites and post cure them conventionally and using microwaves;
- Study the effects of the sawdust selection (size and weights) in the properties of the composites;
- Study the effect on the properties of the composites by adding different amounts of palm oil; and
- Compare the properties of the epoxy/sawdust composites with palm oil after post-curing them conventionally and by microwave.

1.5 Conclusion

This project aims to research the effect sawdust and palm oil have on the flexural and thermal properties of epoxy composites. Chapter 2 provides a literature review that reviews existing research and past studies into epoxy resins, its applications and the use of other fillers, and plasticizers in epoxy resins.

2 Literature Review

2.1 Introduction

The literature review will describe the engineering aspects of the project: epoxy resin chemistry, the epoxidation process, the advantages of using epoxy over other resins, the effect and chemical process of adding different fillers to the composite, and the effect that the filler and additive should have on the composite. The post curing process will be discussed in terms of its affect on a sample. Finally the testing process will also be described in detail to ensure that the reader fully understands what is being calculated.

2.2 Introduction to Composite Materials

A composite material is made by combining two or more materials to create a unique combination of properties (Beer, Johnston & DeWolf, 2002). Typically, composite materials are formed by reinforcing fibres in a matrix resin. The reinforcements can be fibres, particulates or whiskers, and the matrix material can be metals, plastics or ceramics. The versatility and amount of materials available allows engineers a spectrum of possible composites that can achieve any required combination of mechanical properties.

Fillers restrict the movement of the polymer chains in the composite material (Strong 2000; Seymour, 1975). Fillers are also used for the control of viscosity, reducing shrinkage and coefficient of thermal expansion, and for reducing the cost of the overall composite (Kulshreshthla & Vasile, 2002). Additives such as compatible solvents increase flexibility of polymers by permitting movement of the polymer chains. Non-volatile compatible solvents are called plasticizers since they promote segmental motion and reduce both Glass Transition Temperature (Tg) in accordance with the amount added. (Seymour, 1975)

2.3 Epoxy

2.3.1 Chemistry

This section will provide a brief explanation of the chemistry involved in epoxy polymerization. It is important to understand how the epoxy binds together and the strength of the epoxy resin. This will be useful when explaining the process of adding different fillers and additives. A greater understanding of epoxy will ensure a more accurate interpretation of the results of the project.

Strong (2000) characterises an epoxy resin by the presence of the three-membered ring epoxy group. The groups are not typically part of the polymer repeating unit but are attached to the ends of a polymer, as shown in Figure 1. For cross linking to occur, at least two epoxy groups must be on each polymer molecule. A molecule with two epoxy groups is defined as a diepoxy.

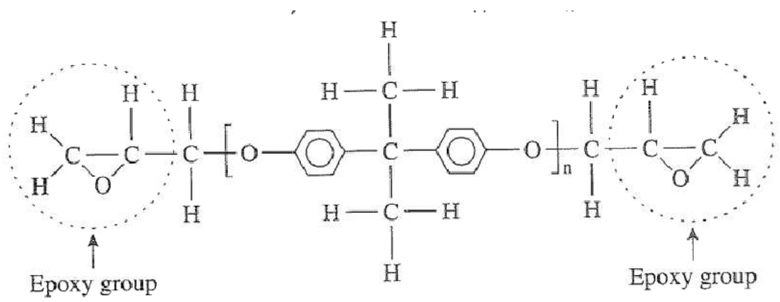

Figure 1: Typical epoxy Resin (Strong 2000)

The cross linking of an epoxy resin is initiated by the opening of the epoxy ring by a reactive group on the end of another molecule. Molecules that have reactive groups and are used to cure epoxies are called hardeners. The reaction is started merely by mixing the epoxy with the hardener (Strong, 2000). The hardener consists of polyamine monomers, known as diamine. Diamine is a compound with two amino groups (Hollaway 1994). There are two bonds which occur when the epoxy resin is initiated, one bond occurs with a carbon atom that was in the epoxy ring, this bond creates an hydroxide (OH) group which is important in some of the properties of the epoxy resin, such as bondability. The second bond is between the oxygen of the epoxy ring and the hydrogen that was on the amine. The bond between the amine and the carbon is the main component of cross linking (the epoxy reaction can be seen in Figure 2). The amine molecule usually has another amine group on the opposite end of the molecule that can react with a second epoxy molecule. The two epoxy molecules would therefore be joined together by the amine molecule (Strong 2000; Hollaway 1994). This is, of course, cross linking.

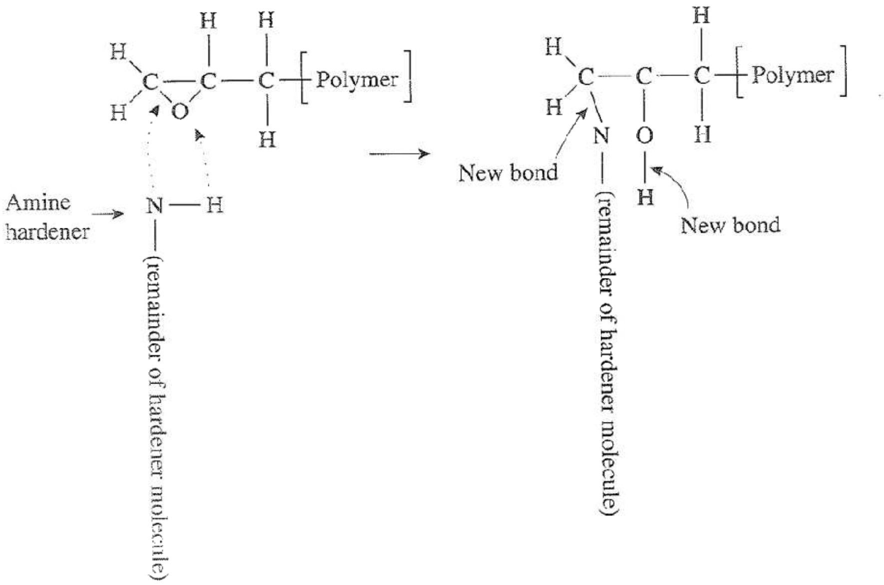

Figure 2: An epoxy reaction (Strong 2000)

2.3.2 Advantages

There are many advantages with using epoxy resins: epoxy resins adhere well to a wide variety of fillers, reinforcing agents and substrates. Epoxidation does not release any volatiles or water, so shrinkage is less than that for phenolic or polyester resins (Gruenwald 1993). The applications of epoxy resins include structural parts, potting, encapsulating compounds, tooling compounds, moulding powders and adhesives (Strong 2000; Penn & Chiao 1969).

2.4 Plasticizer

This section will focus on the purpose of a plasticizer in a composite material, the affect of the plasticizer on the epoxy structure, and how the flexural and thermal properties are influenced by the addition of a plasticizer.

The purpose of a plasticizer is to convert an otherwise hard and rigid plastic to a flexible or semi flexible tough part. The incorporation of a plasticizer, which in most cases is a low viscous liquid, is easier to accomplish and much more flexible than formulating copolymers (Seymour 1975; Strong 2000).

When the plasticizer is added to the polymer structure, it does not dissolve in the plastic material, rather, the plasticizer will causes the polymer structure to swell. This swelling permits increased chain movement, especially locally, which makes the plastic material softer and more flexible. This greater chain movement means that the material changes from the hard and brittle state to the more flexible and soft state. This process is called plasticization. (Gruenwald 1993; Seymour 1975; Strong 2000)

This increased flexibility reduces flexural properties and also lowers the Tg of the plastic material: the greater flexibility also means that the plastic material becomes easier to process and usually melts at a lower temperature (Strong 2000).

The amount of plasticizer that is added to the plastic material determines the properties of the plastic. If the plasticizer concentration is too low or the plasticizer is poorly distributed, the plastic material will not be flexible enough. If too much plasticizer is added, the plastic material will have general chain movement (as opposed to local chain movement) and the strength of the material will be lost. (Strong, 2000)

2.4.1 Vegetable and Palm oil

As the plasticizer in the composite is palm oil, this section will discuss the origin of the palm oil and the main constituents of the palm oil.

Palm oil is an edible plant oil derived from the pulp of the fruit of palm trees. Vegetable fats and oils are lipid materials extracted from plants and are composed of triglycerides. Vegetable oils (such as palm oil) present a likely candidate for conversion in polymeric materials because of their molecular structure.

2.4.2 Triglycerides

When selecting liquid plasticizers that possess many of the typical characteristics of solvents their chemistry must be taken into account to achieve compatibility with the polymer (Gruenwald 1993). As the main constituent of the palm oil is triglycerides, this section will briefly outline the structure of a triglyceride and their previous uses.

Triglycerides are the main constituents of vegetable oils and animal fats. A triglyceride is a chemical compound formed from one molecule of glycerol and three fatty acids (Zamora 2005; William & Hillmyer, 2008), shown in Figure 3.

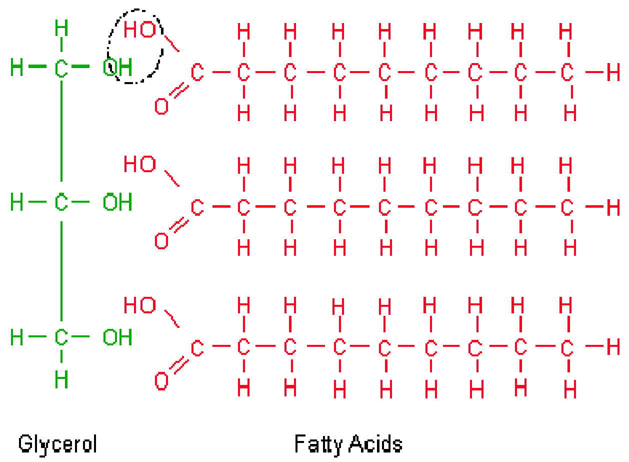

Figure 3: Triglyceride compound (Gregory, 2006)

Triglyceride oils have been used in the preparation of polymeric materials such as paint bases since the 19th century. One of the prohibiting factors and the reason there are currently few commercial examples of plant derived plastics, is because they have not been price competitive with plastics derived from fossil fuels (William & Hillmyer, 2008).

2.5 Fillers

Fillers play an important role in epoxy composites, it is important to understand how they interact in the composite and how the fillers affect the composites flexural and thermal properties (Kulshreshthla & Vasile, 2002).

The effect on mechanical properties of adding reasonably low concentrations of fillers to the plastic is generally not substantial, although some minor increases in stiffness or reduced strength and reduced elongation is common. Fillers are generally added to reduce the cost of the total material. In many cases the changes in mechanical properties due to the addition of fillers does not impact on its application (Kulshreshthla & Vasile, 2002; Xanthos 2005; Strong 2000).

The modulus of elasticity of plastics increases when fillers are used, however, tensile and impact properties are in most cases reduced. The loading of fillers in plastics is dependent on the amount, type, shape and the size of the filler particles. (Kulshreshthla & Vasile 2002; Gruenwald, 1993)

2.5.1 Sawdust

As the filler in the composite is sawdust, this section will discuss how the sawdust affects the composite and how it reacts when added in epoxy.

The mechanical behaviour of particle filled materials depends not only on the individual properties of the two components and their concentrations, but also on the size, shape and state of agglomeration of the minor component, and on the degree of adhesion between the filler and the matrix. (Xanthos, 2005; Clemons & Caulfield, 2005A; Mosiewicki, Borrajo & Aranguren 2005)

Sawdust is an inexpensive filler that reduces the overall cost of polymer composites. Although the sawdust results in loss of some properties; (ultimate strength, elongation and water sorption), it may be counteracted by a gain in other properties (e.g. young’s modulus, reduced weight, and reduced wear). The main advantages of sawdust are low cost, low density and resistance to breakage during processing (Clemons & Caulfield, 2005A). The main drawbacks of sawdust are its relatively low degradation temperature and hygroscopicity, which weaken its adhesion with the hydrophobic polymers. The polar nature of wood based fillers adversely affects the dispersion of polar materials in a non polar matrix. (Clemons & Caulfield, 2005A; Marcovich, Reboredo, & Aranguren 1996)

Due to different species, a natural variability within species and the differences in climates and growing seasons, natural fiber dimensions as well as physical and mechanical performance can be highly variable (Clemons & Caulfield, 2005A).

2.5.2 Wood Anatomy

It is important to discuss how wood anatomy reacts in the epoxy and what constituents in the wood anatomy affect the adhesion between the sawdust and the epoxy resin.

As with most natural materials, the anatomy of wood is complex. Wood is porous, fibrous and anisotropic (Marcovich et al 1996; Clemons & Caulfield, 2005A). Wood is often subdivided into two broad classes, namely softwoods and hardwoods, which are classified by botanical and anatomical features rather than the hardness of the wood. (Clemons & Caulfield, 2005A)

Wood is primarily composed of hollow, elongated, spindle-shaped cells (called tracheids or fibers) that are arranged parallel to each other along the trunk of the tree. When wood is reduced to sawdust, the resulting particles are actually bundles of wood fibers rather than individual fibers and can contain lesser amounts of other features such as ray cells and vessel elements (Clemons & Caulfield, 2005A). A schematic of softwood and hardwood can be seen in Figure 4 and Figure 5 respectively.

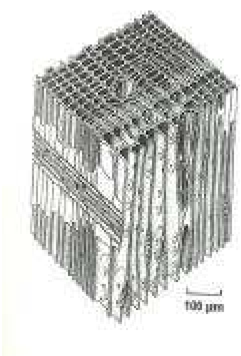

Figure 4: Schematic of a softwood (Clemons & Caulfield, 2005A)

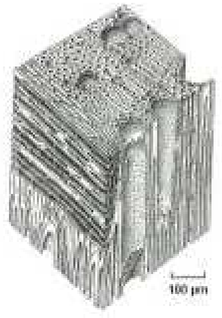

Figure 5: Schematic of a hardwood (Clemons & Caulfield, 2005A)

2.5.3 Chemical Components

Wood is a complex, three-dimensional polymer composite primarily made of cellulose, hemicelluloses and lignin. These three hydroxyl-containing polymers are distributed throughout the cell wall (Petterson, 1984).

The lignin, hemicelluloses, and pectin's collectively function as the matrix and adhesive, helping to hold together the cellulosic framework structure of the natural composite fiber (Clemons & Caulfield, 2005A). Refer to Table 1 for the chemical composition of selected woods.

Pectin's are complex polysaccharides, the main chains of which consist of a modified polymer of glucuronic acid and residues of rhamnose. Pectin's are important in non-wood fibers, especially bast fibers. (Clemons & Caulfield, 2005A)

Cellulose shows the least variation in chemical structure. It is a highly crystalline, linear polymer of anyhydroglucose units with a degree of polymerization of around 10,000. It is the main component providing the wood's strength and structural stability. (Petterson, 1984)

Lingin is an amorphous, cross linked polymer network consisting of an irregular array of variously bonded hydroxyl- and methoxy-substituted phenylpropane units. (Petterson, 1984)

Species	Cellulose	Hemicellulose	Lignin
Ponderosa Pink	41	27	26
Loblolly Pine	45	23	27
Incense Cedar	37	19	34
Red Maple	47	30	21
White Oak	47	20	27
Southern Red Oak	42	27	25

Table 1: Approximate chemical compositions (%) of selected woods. (Petterson, 1984)

Table 1 illustrates that different species of wood contain different chemical compositions; the strength of binding between wood particles and epoxy would vary between different species of wood.

2.5.4 Moisture

The moisture content in the sawdust greatly affects the polymerization process and so this section will outline the effect the moisture in the sawdust will have on the composites.

Moisture in the sawdust interferes with and reduces hydrogen bonding between cell wall polymers during curing, hygroscopicity can cause problems both in composite fabrication and the moisture can also plasticize the polymer, altering the composite's mechanical performance (Clemons & Caulfield, 2005B)

2.5.5 Durability

This section will discuss the durability of the sawdust in the epoxy composite, how it reacts when UV radiation is exposed to the composite and how the chemical components of the sawdust degrades naturally.

Natural fibers (such as sawdust) undergo photochemical degradation when exposed to UV radiation. They are degraded biologically because organisms recognize the chemical constituents in the cell wall and can hydrolyze them into digestible units using specific enzyme systems (Clemons & Caulfield, 2005A). Also, if the moisture content of the sawdust in the composite exceeds the fiber saturation point (approximately 30% moisture), decay fungi can begin to attack the wood component leading to weight loss and significant reduction in mechanical performance (Clemons & Caulfield, 2005B).

Though the degradability of natural fibers can be a disadvantage in durable applications where composites are exposed to harsh environments, it can also be an advantage when degradability is desired (Clemons & Caulfield, 2005A).

2.6 Post Curing

Curing is a process in which the linear resins, in the presence of a proper hardener or curing agent, are converted into a three-dimensional thermoset network. In this process, resin and hardener are mixed together. Once this mixing has occurred, curing begins and proceeds at a rate dependent upon each other.

Post curing is additional heat applied to an epoxy to help it reach its full physical characteristics. When the epoxy initially cures, the strength of the cross linking is limited. By post curing the epoxy the amount of cross linking is increased and the strength of the epoxy is also enhanced (Strong 2000). There are two methods of post curing that are used for epoxies, being by the microwave and conventionally by an oven.

2.6.1 Conventional Post Curing

When appropriate sites for reactions exist, cross links are normally formed by heating the polymer materials, a process called curing. The heating provided by conventionally curing provides sufficient energy to excite the molecules and cause them to move close enough together that attractions between the bonding sites can occur, causing the bonds to form (Strong 2000).

Conventional post curing maintains the polymer materials at an elevated temperature for an extended period, providing enough time and energy to post cure the polymer.

2.6.2 Microwave Post Curing

High-energy microwaves are another radiation source used in polymer processing. Microwaves, much like normal heating, supply energy for the traditional cross linking to occur. The use of microwaves in this application is similar to their use in cooking, where microwaves can substitute thermal heating. All of the normal components for traditional thermal curing (peroxides, accelerators, and so on) are present for microwave curing except, of course, the heat. Post curing in a microwave is much more rapid than conventional curing. (Strong, 2000)

2.7 Tests

Standard tests are used to find and compare certain mechanical properties of different composites. It is ideal to prepare a particular number of specimens in order to increase reliability and to apply a statistical approach to the test data (Seymour 1975). This project measures and compares the flexural and thermal properties of different samples.

2.7.1 Flexural Tests

The three point loading test is used to measure the flexural properties of the composites. The test is achieved by applying the force to the specimen at three points (see Figure 6). The central loading point being equidistant from the outer two supporting points. The specimen sits on the outer supporting rods and the force is applied through the central loading rod, which has both a force transducer and some form of displacement measuring device attached. (Brown, 2002)

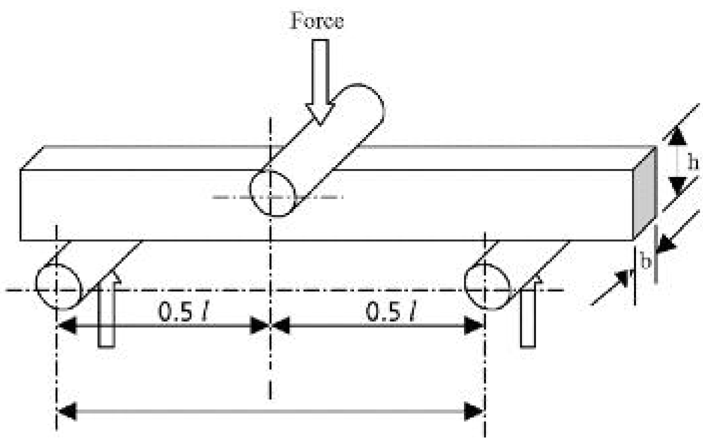

Figure 6: Three point loading test (Brown, 2002)

The three point loading test was used to find the Peak Load (N), Strain at Peak and Strain at Break. With this data and the size parameters, the software package calculated the Peak Flexural Stress (MPa), and Flexural Modulus (MPa).

The stress and strain are calculated on the maximum outer fibre with the stress calculations only being valid up to a maximum fibre strain of 5%. In principle the same parameters are measured as those in a tensile test because plastics are seldom completely isotropic through the thickness. (Brown, 2002)

Peak Flexural Stress

The peak flexural stress of a material is the peak force exerted per unit area.

Peak Flexural Stress:

$$\sigma_f = \frac{3Fl}{2bh^2} \tag{1}$$

Where:

σ_f = Flexural stress (N mm^2)

F = Force (N)

l = Support span – the length of the beam between the centres of the two outer supporting rods (mm)

b = The width of the beam (mm)

h = The thickness of the beam (mm)

Flexural Strain

Strain is defined as the deformation of the member per unit length (Beer, Johnston & DeWolf 2002).

Flexural Strain:

$$\varepsilon_f = \frac{3hs}{l^2} \tag{2}$$

Where:

εf = Flexural strain

h = The thickness of the beam (mm)

s = Deflection of the specimen at mid span (mm)

l = Support span – the length of the beam between the centres of the two outer supporting rods (mm)

Flexural Modulus

The Flexural Modulus is the ratio of stress to strain in flexural deformation, or the tendency for a material to bend. It is determined from the slope of a stress-strain curve produced by a flexural test, and uses units of force per area. It is an intensive property. (Hodgkinson, 2000)

Flexural Modulus:

$$E_f = \frac{l^3}{4bh^3} slope \tag{3}$$

Where:

l = Support span – the length of the beam between the centres of the two outer supporting rods (mm)

b = The width of the beam (mm)

h = The thickness of the beam (mm)

slope = Gradient of straight line portion of load deflection curve

The *slope* of Sample 54 is illustrated in red in Figure 7.

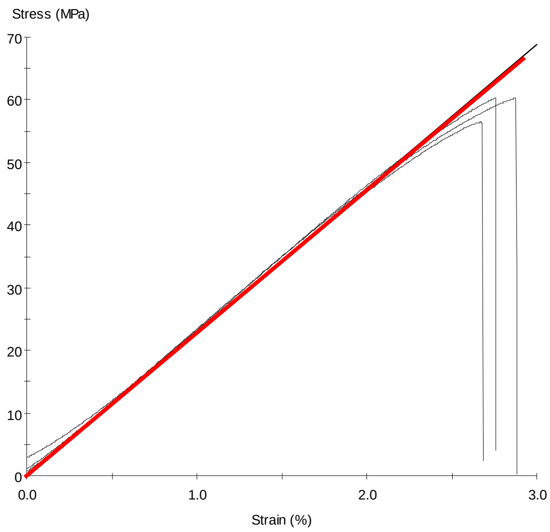

Figure 7: Load Defection Curve: Determining the Modulus of Elasticity of Sample 54

2.7.2 Dynamic Mechanical Analysis

There is a strong dependence on temperature and rate of deformation of the properties of polymers compared to those of other materials such as metals. This strong dependence of properties on temperature and on how fast the material is deformed (time scale) is a result of the viscoelastic nature of polymers. Viscoelasticity implies behaviour similar to both viscous liquids in which the rate of deformation is proportional to the applied force and to purely elastic solids in which the deformation is proportional to the applied force. (Nelsen & Landel, 1994)

Dynamic Mechanical Analysis (DMA) provides more information about a material than other tests. Dynamic tests over a wide temperature and frequency range are especially sensitive to the chemical and physical structure of plastics. DMA measure the response of a material to a sinusoidal or other periodic stress. Since the stress and strain are generally not in phase, two quantities can be determined: a modulus and a phase angle or a damping term.

The outputs obtained from performing DMA are storage modulus and damping coefficient (a DMA result can be seen in Figure 8).

Tan δ is a damping term, a measure of the ratio of energy dissipated as heat to the maximum energy stored in the material during one cycle of oscillation. The peak of Tan δ exhibits the glass transition temperature (Tg). The Tan δ is indicated as the blue line in Figure 8.

Storage modulus (MPa) is the ratio of stress to strain under vibratory conditions (Meyers and Chawla, 1999). The storage modulus is indicated as the purple line in Figure 8. For any instant in temperature, the storage modulus is referred to as the modulus of elasticity.

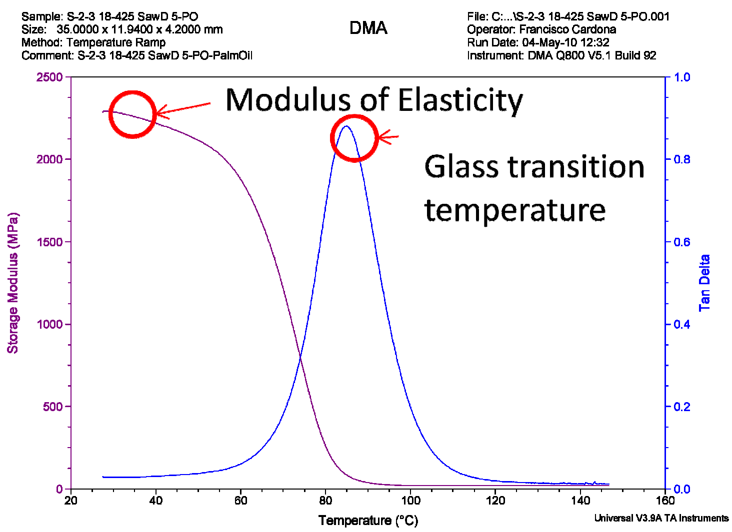

Figure 8: Results from DMA testing

2.8 Microscope

Microscope analysis provides the ability to view the specimen up close and supplies information about the level of adhesion achieved between epoxy and sawdust. The Olympus BX41M is used to complete the microscope analysis.

2.9 Safety

Safety and cleanliness are of utmost importance in maintaining a good workplace and in improving the efficiency of the facility. (Strong, 2000)

One of the major problems with manufacturing resins is the potential toxicity of the chemicals involved in these processes. Liquid chemicals must be handled carefully, with full understanding of the potential dangers. To ensure this, Material Safety Data Sheets (MSDS) should be consulted before any use of the materials takes place. MSDS sheets are sent with the chemicals and must be stored in convenient locations so that any person handling the chemical can inspect them. (Strong, 2000)

Hollaway (1994) made some simple rules when making composites in a facility:

Do:

- Store and handle raw materials in accordance with the supplier’s instructions and legal requirements;
- Be aware of health and safety hazards associated with the process;
- Ensure that catalyst and accelerators are never stored together, or with resin;
- Always have an inert, absorbent material available in case of spillage;
- Provide and use the appropriate protective clothing and cleaning materials;
- Protect against the toxic and harmful effects of the raw materials by providing extraction and dust control;
- Ensure adequate ventilation and fume control;
- Ensure good housekeeping;
- Ensure that if respiratory protective equipment is used, that it is suitable for the purpose; and
- Use materials with low emissions wherever possible.

Never:

- Directly mix catalyst and accelerator;
- Smoke in working areas;
- Use sawdust and combustible materials to absorb spillages;
- Use solvents for cleaning hands; and
- Allow waste to accumulate.

2.10 Environment

A major consideration in plastic manufacturing is the environmental aspects, as understanding the environmental impact of any project is fundamental by today's standards. Strong (2000) describes the impact of plastics in everyday life. Plastics have become common materials in everyday life and along with other materials such as paper are often used in disposable applications that are a major contributor to solid waste. While the use of plastics in disposables is still much less than paper based products, the wide use and growth of plastics in these applications elevates concern about plastics as a serious pollution problem. When not disposed of properly, plastic materials are widely seen and often criticized, in part because of their long life and obviousness. The disposal problem is not simply technical, but includes significant social, economic, and political aspects. All of these aspects should be brought together to work on finding the most intelligent method of using and disposing of plastics as well as other materials (Strong 2000).

2.11 Work of Others

The work of others provides information that is relevant to this project. This section includes information from studies around the world.

Mosiewicki, Borrajo & Aranguren (2005) provided a study titled 'Mechanical properties of woodflour/linseed oil resin composites'. Several important statements they made were:

- The wood particles have high strength and modulus, so they can impart better mechanical properties to this polymer in order to obtain a composite with better properties than those of the unfilled material. However, increasing the composite fiber weight fraction may produce an increase in the void volume fraction, which affects the physical and mechanical properties of the composites.

O’Donnell, Dweib and Wool (2003) provided a study titled ‘Natural fiber composites with plant oil-based resin’. An important point made was that:

- The natural fibers exhibit many advantageous properties; they are a low-density material yielding relatively light weight composites with high specific properties.

Marcovich et al (1996) provided a study titled ‘Composites from sawdust and unsaturated polyester’. Several important points that were made were that:

- Fillers are added to polymer matrices in order to improve thermal and mechanical properties;
- A practical interest in this subject has arisen mainly because of economics originated from the addition of mineral (inorganic) fillers to known polymers, increasingly to enlarge their potential and actual applications; and
- Wood fiber show very good mechanical properties (tensile strength between 0.5 and 1.5 GPa and Young’s modulus between 10 and 80 GPa). Moreover, compared to inorganic fillers, organic materials impart added benefits such as weight reduction, a highly reduced wear of the processing machinery, and a relative reactive surface.

3 Research Design and Methodology

This chapter of the report will state and justify methods that were undertaken to complete the project. This section will analyse all steps that were taken from obtaining the ingredient, to making the specimen and extracting the data.

3.1 Obtaining Ingredients

Sawdust was obtained free of charge from the Toowoomba Timber Mill on North Street, Toowoomba, Queensland. The sawdust used was Cyprus pine, which is commonly used as floorboards in houses. The sawdust was sieved at the Centre of Excellence in Engineering Fibre Composites (CEEFC) into three sizes of <425µm, 425 < 600µm and 600 < 1180µm.

Sawdust acts as a filler in the epoxy composite. The sawdust was dried in an oven at 85^{o}C for 4 hours. As moisture accelerates the epoxidation process and can create defective samples, as explained in Chapter 2, it is important that the sawdust has minimal moisture content. Due to the polar nature of sawdust, it is beneficial to the non-polar epoxy composite that the sawdust is as dry as possible to bind to the epoxy resin. Although, in a practical application this is often quite difficult to control as sawdust can absorb moisture in the air.

The palm oil is commercially available. Palm oil acts as a plasticizer in the epoxy composite, a plasticizer is a material which when added to another material makes it flexible, resilient and easier to handle. Plasticizers improve toughness by reducing the brittleness of the composite (Plasticisers Information Centre, 2010), as explained in Chapter 2.

The University of Southern Queensland (USQ) purchased the epoxy and hardener from ATL Composite at $58.81 for 4kg and $29.87 for 1kg. Kinetix R246TX is the epoxy used in this project and is a solvent free, thixotropic epoxy resin specifically formulated with H160 hardener to cure at room temperature. The thixotropic nature of Kinetix R246TX reduces vertical drainage when high resin contents are employed in heavy laminates, making it suitable for fibre composite boat construction. The R246TX has a 1:4 hardener to resin mix ratio. (R246TX thixotropic, 2007)

3.2 Mixing

The samples were mixed in plastic containers. All samples contained 25g hardener and 100g epoxy (satisfying the 1:4 hardener to epoxy ratio). The appropriate volume of palm oil was added into the solution. The solution was then stirred with a spoon until the solution in the plastic container appeared homogenous. The appropriate amount of sawdust was then added. The sample was stirred until the sawdust was appropriately dispersed.

Appendix B contains the tables associated with the different weights and sizes of sawdust and palm oil used in the different samples, as well as the method of post curing.

The quality controls that were implemented to ensure satisfactory samples included scales (that ensured the accurate weight). The scales were tared before each ingredient was added to ensure correct weight. The solution was stirred for a further 20 seconds after it appeared homogenous, to ensure the proper dispersion of sawdust.

3.3 Curing

The curing of the samples was performed in two stages: initial and post curing. Once the samples were made, initial curing started at room temperature for a period greater than 24 hours. This gave enough time for the exothermic reaction to occur.

The samples were then post cured in the oven or the microwave for set times and temperature. Times and temperature for the oven and microwave are shown in Table 2 and Table 3, respectively.

Oven	
Time (hours)	**Temperature (^oC)**
16	**40**
16	**50**
8	**60**

Table 2: Times and temperatures for curing in oven

The samples remained in the oven for the entire set time of the curing.

The oven that was used to post cure the samples can be seen in Figure 9.

Figure 9: Oven that was used to post cure the samples

Microwave (Power: 160 W)	
Time (minutes)	**Temperature (^oC)**
6	**40**
8	**50**
10	**60**

Table 3: Times and temperatures for curing in microwave

The microwave curing was achieved in stages to ensure that the sample had achieved the specified temperature. After each step of the microwave curing, the temperature of the sample was measured with an infrared thermocouple (as shown in Figure 10). If the sample was not at the required temperature of the stage, the sample was placed back in the microwave until the correct temperature was achieved. Upon achieving the required stage temperature, samples were then allowed to cool to room temperature before the next stage began. A picture of the microwave can be seen in Figure 11.

Figure 10: Measuring the temperature of the epoxy sample with an infrared thermocouple

Figure 11: Microwave that was used to post cure the samples

3.4 Sample Shaping

The samples then went to the workshop to be cut and polished for testing. The specimens were made using the wet saw and rotating sander.

The bottom of the samples was polished to ensure a flat surface. The samples were then securely placed in position in the wet saw. The wet saw cut the sample into four specimens. The illustration in Figure 12 shows the locations of the cuts the wet saw made. The flexural tests required specimens to fit dimensions of 10mm x 16mm, and the DMA tests required specimens to fit dimensions of 4mm x 10mm x 60mm. There were three flexural tests and one DMA test. Figure 13 shows the final dimensions of the two types of specimens.

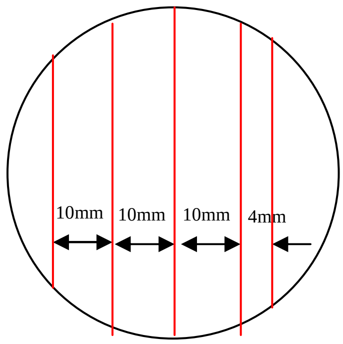

Figure 12: Configurations of each sample. Red mark defines the cuts that were made with the wet saw

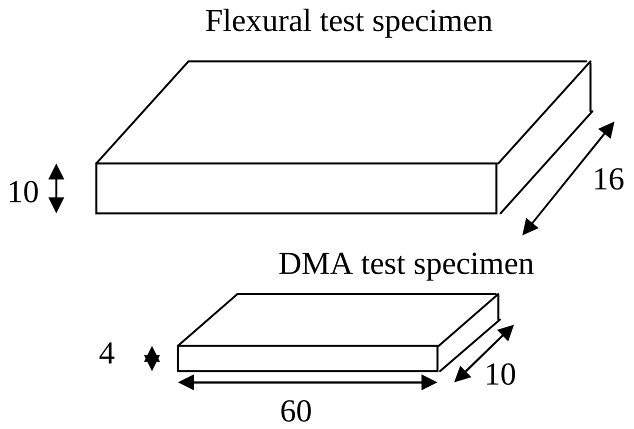

Figure 13: Dimensions necessary for the flexural tests and the DMA tests

The specimens were then polished again to ensure a smooth rectangular shape. A set of finished specimens are depicted in Figure 14.

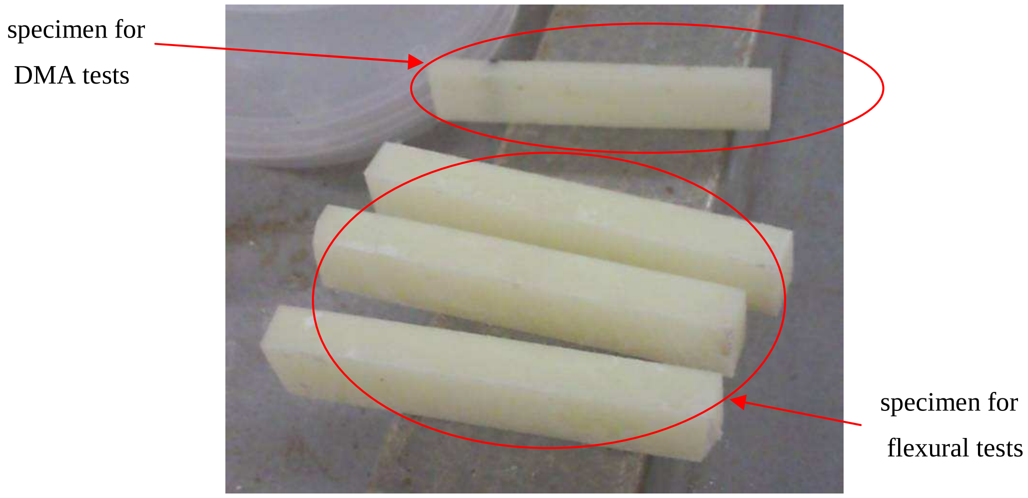

Figure 14: Pre made specimens

3.5 Defects

Throughout the manufacturing stages, each specimen was continually inspected for any defects. Known defects that did occur are physical (improperly cut), and chemical (incorrect amounts of a certain chemical or filler).

While producing the samples, there were several known defects that were controllable; Sample 35 had to be remade because it's original sample had an incorrect ratio of mixture (the sample did not contain enough hardener), and Sample 27 was incorrectly cut (was incorrectly positioned in the wet saw and cut incorrectly sized test specimens). As a result of these defects, Sample 27 and Sample 35 were remade. When manufacturing the first set of samples, moisture was not adequately removed from the sawdust, and this accelerated the epoxidation process, Figure 15 illustrates the effect of epoxy/sawdust samples which have not had their moisture adequately removed.

Figure 15: Accelerated epoxidation of several samples

Several samples exhibited small air bubbles (see Figure 16). This is hard to manage as you cannot see air bubbles while manufacturing the samples.

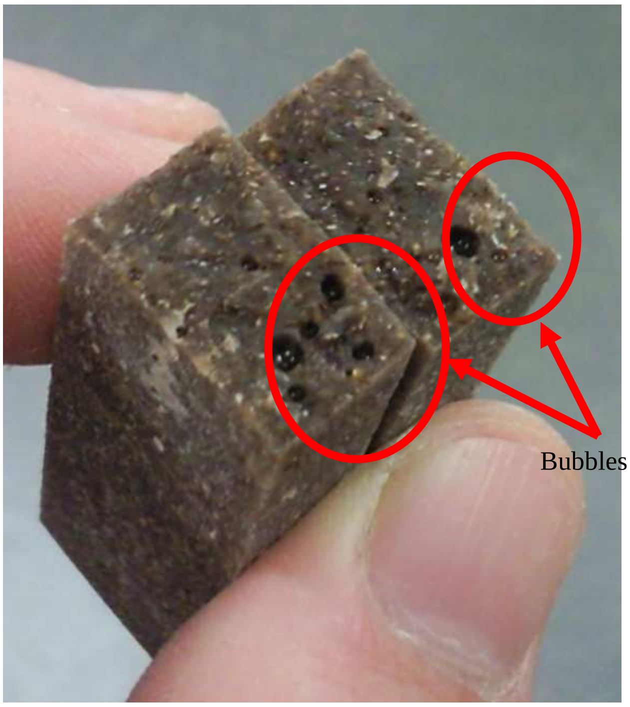

Figure 16: Bubbles found in several epoxy composites

3.6 Testing

The testing of the specimens was conducted in two stages: flexural testing and DMA testing. Both the three point bending test and the DMA testing machine are located in the CEEFC.

3.6.1 Flexural Testing

The flexural tests were undertaken by the 10kN MTS Machine, see Figure 17. TESTWORK 4 is the software package used to control the testing.

Figure 17: 10kN MTS Machine

The flexural test is a three point bending test that consists of two cross beams with a span of 64mm that held the specimen into position, a middle crossbeam lowered at a rate of 2mm/min, TESTWORK 4 records the output load. With the output load and the size parameters, the software can calculate the flexural stress, strain and modulus of elasticity. Refer to Appendix C for the full set of data output from flexural tests.

3.6.2 DMA Testing

DMA testing is used to characterize the viscoelastic behaviour of a material at a known temperature range by measuring storage modulus and glass transition temperature.

The DMA machine used throughout the testing is a TA instruments Q800, seen in Figure 18. Tests were performed using the dual cantilever mode with a temperature change of 3^{o}C/min with a fixed frequency of 1Hz. The sample was mounted into position and secured at both ends and flexed in the middle (seen in Figure 18). The test was then started and the mechanical properties of the specimen were recorded. Refer to Appendix D for the full set of data output from DMA.

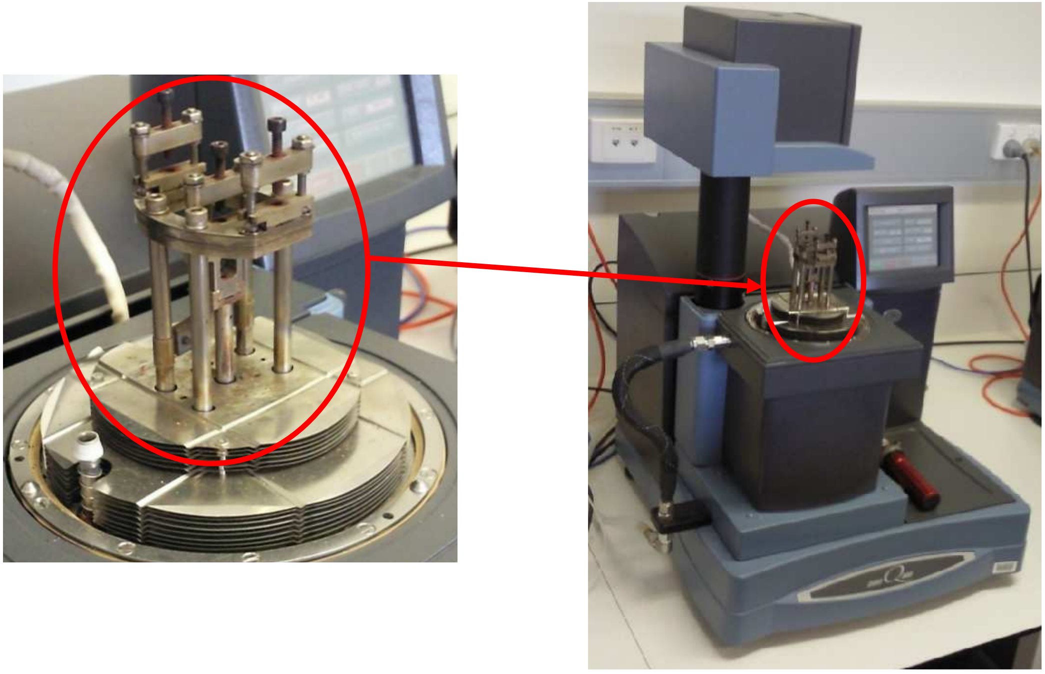

Figure 18: Q800 DMA Testing Machine

3.6.3 Optical Microscope

Samples were examined with an Olympus BX41M optical microscope, shown in Figure 19. The microscope has a magnification range from 50X to 200X. The sawdust-matrix interface was examined to determine the level of adhesion achieved.

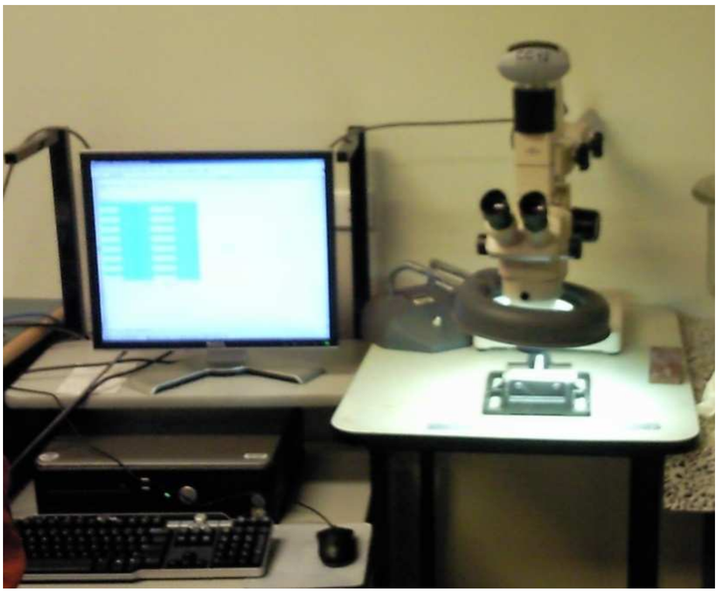

Figure 19: Olympus BX41M Optical Microscope

3.7 Resource Analysis

All required resources for the successful completion of this project are available for use at the CEEFC. The CEEFC is a commercial research centre with ties to USQ and therefore the facilities are more than satisfactory for the successful completion of this project.

4 Results and Discussion

4.1 Introduction

This chapter analyses and discusses the results obtained from the flexural, DMA and microscopic testing which was outlined in Chapter 3. The results will commence with the flexural results, and will provide a full analysis of the relationships between flexural stress, maximum flexural strain and flexural modulus and the size and percentage by weight of sawdust and palm oil. Refer to Appendix C for the tables of results and data obtained during flexural testing.

The analysis will then continue with the DMA results, and will provide an analysis of the relationships between the glass transition temperature, and modulus of elasticity and the size and percentage by weight of sawdust and palm oil. Refer to Appendix D for the tables of results and data obtained during data.

The investigation will then conclude with the microscope analysis.

4.2 Flexural Results

4.2.1 Relationship between amount of Palm Oil (wt%) and Flexural Stress

This section compares the flexural stresses of different sized SD with varying percentages of weight of PO. This section will investigate the relationship between flexural stress and the size of the sawdust particles and between the flexural stress and the amount of PO added in the sample. The flexural stress (MPa) of samples containing 15 wt% SD post cured in a microwave is shown in Figure 20. The flexural stress of samples with 5 wt% SD, 10 wt% SD and 20 wt% SD exhibit a similar pattern to that of 15 wt% SD.

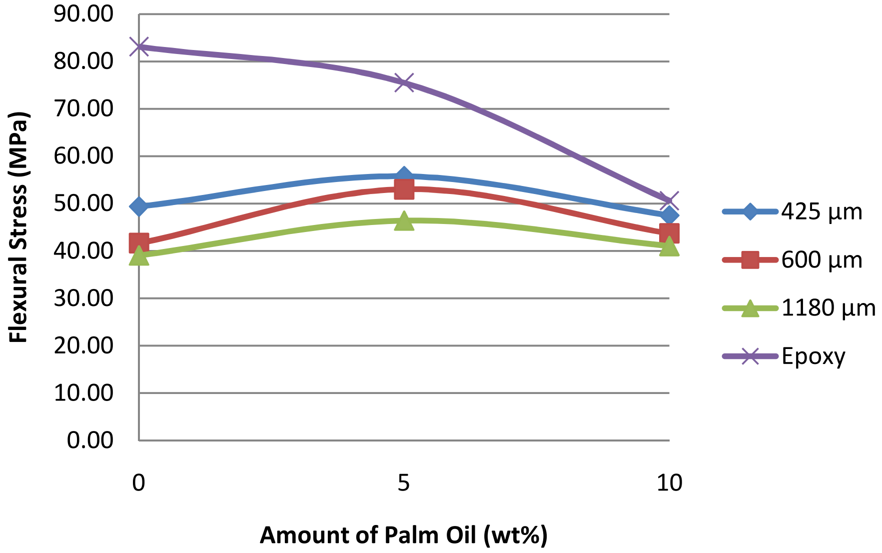

Figure 20: Flexural stress of epoxy composites reinforced with 15 wt% SD, with varying wt% of PO.

The neat epoxy samples exhibit the highest peak flexural stress. The samples with 425 µm SD have a higher peak flexural stress than those of the 600 µm and 1180 µm. The samples with 600 µm have a marginally higher flexural stress than those with 1180 µm. It is fair to say that the flexural stress decreases with increasing sizes of SD.

Analysing the results with 0 wt% PO, the neat epoxy sample had a flexural stress of 83.11 MPa. The sample with 425 µm SD had a flexural stress of 52.69 MPa which is 36.6% lower than the neat epoxy sample. The sample with 600 µm SD had a flexural stress of 42.79 MPa, 18.8% lower than the 425 µm SD sample. Finally, the sample with 1180 µm SD had a flexural stress of 39.27 MPa, 8.23% lower than the 600 µm SD sample.

Mosiewicki, Borrajo and Aranguren (2005) explained that increasing the composite fiber weight fraction may produce an increase in the void volume fraction, which affects the physical and mechanical properties of the composite. Thus, the greater the amount and size of the SD added in the sample directly affects the physical and mechanical strength of the sample.

Gruenwald (1993) stated that lower particle sizes are generally more beneficial in improving mechanical properties. The results above clearly exhibit this pattern; the specimens with lower particle sizes had the highest peak flexural stress, while the specimens with the largest particle sizes had the lowest peak flexural stress.

Figure 20 illustrates the flexural stress of varying wt% of PO reinforced epoxy matrix post cured in a microwave. The stress of the neat epoxy sample decreases with increasing amounts of PO. It can be seen that the flexural stress of the neat epoxy sample is higher than those of the composites with any wt% of SD. The neat epoxy sample exhibits the plasticizing effect of the palm oil. The stresses in the samples with SD increase marginally with 5 wt% PO and then decrease again with 10 wt% PO.

Analysing the results of the 425μm SD samples, the flexural stress starts at 52.69MPa with 0 wt% PO, the flexural stress increases 1.2% to 53.33MPa with samples with 5 wt% PO, finally the flexural stress decreases 7.46% to 49.35MPa with samples with 10 wt% PO.

4.2.2 Relationship between amount of Sawdust (wt%) and Flexural Stress

This section compares the flexural stresses of different sized SD particles with varying wt% of SD. This section will investigate the relationship between the flexural stress and the size of the sawdust and the flexural stress and the amount of SD added. The flexural stress (MPa) of samples containing 0 wt% PO post cured in a microwave is shown in Figure 21.

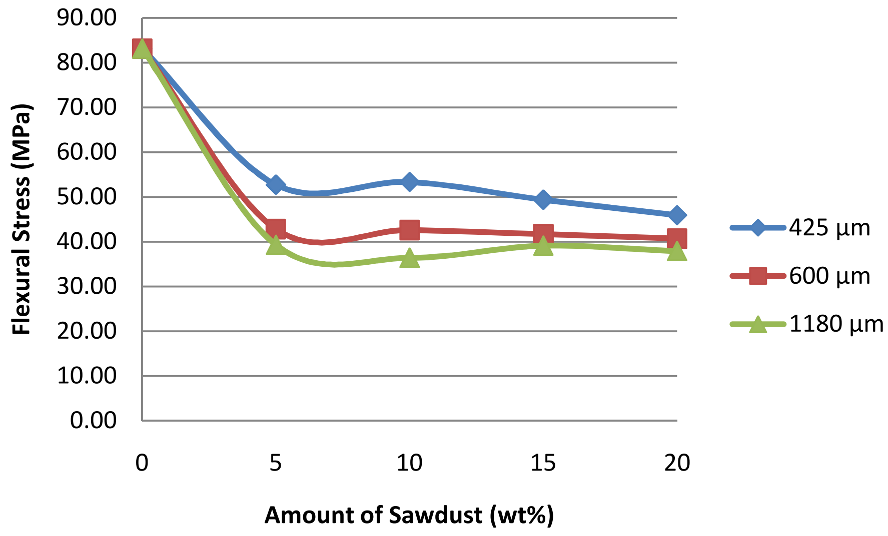

Figure 21: Flexural stress of epoxy composites reinforced with 0 wt% PO, with varying wt% of SD.

It can be seen in Figure 21 that the neat epoxy sample exhibited a considerably higher peak flexural stress, and that the flexural stress decreases linearly with increasing sizes of SD. The 425 µm samples had the highest peak flexural stress, followed by the 600 µm samples and then the 1180 µm samples with the lowest flexural stress.

When the composites were not reinforced with any PO (Samples 1-13, 40-52) the amount of SD in the sample did not considerably affect the peak flexural stress of the sample; the stress appeared to stay relatively stable with increasing amounts of SD. When the composites were reinforced with PO (Samples 14-39, 53-78) the stress appeared to decrease marginally with increasing amounts of SD.

4.2.3 Relationship between amount of Palm Oil (wt%) and Flexural Strain

This section compares the flexural strain of different sized SD particles with varying wt% of PO. This section will investigate the relationship between the maximum flexural strain the size of the sawdust, and between the maximum flexural strain and the amount of PO in the sample. The maximum flexural strain (%) of samples containing 5 wt% SD and 15 wt% SD post cured in a microwave is shown in Figures 22 - 23. The flexural strain of samples with 5 wt% SD exhibit a similar pattern to that of 10 wt% SD, and the flexural strain of samples with 15 wt% SD exhibit a similar pattern to that of 20 wt% SD.

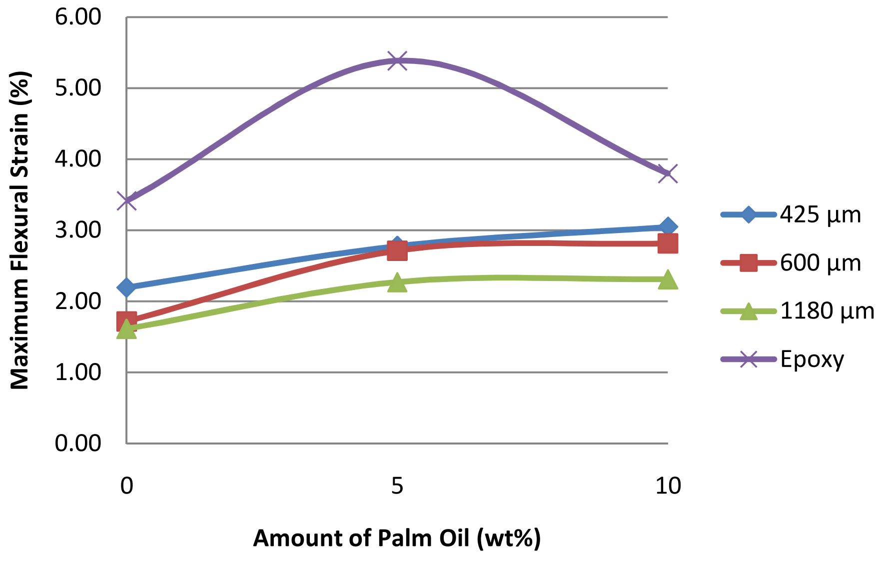

Figure 22: Flexural strain of epoxy composites reinforced with 5 wt% SD, with varying wt% of PO.

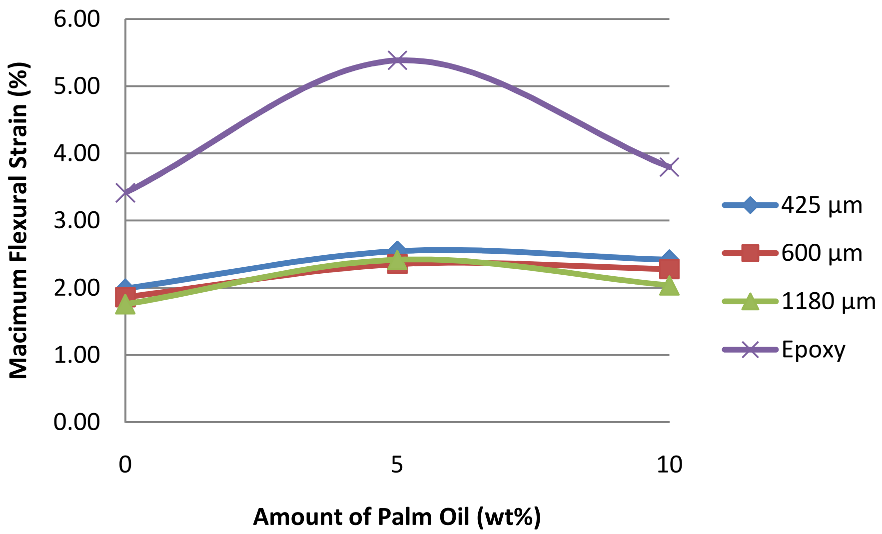

Figure 23: Flexural strain of epoxy composites reinforced with 15 wt% SD, with varying wt% of PO.

From Figures 22 & 23, it can be seen that the epoxy sample had the greatest maximum flexural strain. The flexural strain decreased with increasing sizes of SD. Although, in Figure 23 it can be seen that the 425 µm, 600 µm and 1180 µm samples all had similar flexural strains, as opposed to Figure 22 where the discrepancy between the 425 µm and the 600 µm and 1180 µm is clearly distinguishable.

Analysing the results of with 5 wt% SD samples, the flexural strain of the neat epoxy sample starts at 3.41 with 0 wt% PO, the flexural strain decreases 35.78% to 2.19 with 425 µm SD, the flexural strain decreases 21.46% to 1.72 with 600 µm SD, and finally the flexural strain decreases 6.39% to 1.61 with 1180 µm SD.

A project in 2009 conducted by Ku et al found that the only drawback for the use of finer particles was their tendency to agglomerate. Fine SD particles were difficult to disperse, and they agglomerated and behaved as large single particles. The research undertaken for this project confirms the research undertaken by Ku et al (2009), as the 425 µm samples with higher particulate ratio acted similarly to that of the 600 µm and 1180 µm. Therefore it can be claimed that the 425 µm particles agglomerated and behaved as large single particles. This agglomeration of particles started to occur when the epoxy composites was reinforced with 15 wt% SD. However the agglomeration of particles in the flexural stress for the 425 µm only occurred at the 20 wt% SD. It can be argued that the effects of agglomeration of particles can be seen at 15 wt% SD and that more effects occurred with increasing wt% of SD.

The amount of PO in the sample affects the flexural strain of the sample, as shown in Figures 22 & 23. The strain in the samples with SD increases marginally with increasing amounts of PO; this is a clear example of the plasticizing affects of PO. When a plasticiser is added to an epoxy sample, the product is softened, which in turn increases flexibility.

The neat epoxy sample with 10 wt% PO has a stress and strain that does not follow the conventional patterns in the data. It will be mentioned that the results from Sample 66 (0 wt% SD, 10 wt% PO) has unreliable data that will not be further analysed.

4.2.4 Relationship between amount of Sawdust (wt%) and Flexural Strain

This section compares the flexural strain of different sized SD particles with varying wt% of SD. This section will investigate the relationship between the flexural strain and the size of the SD, and between the flexural strain and the amount of SD added. The flexural strain (%) of samples containing 5 wt% PO post cured in a microwave is shown in Figure 24. The flexural strain of samples with 0 wt% PO and 10 wt% PO exhibit a similar pattern to that of 5 wt% PO.

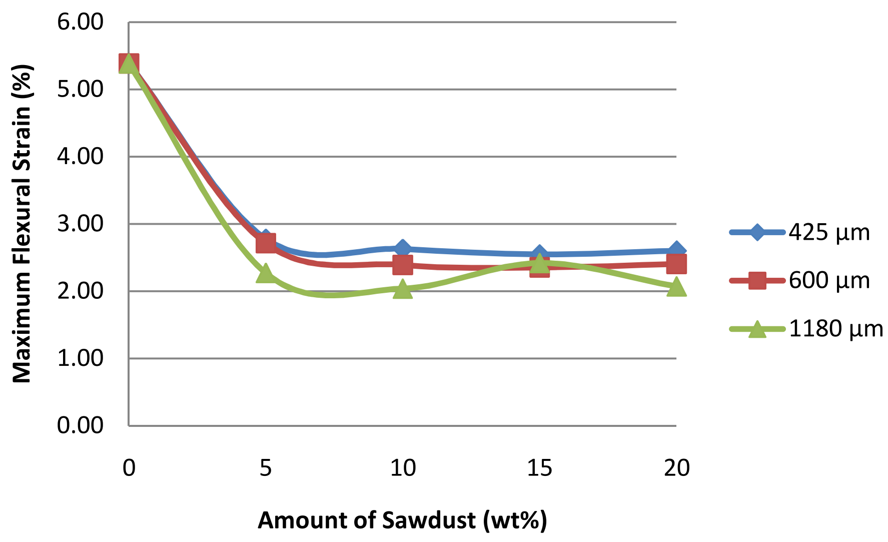

Figure 24: Flexural strain of epoxy composites reinforced with 5 wt% PO, with varying wt% of SD.

It can be seen that the neat epoxy sample exhibited a higher strain than all the other samples. The 425 µm samples had the highest strain, followed by the 600 µm samples and then the 1180 µm samples. This has a similar relationship with the flexural stresses (see Figure 21).

The amount of SD in the sample does not greatly affect the strain of the sample, as shown in the graph. The strain seems to stay relatively stable with increasing amounts of SD. This also has a similar relationship with the flexural stresses (see Figure 21).

4.2.5 Relationship between amount of Palm Oil (wt%) and Flexural Modulus

This section compares the flexural modulus of different sized SD with varying wt% of PO. This section will investigate the relationship between the flexural modulus and the size of the SD, and between the flexural modulus and the amount of PO. The flexural modulus (MPa) of samples containing 20 wt% SD post cured in a microwave is shown in Figure 25. The flexural modulus of samples with 5 wt% SD, 10 wt% SD, and 15 wt% PO exhibit a similar pattern to that of 20 wt% SD.

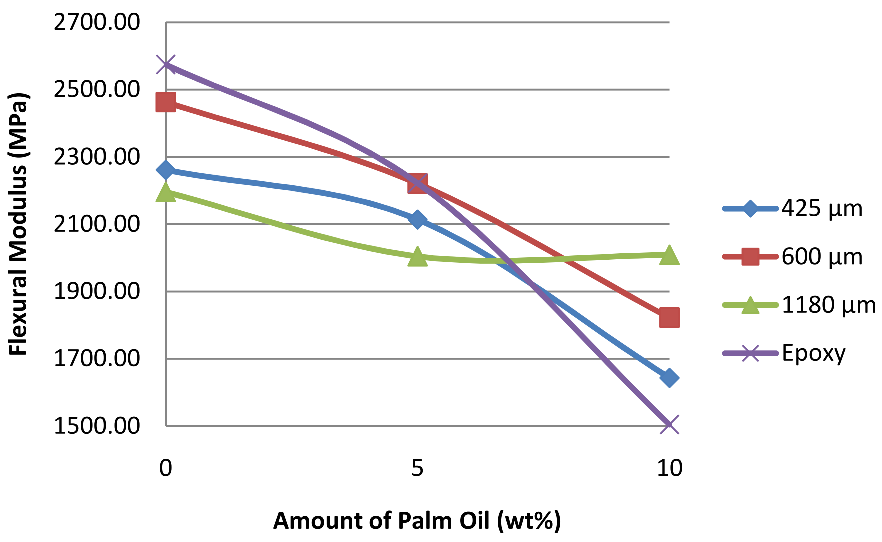

Figure 25: Flexural modulus of epoxy composites reinforced with 20 wt% SD, with varying wt% of PO.

From Figure 25 it can be seen that all samples share a similar flexural modulus. It may be argued that the size of the SD particles have minimal effects on the flexural modulus; the epoxy sample has a similar flexural modulus to the other samples, so the size and wt% of SD has a minimal affect on the flexural modulus of the samples.

The flexural modulus in the samples with SD decreased linearly with increasing amounts of PO. This is an example of the plasticizing affect of PO; the resistance of the sample to bend should decrease with increasing amounts of PO.

The highest flexural modulus was neat epoxy resin sample (Sample 40, 0 wt% SD, 0 wt% PO) with a flexural modulus of 2574 MPa. The sample that had the lowest flexural modulus was Sample 66 (0 wt% SD, 0 wt% PO) with a 1504.33 MPa.

4.2.6 Relationship between amount of Sawdust (wt%) and Flexural Modulus

This section compares the flexural modulus of different sized SD with varying wt% of SD. This section will investigate the relationship between the flexural modulus and the amount of SD added. The flexural modulus (MPa) of samples containing 5 wt% PO post cured in a microwave is shown in Figures 26. The flexural modulus of samples with 0 wt% PO, and 10 wt% PO exhibit a similar pattern to that of 5 wt% PO.

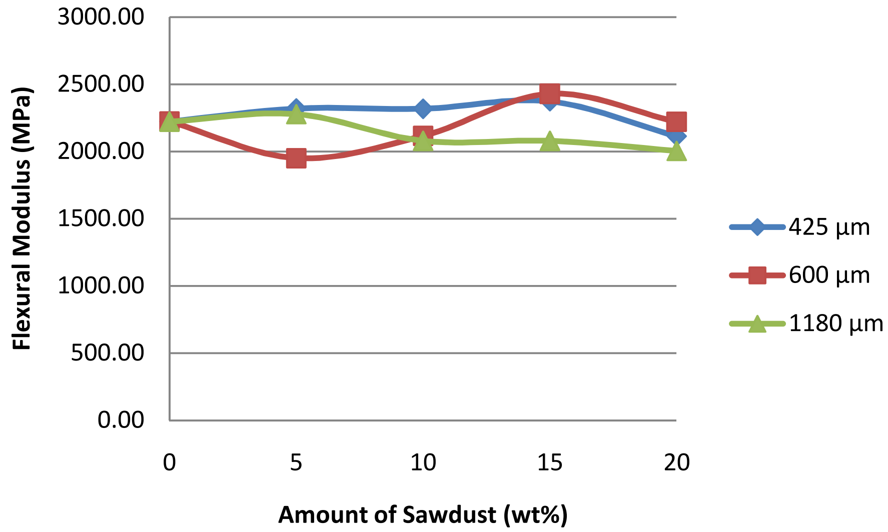

Figure 26: Flexural modulus of epoxy composites reinforced with 5 wt% PO, with varying wt% of SD.

From Figures 26 it can be seen that the neat epoxy sample exhibits a flexural modulus similar to that of the other samples with sawdust.

The amount of SD in the sample had a minimal impact on the flexural modulus of the samples. The size of the SD does not factor in the results.

The neat epoxy sample had a flexural modulus of 2222 MPa. The sample with the highest flexural modulus was Sample 60 (600 µm, 15 wt% SD, 5 wt% PO) with 2428.67 MPa. The sample with the lowest flexural modulus was Sample 58 (425 µm, 5 wt% SD, 5 wt% PO) with 1949.67 MPa.

4.2.7 Relationship between Microwave and Conventional Post Curing and Flexural Properties

This section will investigate the relationships gathered between the samples which were post cured conventionally to those which were post cured using a microwave. The relationships observed are between the flexural stress, flexural strain and flexural modulus of samples that were post cured in the microwave as compared to those which were post cured conventionally.

The relationships that were observed in the previous sections (which were post cured in a microwave) are the same to those which were post cured conventionally. It can be argued that the post curing method does not affect the relationship between the flexural properties and the size and amount of SD and PO.

The following section will investigate the average of samples which were post cured conventionally, to those which were post cured in a microwave. The average peak flexural stress, average strain at peak and average flexural modulus of samples are in accordance to their method of post curing, these results are shown in Table 4.

	Peak Flexural Stress Average	Strain At Peak Average	Flexural Modulus Average
	MPa	**%**	**MPa**
Conventionally	52.17	2.40	2322.89
Microwave	47.52	2.40	2143.11
Percentage Increase	8.91	0.29	7.74

Table 4: Comparing the average of Peak Flexural Stress, Strain at Peak and Flexural Modulus of samples post cured conventionally, to those post cured using a microwave

It can be seen in Table 4 that the peak flexural stress is on average 8.91% greater when post cured conventionally, the strain at peak is similar with no noticeable variance, and the flexural modulus is on average 7.74% greater when post cured conventionally.

The average peak flexural stress, average peak flexural strain and average flexural modulus of the composites cured conventionally compared to those which are cured with a microwave reinforced with varying wt% PO is illustrated in Figures 27 – 29.

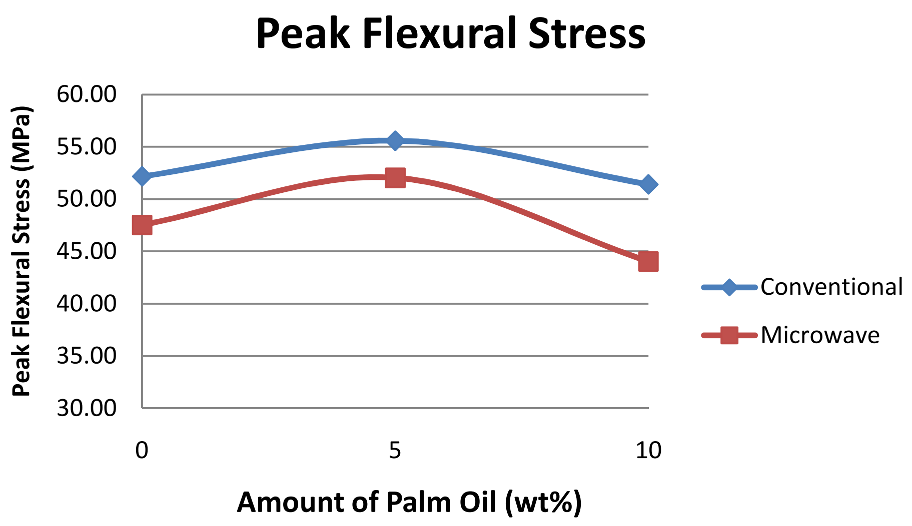

Figure 27: Comparing the average Peak Flexural Stress of epoxy composites cured conventionally and with a microwave reinforced with varying wt% PO

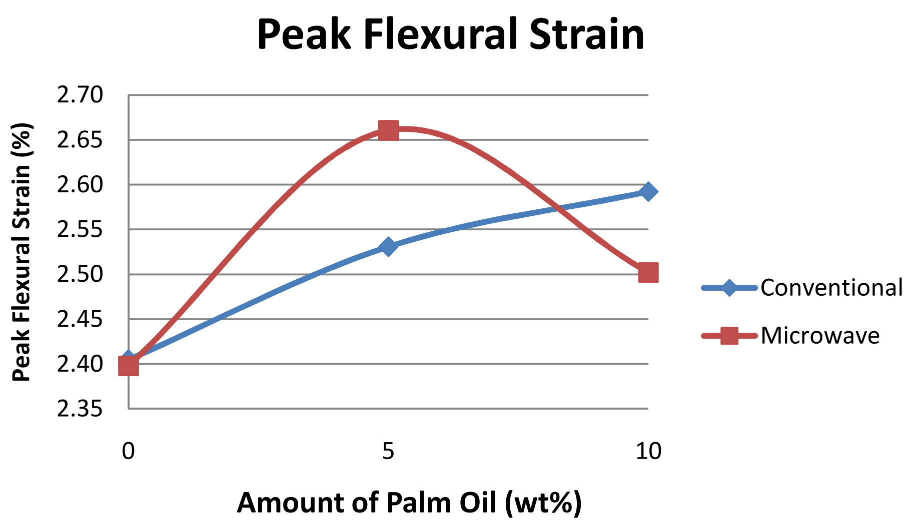

Figure 28: Comparing the average Peak Flexural Strain of epoxy composites cured conventionally and with a microwave reinforced with varying wt% PO

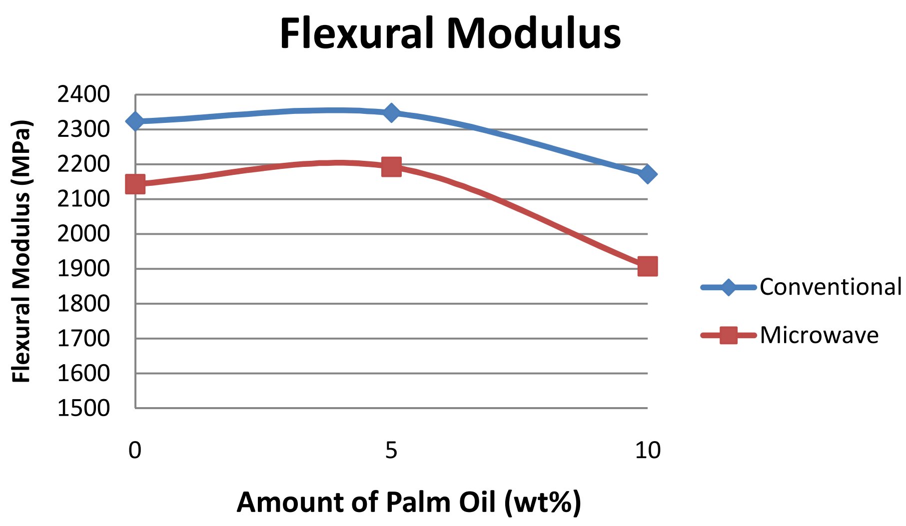

Figure 29: Comparing the average Flexural Modulus of epoxy composites cured conventionally and with a microwave reinforced with varying wt% PO

From Figure 27 & 29 it can be seen that the flexural stress and flexural modulus of samples that were post cured conventionally are stronger than those which were post cured in the microwave. From Figure 28, it can be seen that the peak flexural strain of samples post cured conventionally were similar to those which were post cured in the microwave.

The oven allowed the samples to stay at an elevated temperature for an extended period, while the microwave achieves the elevated temperature but cannot maintain it for an extended period. The extra period of time at an elevated temperature allows more cross linking to occur, therefore, further strengthening the samples. Thus conventional curing is more effective.

This study and results shows similar outcomes as previously undertaken research.

Ku et al (2008) made phenol formaldehyde composites and tested for fracture toughness. It was discovered that the flexural strength and flexural strain of the composites post cured conventionally were much better than their counterparts post cured in microwaves, it was also found that the young's modulus of the composites post cured conventionally were greater than the composites post cured in the microwave.

4.3 Dynamic Mechanical Analysis Results

The behaviour of the manufactured composite samples under elevated temperatures from DMA will be investigated and analysed within this section. The glass transition temperatures of the manufactured samples will be the material properties focused on in detail.

The storage modulus provided similar relationships to those of the flexural modulus; however the recorded modulus from the DMA testing machine was on average 14.98% lower than those which were tested with the flexural tests. The data collected from the flexural tests will be used in this project because of its reliability: the flexural results were the average of three tests, whereas the thermal results were the product of one test.

4.3.1 Relationship between amount of Palm Oil (wt%) and Glass Transition Temperature

From the data collected from the DMA tests it can be claimed that the amount and size of SD particles and PO does not affect the Tg. The Tg value should decrease with increasing amounts of PO, however no significant change was recorded. This means that the strength of the epoxy cross linking is not weakened with increasing amounts of PO.

4.3.2 Relationship between Microwave and Conventional Post Curing and Thermal Properties

The following section will investigate the average thermal properties of samples which were post cured conventionally, to those which were post cured in a microwave. The average Tg of the composites cured conventionally compared to those which are cured with a microwave reinforced with varying wt% PO is illustrated in Figure 30.

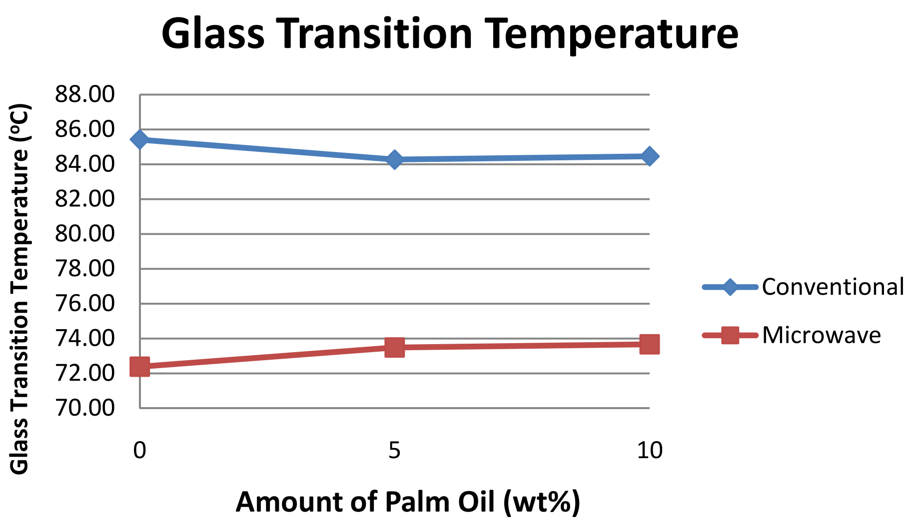

Figure 30: Comparing the average Glass Transition Temperature of epoxy composites cured conventionally and with a microwave reinforced with varying wt% PO

It can be seen that the Tg of samples post cured conventionally are greater than those which were post cured in a microwave. The graph also illustrates no significant change with results with increasing amounts of PO.

The average Tg of samples in accordance to their method of post curing is shown in Table 5. The relevant standard deviation is also incorporated in the table to compare the reliability of the results. The standard deviation refers to the difference in results over all the samples, as opposed to the reliability of each sample.

	Tg Average	Standard Deviation
	MPa	
Conventionally	84.71	1.46
Microwave	73.17	1.27
Percentage Increase	13.62	13

Table 5: Comparing the average Glass Transition Temperature of samples post cured conventionally, to those post cured using a microwave

It can be seen in Table 5 that the Tg is on average 13.62% greater when post cured conventionally. This data once again shows the effect of cross linking between conventional and microwave post cured samples.

The standard deviations of the various samples are low, confirming that the Tg of samples does not vary when various amounts and sizes of SD particles and PO are added in samples.

4.3.3 Conclusion

It can be seen from the previous sections that the amount and size of SD particles, as well as amount of PO does not affect the Tg of the epoxy composite. The only significant variation between samples is the affect of the post curing treatment. The samples post cured conventionally exhibit a much higher Tg of samples post cured in a microwave.

4.4 Optical microscope

The microscope analysis was performed on different samples to determine the porosity formation of the size and number of air bubbles. This key characteristic has an impact on the flexural properties.

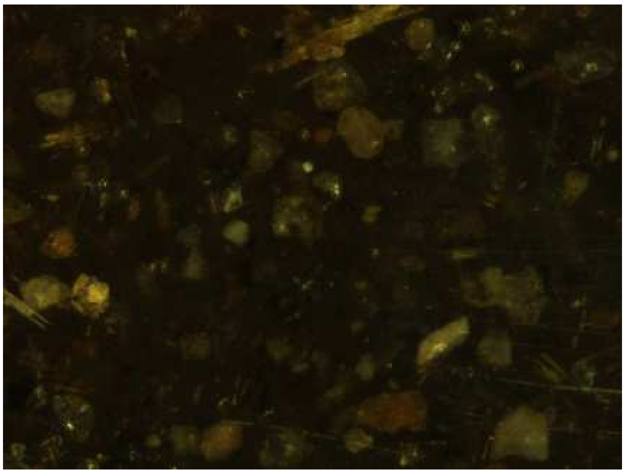

Figure 31: Optical microscope of Sample 2 (425 µm, 5 wt% SD, 0 wt% PO)

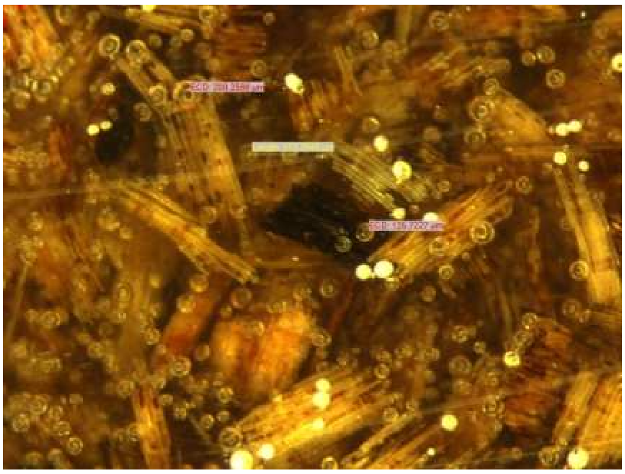

Figure 32: Optical microscope of Sample 9 (600 µm, 20 wt% SD, 0 wt% PO)

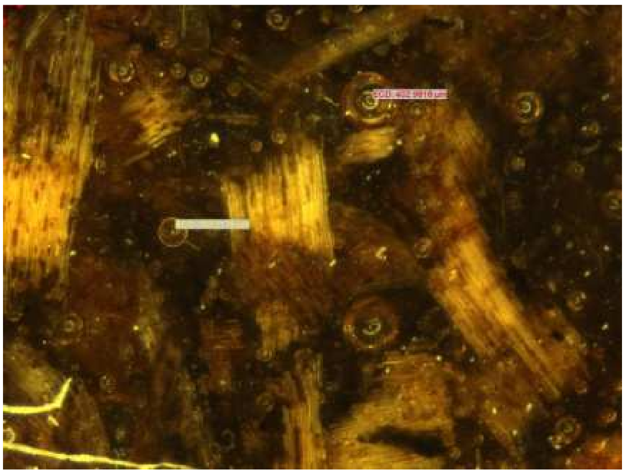

Figure 33: Optical microscope of Sample 13 (1180 µm, 20 wt% SD, 0 wt% PO)

Sample 2, seen in Figure 31, shows a sample with 425 µm, 5 wt% SD, with 0 wt% PO. Under the microscope, the sample exhibited a minimal amount of air bubbles, and also indicated dirt in the sample which has darkened the sample.

Sample 9, seen in Figure 32, shows a sample with 600 µm, 20 wt% SD, with 0 wt% PO. Under the microscope, the sample exhibited a vast quantity of large air bubbles, the largest bubble found using the microscope had a circumference of 209 µm. The sample also exhibited a reduced contamination by dirt.

Sample 13, seen in Figure 33, shows a sample with 1180 µm, 20 wt% SD, with 0 wt% PO. Under the microscope, the sample exhibited a vast quantity of large air bubbles, the largest bubble found using the microscope had a circumference of 402 µm.

This suggests that the size and quantity of air bubbles increases with the size of the sawdust; the larger the sawdust the larger the air bubbles and the amount of air bubbles.

It can be seen in Figures 31-33 that there are no voids around the sawdust particles; it can be claimed that there adhesion has been achieved between sawdust and epoxy.

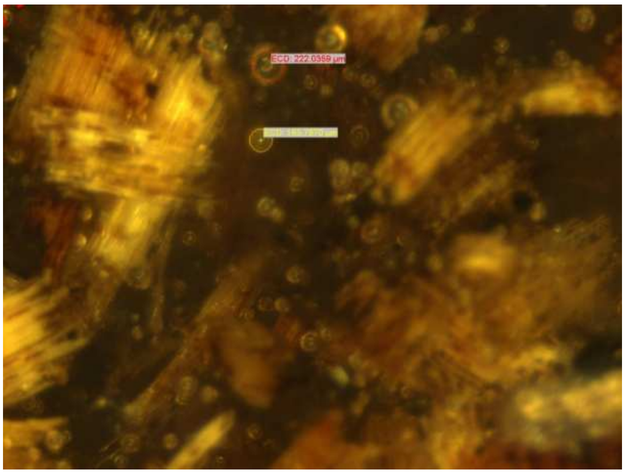

Figure 34: Optical microscope of Sample 10 (1180 µm, 5 wt% SD, 0 wt% PO)

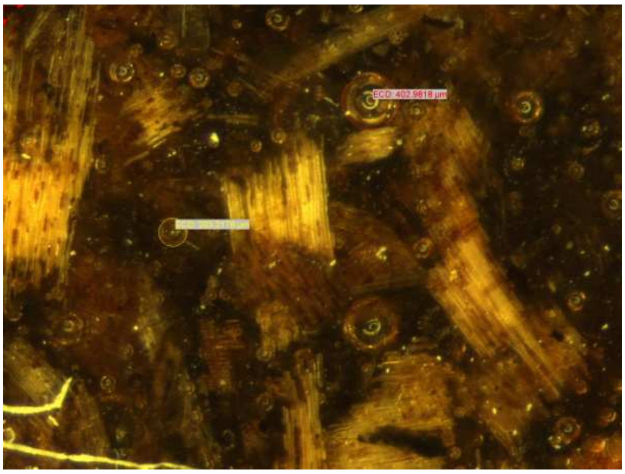

Figure 35: Optical microscope of Sample 13 (1180 µm, 20 wt% SD, 0 wt% PO)

Sample 10, seen in Figure 34, shows a sample with 1180 µm, 5 wt% SD, with 0 wt% PO. Under the microscope, the sample exhibited a large quantity of air bubbles with a variety of sizes. The largest bubble found using the microscope had a circumference of 222 µm.

Sample 13, seen in Figure 35, shows a sample with 1180 µm, 20 wt% SD, with 0 wt% PO. Under the microscope, the sample exhibited a large quantity of air bubbles, and with varying sizes of air bubbles. The largest bubble found using the microscope had a circumference of 402 µm.

This suggests that the size and quantity of air bubbles increases with the amount of sawdust; the more sawdust in the samples the larger the size and amount of air bubbles.

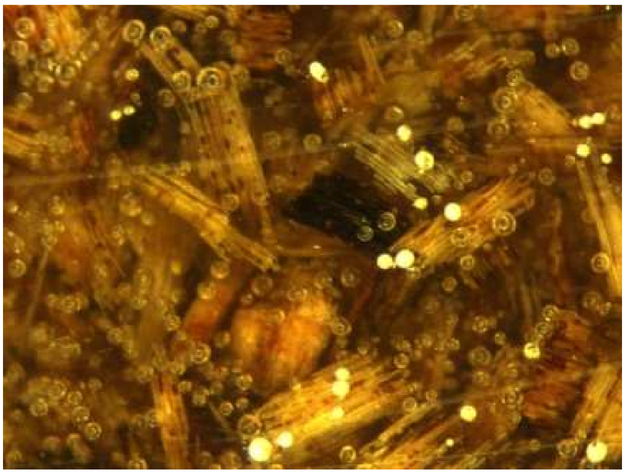

Figure 36: Optical microscope of Sample 9 (600 µm, 20 wt% SD, 0 wt% PO)

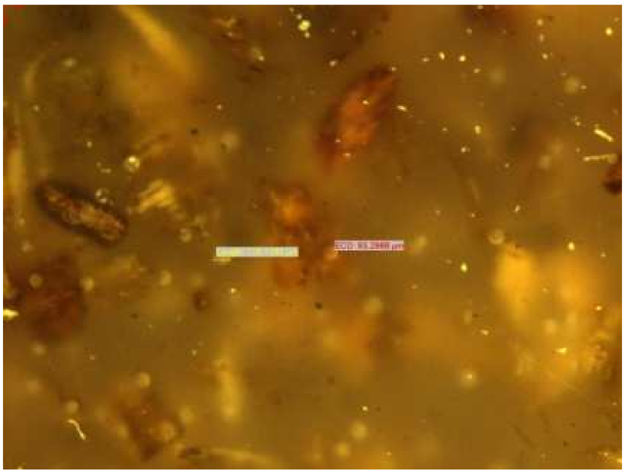

Figure 37: Optical microscope of Sample 22 (600 µm, 20 wt% SD, 5 wt% PO)

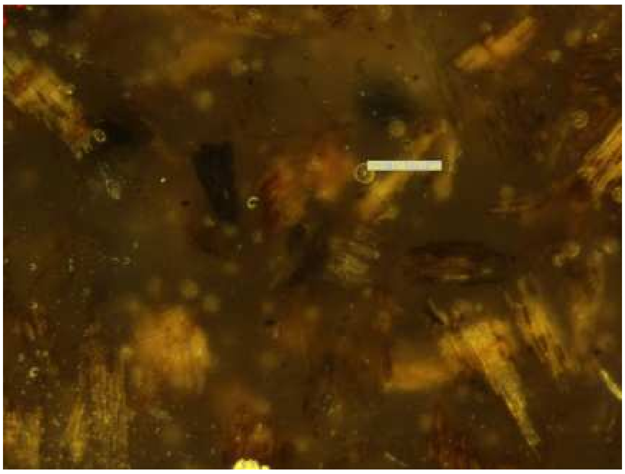

Figure 38: Optical microscope of Sample 35 (600 µm, 20 wt% SD, 10 wt% PO)

Sample 9, seen in Figure 36, shows a sample with 600 µm, 20 wt% SD, with 0 wt% PO. Under the microscope, the sample exhibited a large quantity of air bubbles with a variety of sizes. The largest bubble found using the microscope had a circumference of 209 µm.

Sample 22, seen in Figure 37, shows a sample with 600 µm, 20 wt% SD, with 5 wt% PO. Under the microscope, the sample exhibited an average quantity of air bubbles with a variety of sizes. The largest bubble found using the microscope had a circumference of 93 µm.

Sample 35, seen in Figure 38, shows a sample with 600 µm, 20 wt% SD, with 10 wt% PO. Under the microscope, the sample exhibited a large quantity of air bubbles with a restricted variety of sizes. The largest bubble found using the microscope had a circumference of 138 µm.

This suggests that the size and amount of air bubbles decreases dramatically with any quantity of palm oil. The difference in size and amount of air bubbles between Sample 9 and Sample 22 is quite dramatic. However the size and amount of air bubbles seems to stabilise when there are increasing amounts of palm oil, as shown between Sample 22 and Sample 35.

There are several relationships found in these comparisons.

- With increasing amounts of PO the quantity and size of air bubbles are reduced;
- With increasing size of SD, the size and amount of the air bubbles are increased; and
- With increasing amounts of SD, the size and amount of air bubbles are increased.

Gases are generated during the epoxidation process, some of these gases get trapped in the samples and become bubbles. Most bubbles are able to be released due the viscosity of the epoxy resin; however, as explained in Chapter 2, fillers such as sawdust increase the viscosity of the resin and can trap the bubbles. Also, the moisture in the SD reacts with the epoxy and additional air bubbles are formed; there is a direct correlation between amount and size of sawdust and the size and amount of bubbles. The PO reduces the viscosity of the resin and allows bubbles to be released easily, explaining the reduction of bubbles with increasing amount of PO.

5 Conclusion

5.1 Introduction

This chapter will provide a detailed discussion of results obtained and shown in Chapter 4. Results include: flexural stress, flexural strain, flexural modulus, and thermal properties of the different weights and sizes of SD and palm oil. Discussions will be dealt with in relation to the aims and objectives of this dissertation, which were to:

- Study the effects of the SD selection (size and weights) in the properties of the composites;
- Study the effect on the properties of the composites by adding different amounts of palm oil; and
- Compare the properties of the epoxy/SD composites with palm oil after post curing them conventionally and by microwaves.

5.2 Discussion of Results

Throughout all the results it was found that the samples that were post cured conventionally exhibited similar relationships to those which were post cured in the microwave. The post curing method only affects the strength of adhesion achieved in the sample, not the relationships that are gathered.

5.2.1 Flexural Stress

The flexural stress of samples post cured in a microwave exhibited similar relationships to those which were post cured conventionally.

The flexural stress:

- Decreased with increasing size of SD;
- Decreased marginally with increasing amount of SD; and
- Increased with 5 wt% PO then decreased with 10 wt% PO.

The neat epoxy sample exhibited the highest flexural stress. The flexural stress decreases with increasing sizes of SD. It was discussed in Chapter 4 that lower particle sizes are generally more beneficial in improving mechanical properties.

When the composites were not reinforced with any PO the amount of SD in the sample did not considerably affect the peak flexural stress of the sample; the stress seems to stay relatively stable with increasing amounts of SD. The composites were then reinforced with 5 wt% and 10 wt% PO. The stresses seem to decrease slightly with increasing amounts of SD.

The stress of the neat epoxy samples decreased with increasing amounts of PO. The PO acts as a plasticizing agent and increases flexibility of the sample, in turn reducing the flexural stress. The stresses in the samples with SD increase marginally with 5 wt% PO and then decrease again with 10 wt% PO.

The samples that were post cured conventionally exhibited an 8.91% higher flexural stress than those which were post cured in a microwave. The oven allows the samples to stay at an elevated temperature for an extended period, while the microwave achieves the elevated temperature but cannot maintain it for an extended period. The extra period of time at an elevated temperature allows more cross linking to occur, therefore, further strengthening the samples.

5.2.2 Flexural Strain

The flexural strain of samples post cured in a microwave exhibited similar relationships to those which were post cured conventionally.

The flexural strain:

- Decreased with increasing size of SD;
- Was not affected by amount of SD added; and
- Increased with increasing amount of PO.

The neat epoxy sample exhibited the highest flexural strain. The flexural strain decreased with increasing sizes of SD.

The strain seems to stay relatively stable with increasing amounts of SD.

The strain in the samples with SD increased with increasing amounts of PO. This is a clear example of the plasticizing affect of the PO.

The samples that were post cured conventionally exhibited similar flexural strain to those which were post cured in the microwave.

5.2.3 Flexural Modulus

The flexural modulus of samples post cured in a microwave exhibited similar relationships to those which were post cured conventionally. The flexural modulus:

- Decreased with increasing amount of PO; and
- Was not greatly affected by the size and amount of SD.

The neat epoxy sample had a similar flexural modulus to other samples containing different weights and sizes of SD, thus it can be argued that the size and weight of SD has minimal affect on the flexural modulus of the samples.

The flexural modulus in the samples with SD decreases linearly with increasing amounts of PO. This is an example of the plasticizing affect of PO; the resistance of the sample to flex should decrease with increasing amounts of PO.

The samples that were post cured conventionally exhibited a 7.74% higher flexural stress than those which were post cured in a microwave.

5.2.4 Thermal Properties

The amount and size of SD particles, as well as amount of PO does not affect the Tg of the epoxy composite. The only significant difference between samples is the affect of the post curing treatment. It can be concluded that the samples post cured conventionally exhibit a much higher Tg of samples post cured in a microwave.

5.2.5 Findings from Microscope

It was observed that there was adhesion was achieved between epoxy and sawdust. The only item that differed between samples was the size and amount of bubbles found. There are several relationships found in these comparisons.

- With increasing amounts of PO the quantity and size of air bubbles are reduced.
- With increasing size of SD, the size and amount of the air bubbles are increased.
- With increasing amounts of SD, the size and amount of air bubbles are increased.

Gases are generated during the epoxidation process; some of these gases get trapped in the samples and become bubbles. Most bubbles are able to be released due the viscosity of the epoxy resin; however, as explained in Chapter 2, fillers such as sawdust increase the viscosity of the resin and can trap the bubbles. Also, the moisture in the SD reacts with the epoxy and additional air bubbles are formed; there is a direct correlation between amount and size of sawdust and the size and amount of bubbles. The PO reduces the viscosity of the resin and allows bubbles to be released easily, explaining the reduction of bubbles with increasing amount of PO.

5.3 Concluding Remarks

The results gathered from the two methods of post curing provided primary information on the effects of each method on the properties of the composites. Although the microwave does not produce results as well as those which were post cured conventionally, if these findings could be used in industry, the use of a microwave would have significant savings in time, money and power usage.

The study also demonstrated the viability of composites with natural fillers and additives in certain applications.

6 Recommendations

6.1 Introduction

The results obtained throughout this report have brought several challenges and limitations regarding the use of renewable resources in composites. The findings in this report will aid the advancement of knowledge and further research within this field of study.

6.2 Limitations of Results

Limitations to consider when reviewing the previous research are:

- Moisture in sawdust;
- Uncontrollable varieties in wood anatomy;
- Inconsistencies in the chemical components of wood;
- Difficulty achieving uniform dispersion of SD; and
- Bubbles trapped in the sample.

6.3 Recommendations for future work

All objectives were fulfilled in the study, which were outlined in the project specification (Appendix A). The objective outlines a comparison of flexural and thermal properties with varying amounts and sizes of sawdust and palm oil, post cured in a microwave and conventionally.

Questions that arose throughout this project that would require future research work are listed below:

- Investigation into creating reproducible properties of sawdust which have different properties, e.g. from different species of plant grown in different climates and seasons; and
- Understanding how different wood properties affect the adhesion between matrix and filler.

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Appendix A – Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/4112 Research Project

PROJECT SPECIFICATION

FOR:	**MICHAEL DONALD**
TOPIC:	**Comparative properties of epoxy/sawdust composites with palm oil cured by microwave and thermal treatment**
SUPERVISOR:	Dr. Harry Ku, Dr Francisco Cardona
ENROLMENT:	ENG4111 – S1, 2010; ENG4112 – S2, 2010
PROJECT AIM:	The aim of this project is to develop composites from sawdust and palm oil post cured by microwave and thermal treatment and to evaluate and compare their thermal and flexural properties. Findings will be analysed in detail in order to establish behavioural trends can be used for theoretical prediction of filler polymer behaviour.

PROGRAMME: **Issue A, 23rd March 2010**

1. Research background information related to topic.
2. Obtain sawdust and sift into various sizes.
3. Manufacture the various specimens ready for curing.
4. Cure the various specimens.
5. Perform the three point test and DMA test and collect and examine the results.
6. View samples using optical microscope
7. Complete literature review
8. Draw up conclusion based on the obtained results.
9. Discussion for the thesis outline with supervisor.
10. Thesis initial drafting. Each chapter in draft form to be shown to supervisor.
11. Finalise the thesis and incorporate modification suggested by supervisor.
12. Complete the thesis in requested format.

AGREED:

___________________ (student) ___________________ (Supervisor)

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

Appendix B - Summary of Manufactured Samples

All samples contain 100 grams of Kinetix R246TX (epoxy) and 25 grams of Kinetix H160 hardener. All samples were initially cured in room temperature for 24 hours.

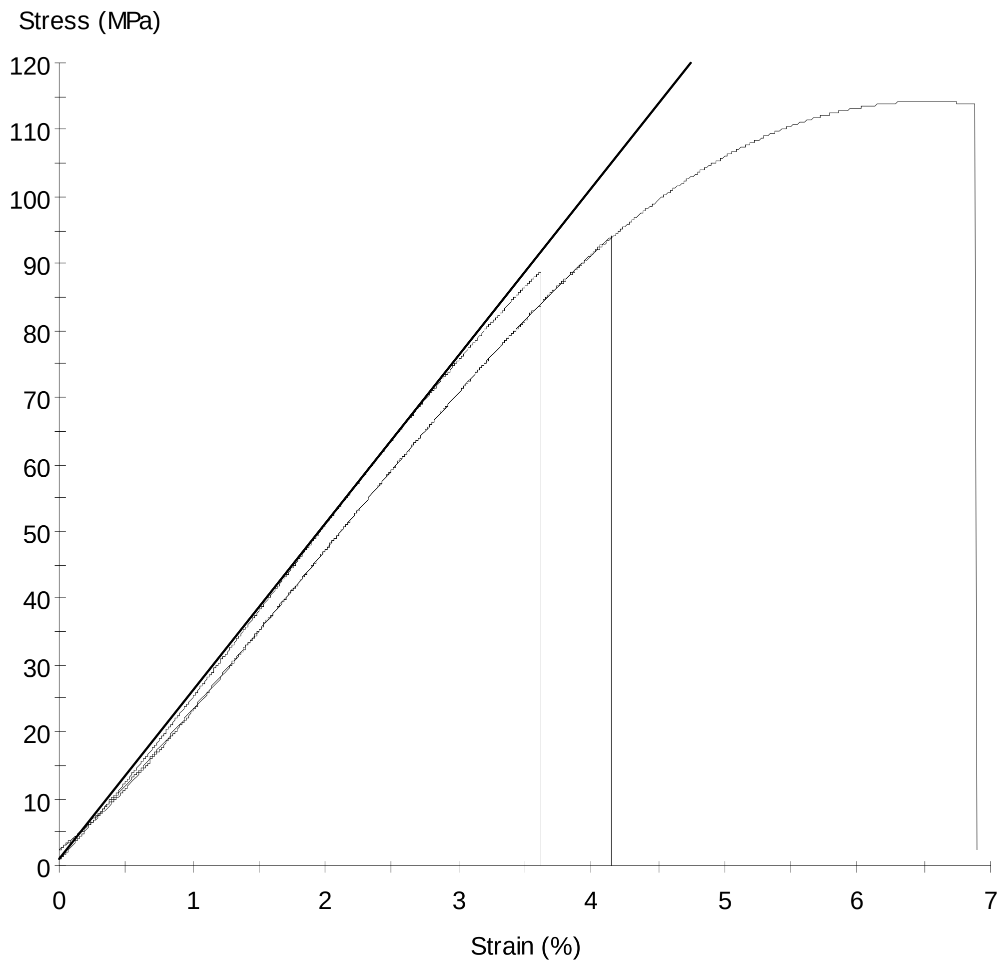
Sample	Sawdust		Palm Oil	Post Curing
#	Weight (% by weight)	Size (μm)	Weight (% by weight)	Method
1	0	0	0	Conventional
2	5	425	0	Conventional
3	10	425	0	Conventional
4	15	425	0	Conventional
5	20	425	0	Conventional
6	5	600	0	Conventional
7	10	600	0	Conventional
8	15	600	0	Conventional
9	20	600	0	Conventional
10	5	1180	0	Conventional
11	10	1180	0	Conventional
12	15	1180	0	Conventional
13	20	1180	0	Conventional
14	0	0	5	Conventional
15	5	425	5	Conventional
16	10	425	5	Conventional
17	15	425	5	Conventional
18	20	425	5	Conventional
19	5	600	5	Conventional
20	10	600	5	Conventional
21	15	600	5	Conventional
22	20	600	5	Conventional
23	5	1180	5	Conventional
24	10	1180	5	Conventional
25	15	1180	5	Conventional
26	20	1180	5	Conventional
27	0	0	10	Conventional
28	5	425	10	Conventional
29	10	425	10	Conventional
30	15	425	10	Conventional
31	20	425	10	Conventional
32	5	600	10	Conventional
33	10	600	10	Conventional
34	15	600	10	Conventional
35	20	600	10	Conventional
36	5	1180	10	Conventional
37	10	1180	10	Conventional
38	15	1180	10	Conventional
39	20	1180	10	Conventional

Sample	Sawdust		Palm Oil	Post Curing
#	Weight (% by weight)	Size (µm)	Weight (% by weight)	Method
40	0	0	0	Microwave
41	5	425	0	Microwave
42	10	425	0	Microwave
43	15	425	0	Microwave
44	20	425	0	Microwave
45	5	600	0	Microwave
46	10	600	0	Microwave
47	15	600	0	Microwave
48	20	600	0	Microwave
49	5	1180	0	Microwave
50	10	1180	0	Microwave
51	15	1180	0	Microwave
52	20	1180	0	Microwave
53	0	0	5	Microwave
54	5	425	5	Microwave
55	10	425	5	Microwave
56	15	425	5	Microwave
57	20	425	5	Microwave
58	5	600	5	Microwave
59	10	600	5	Microwave
60	15	600	5	Microwave
61	20	600	5	Microwave
62	5	1180	5	Microwave
63	10	1180	5	Microwave
64	15	1180	5	Microwave
65	20	1180	5	Microwave
66	0	0	10	Microwave
67	5	425	10	Microwave
68	10	425	10	Microwave
69	15	425	10	Microwave
70	20	425	10	Microwave
71	5	600	10	Microwave
72	10	600	10	Microwave
73	15	600	10	Microwave
74	20	600	10	Microwave
75	5	1180	10	Microwave
76	10	1180	10	Microwave
77	15	1180	10	Microwave
78	20	1180	10	Microwave

Appendix C – Flexural Testing Results

Sample 1

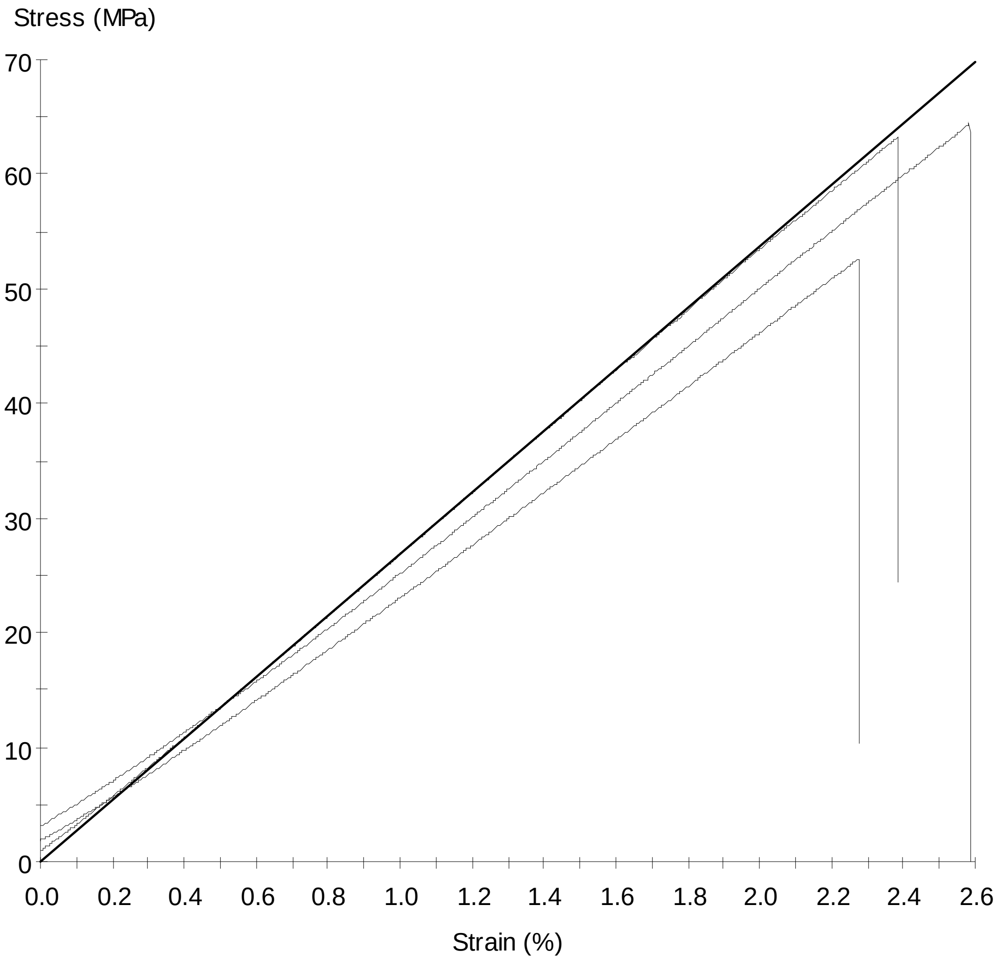
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	13.34	10.06	1606	114.23	6.89	6.51	4.42	4.42	2359
2	14.19	10.08	1413	94.06	4.15	4.15	2.81	2.81	2330
3	13.83	10.10	1304	88.71	3.62	3.61	2.44	2.44	2534
Mean	**13.79**	**10.08**	**1441**	**99.00**	**4.89**	**4.76**	**3.22**	**3.22**	**2408**
Std Dev	**0.43**	**0.02**	**153**	**13.46**	**1.76**	**1.54**	**1.05**	**1.05**	**111**



Stress vs Strain Plot

Sample 2

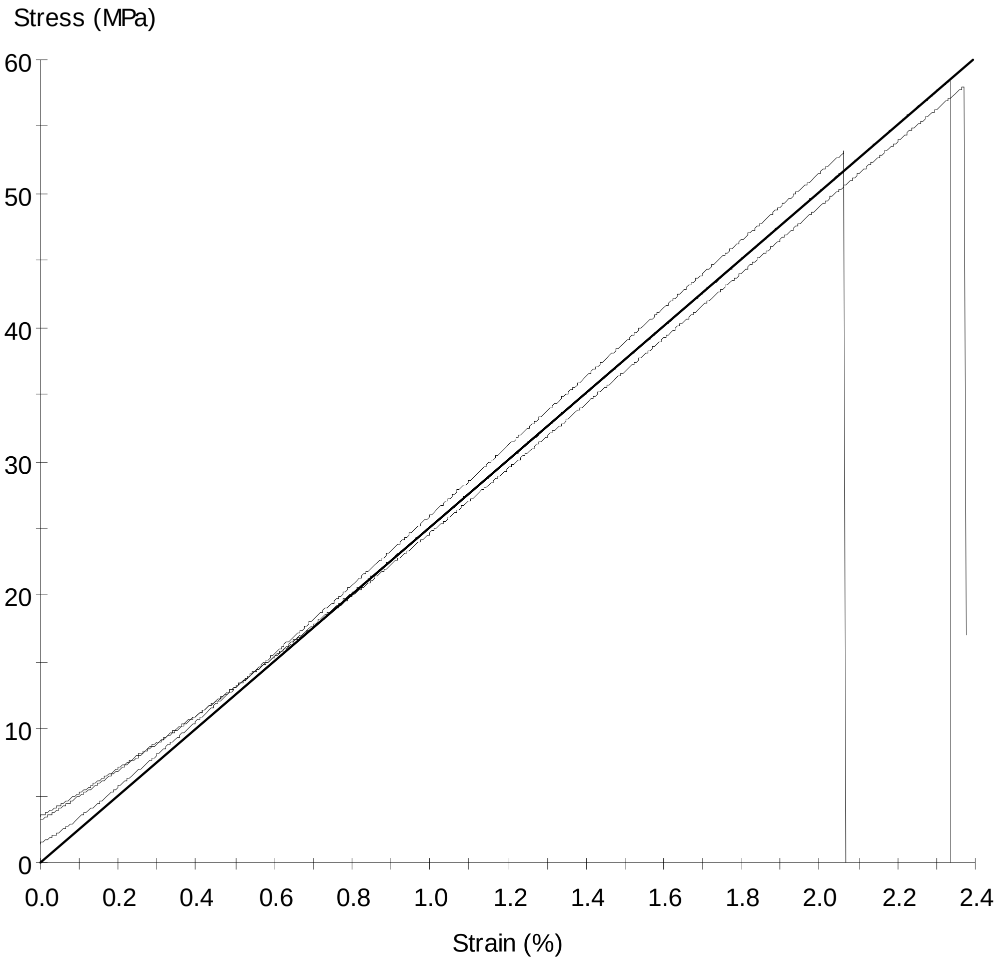
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	13.53	10.02	911	64.36	2.59	2.58	1.76	1.76	2500
2	14.73	9.93	797	52.65	2.28	2.28	1.56	1.56	2302
3	14.45	9.87	928	63.26	2.39	2.39	1.65	1.65	2684
Mean	**14.24**	**9.94**	**878**	**60.09**	**2.42**	**2.42**	**1.66**	**1.66**	**2495**
Std Dev	**0.63**	**0.08**	**71**	**6.47**	**0.16**	**0.16**	**0.10**	**0.10**	**191**



Stress vs Strain Plot

Sample 3

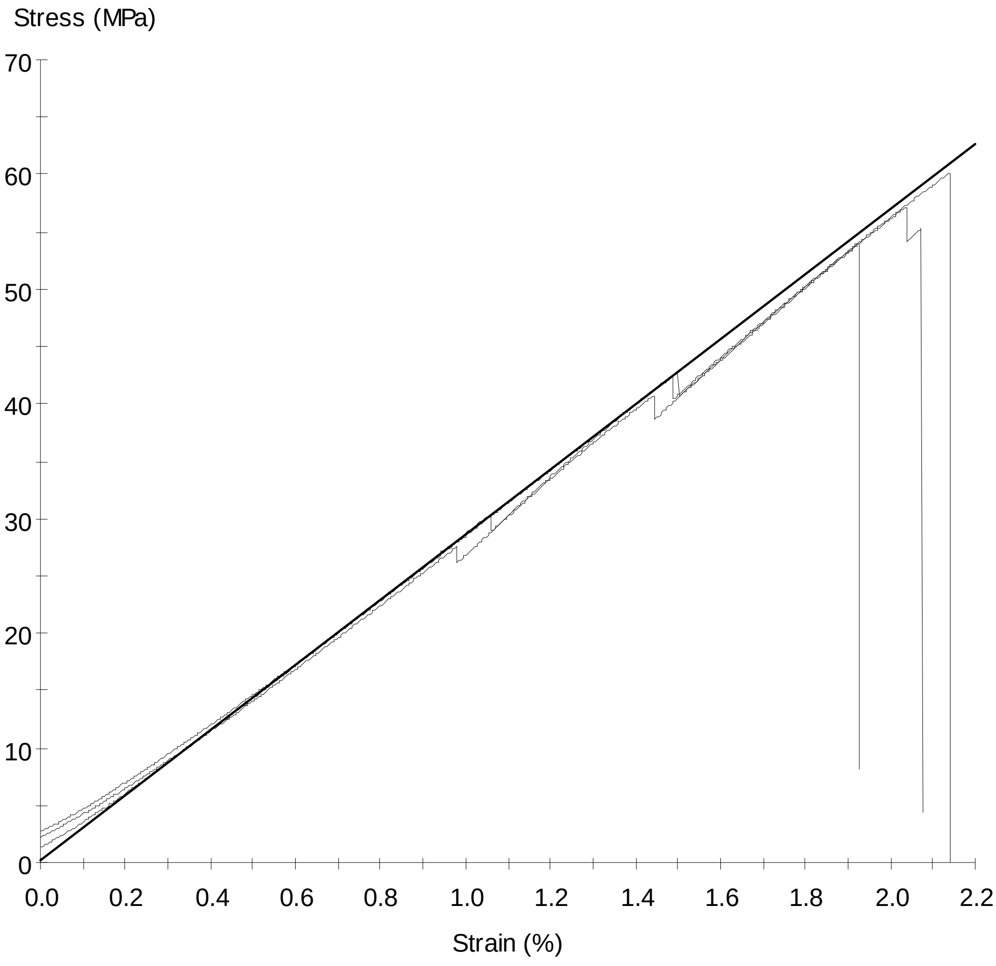
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.45	10.13	877	53.13	2.07	2.06	1.39	1.39	2594
2	15.59	9.97	936	57.99	2.37	2.37	1.62	1.62	2450
3	14.77	10.19	934	58.47	2.34	2.33	1.56	1.56	2506
Mean	**15.27**	**10.10**	**916**	**56.53**	**2.26**	**2.26**	**1.53**	**1.53**	**2517**
Std Dev	**0.44**	**0.11**	**33**	**2.95**	**0.17**	**0.17**	**0.12**	**0.12**	**72**



Stress vs Strain Plot

Sample 4

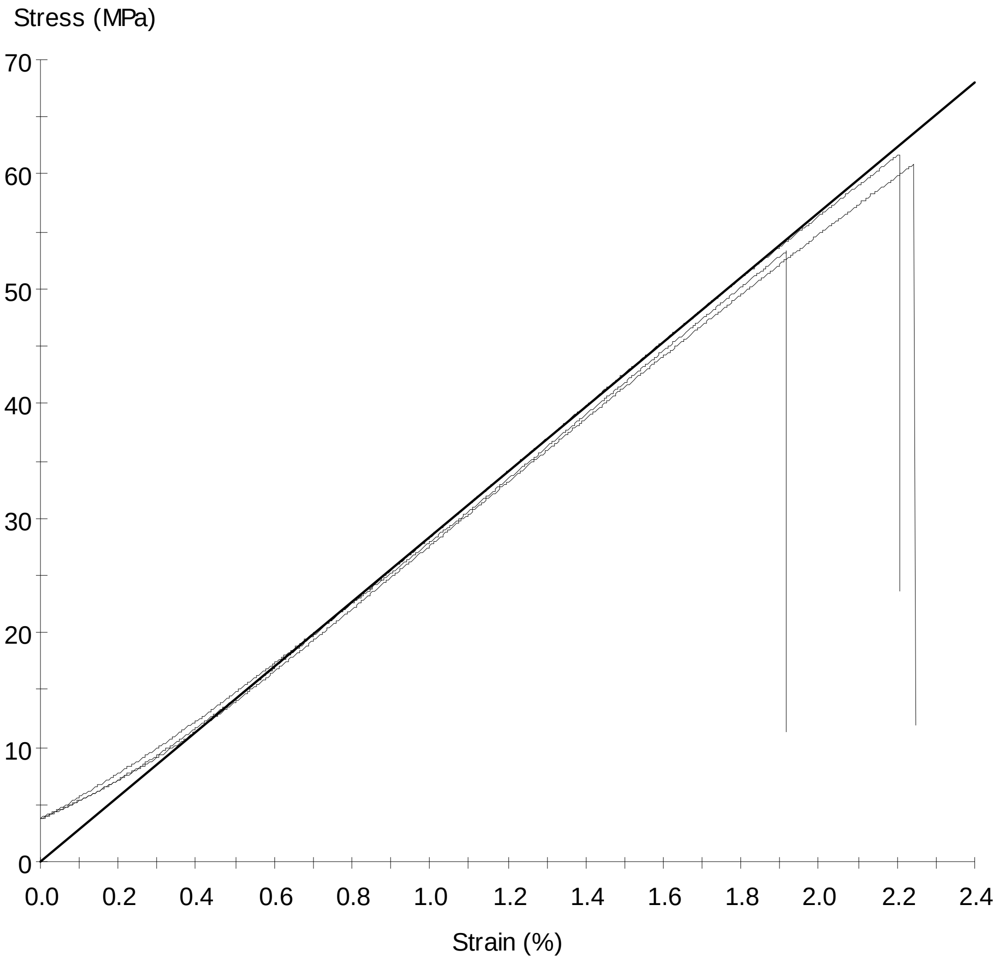
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.06	10.01	958	57.12	2.08	2.04	1.39	1.39	2803
2	16.00	9.97	996	60.10	2.14	2.14	1.47	1.47	2863
3	15.44	10.05	877	54.00	1.93	1.92	1.31	1.31	2851
Mean	**15.83**	**10.01**	**944**	**57.08**	**2.05**	**2.03**	**1.39**	**1.39**	**2839**
Std Dev	**0.34**	**0.04**	**60**	**3.05**	**0.11**	**0.11**	**0.08**	**0.08**	**32**



Stress vs Strain Plot

Sample 5

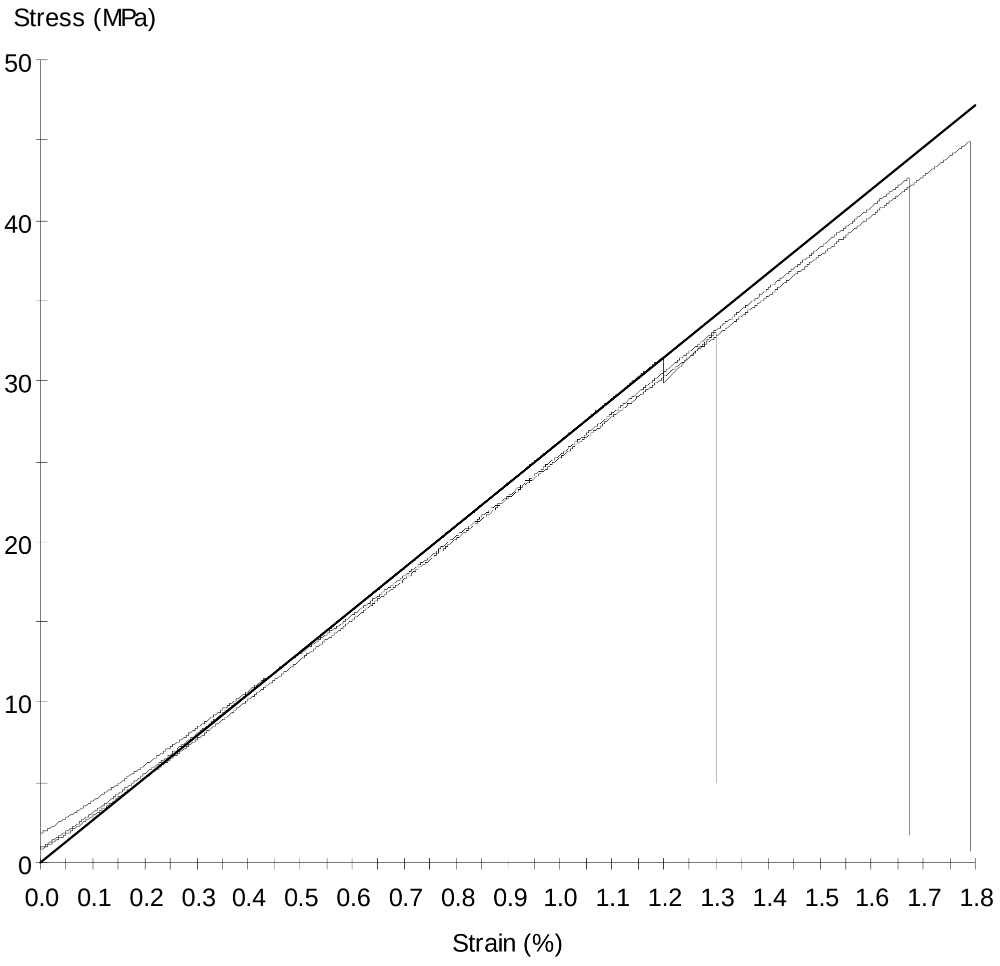
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.94	10.15	1108	60.94	2.25	2.24	1.51	1.51	2758
2	16.70	10.06	939	53.32	1.92	1.92	1.30	1.30	2786
3	16.80	10.14	1110	61.68	2.21	2.20	1.48	1.48	2837
Mean	**16.81**	**10.12**	**1052**	**58.65**	**2.12**	**2.12**	**1.43**	**1.43**	**2794**
Std Dev	**0.12**	**0.05**	**98**	**4.62**	**0.18**	**0.18**	**0.11**	**0.11**	**40**



Stress vs Strain Plot

Sample 6

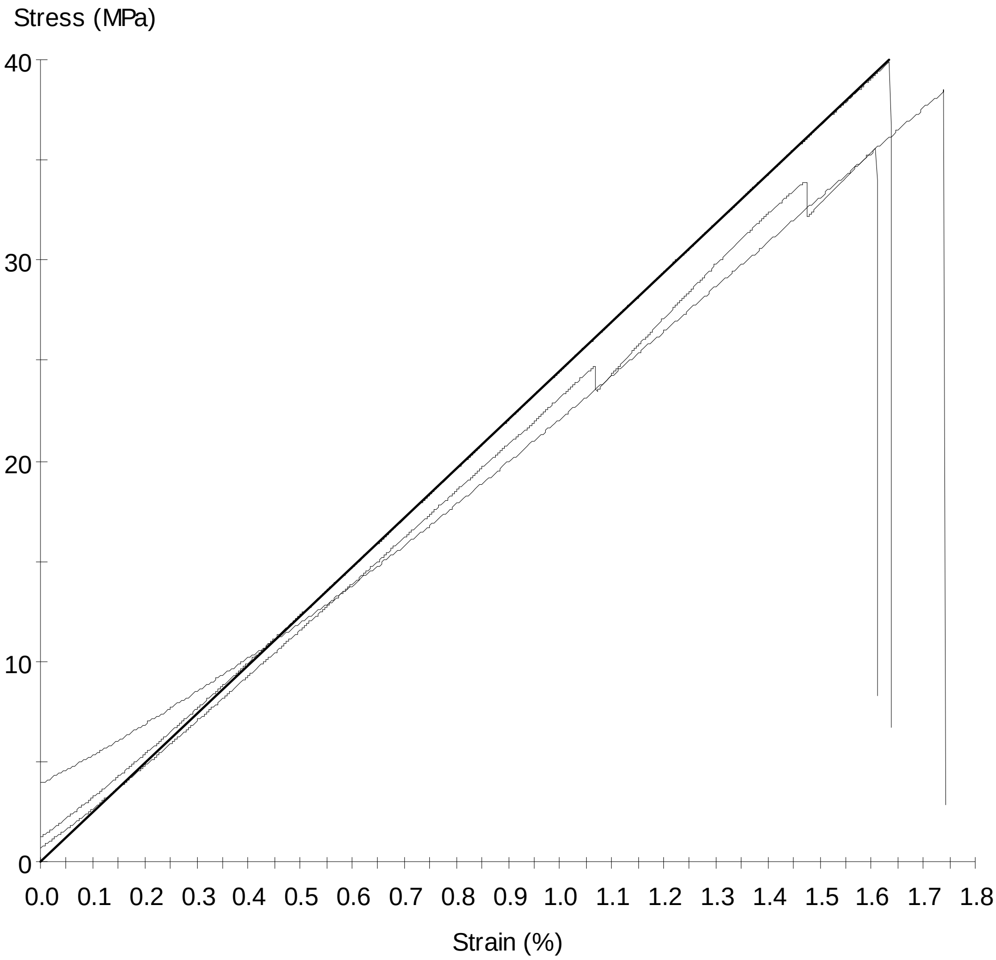
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.80	9.91	646	42.68	1.67	1.67	1.15	1.15	2542
2	14.33	9.91	658	44.91	1.79	1.79	1.23	1.23	2518
3	15.36	9.78	506	33.06	1.30	1.30	0.91	0.91	2621
Mean	**14.83**	**9.87**	**604**	**40.22**	**1.59**	**1.59**	**1.10**	**1.10**	**2560**
Std Dev	**0.52**	**0.08**	**85**	**6.30**	**0.26**	**0.25**	**0.17**	**0.17**	**54**



Stress vs Strain Plot

Sample 7

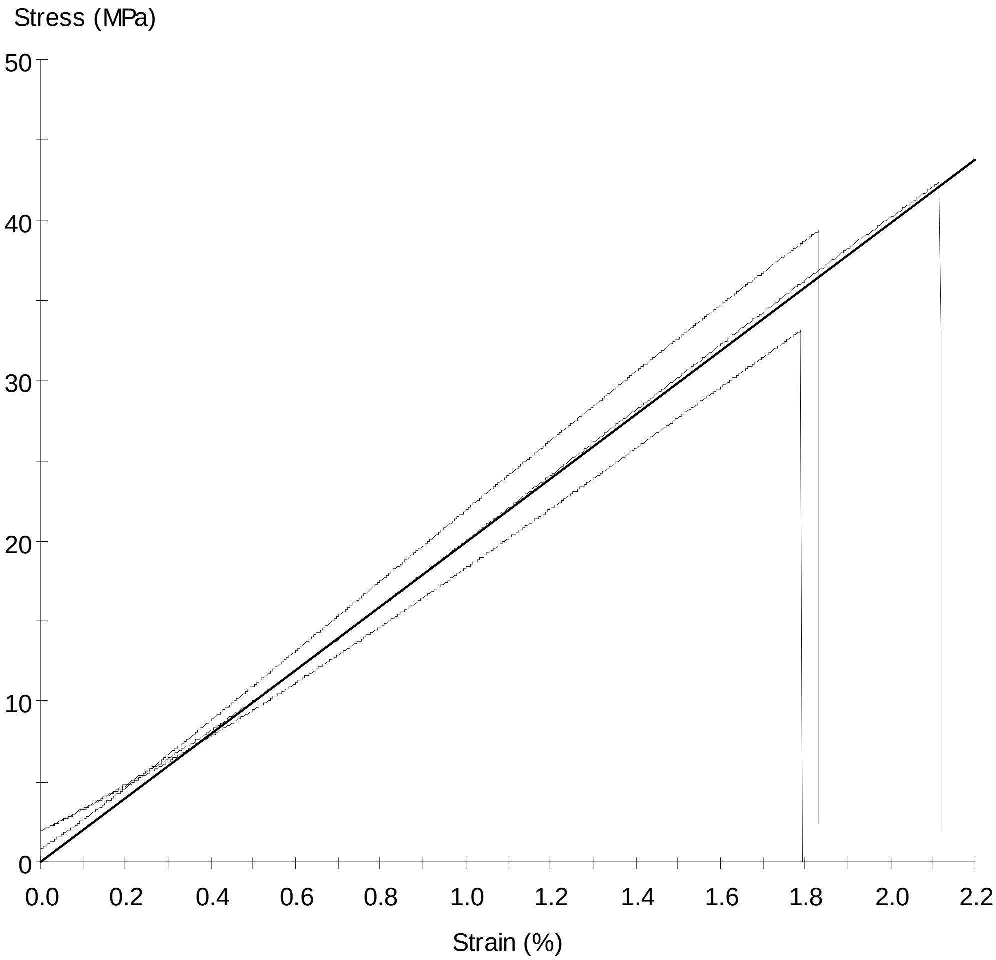
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.31	10.08	615	35.60	1.61	1.61	1.09	1.09	2310
2	16.75	10.22	702	38.49	1.74	1.74	1.16	1.16	2206
3	15.71	10.22	682	39.90	1.64	1.63	1.09	1.09	2446
Mean	**16.26**	**10.17**	**666**	**38.00**	**1.66**	**1.66**	**1.11**	**1.11**	**2321**
Std Dev	**0.52**	**0.08**	**46**	**2.19**	**0.07**	**0.07**	**0.04**	**0.04**	**120**



Stress vs Strain Plot

Sample 8

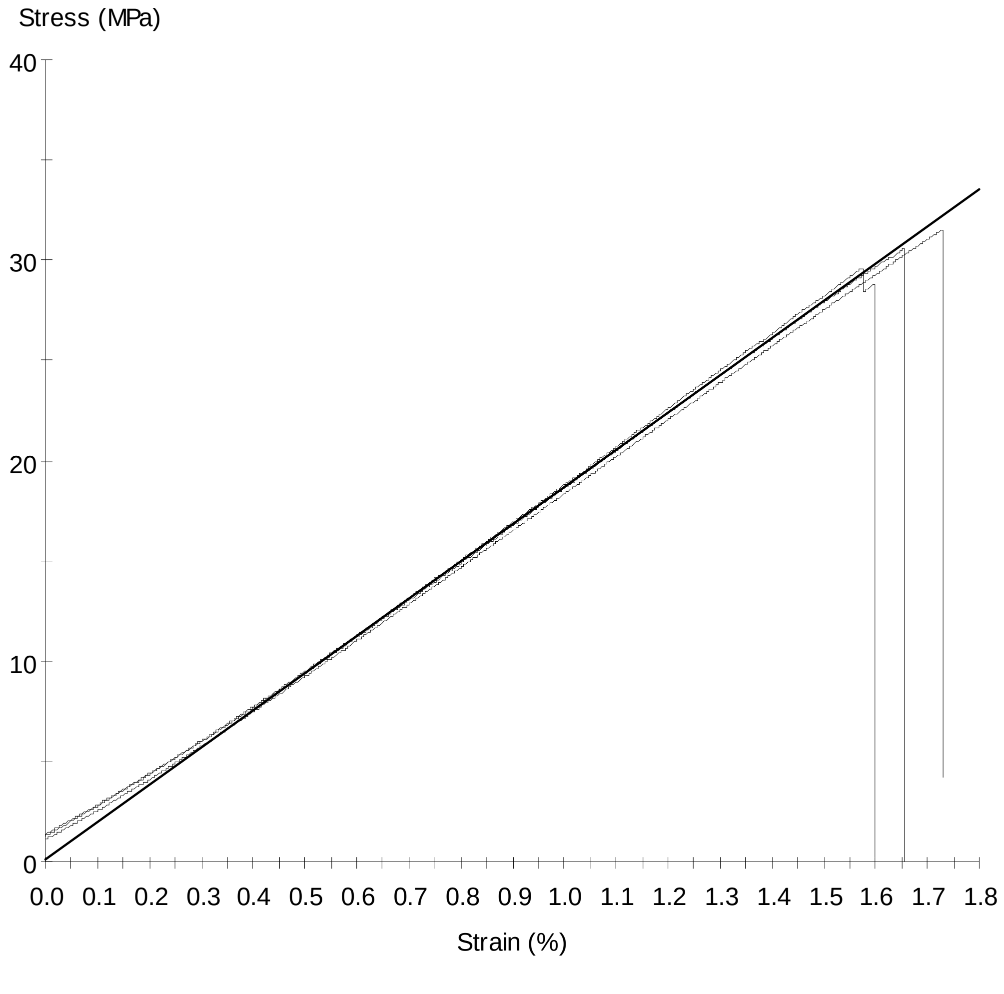
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.36	10.14	615	33.10	1.79	1.79	1.20	1.20	1831
2	16.87	10.09	703	39.32	1.83	1.83	1.24	1.24	2189
3	17.29	10.15	785	42.32	2.12	2.11	1.42	1.42	1990
Mean	**17.17**	**10.13**	**701**	**38.25**	**1.91**	**1.91**	**1.29**	**1.29**	**2003**
Std Dev	**0.27**	**0.03**	**85**	**4.70**	**0.18**	**0.18**	**0.12**	**0.12**	**179**



Stress vs Strain Plot

Sample 9

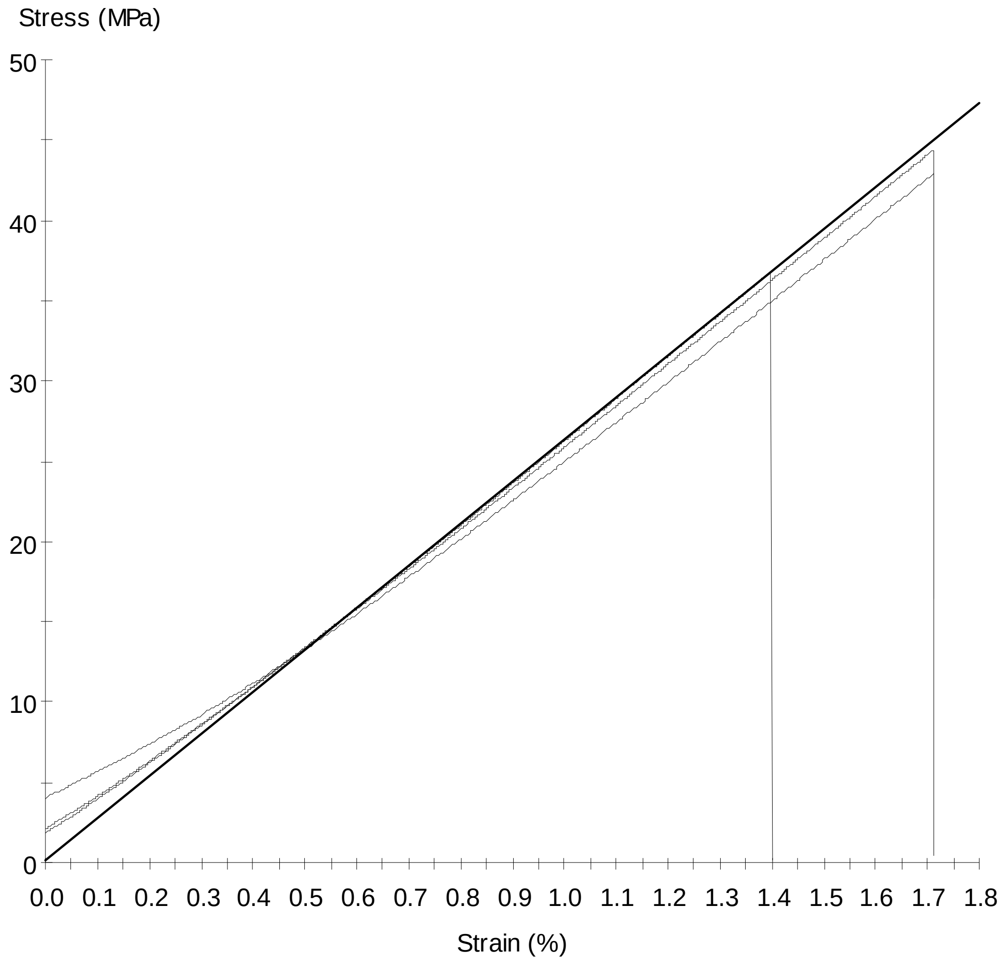
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	19.21	10.02	595	29.61	1.60	1.58	1.07	1.07	1879
2	18.67	9.96	609	31.55	1.73	1.73	1.19	1.19	1834
3	18.28	9.86	566	30.58	1.66	1.66	1.15	1.15	1862
Mean	**18.72**	**9.95**	**590**	**30.58**	**1.66**	**1.65**	**1.14**	**1.14**	**1858**
Std Dev	**0.47**	**0.08**	**22**	**0.97**	**0.07**	**0.08**	**0.06**	**0.06**	**23**



Stress vs Strain Plot

Sample 10

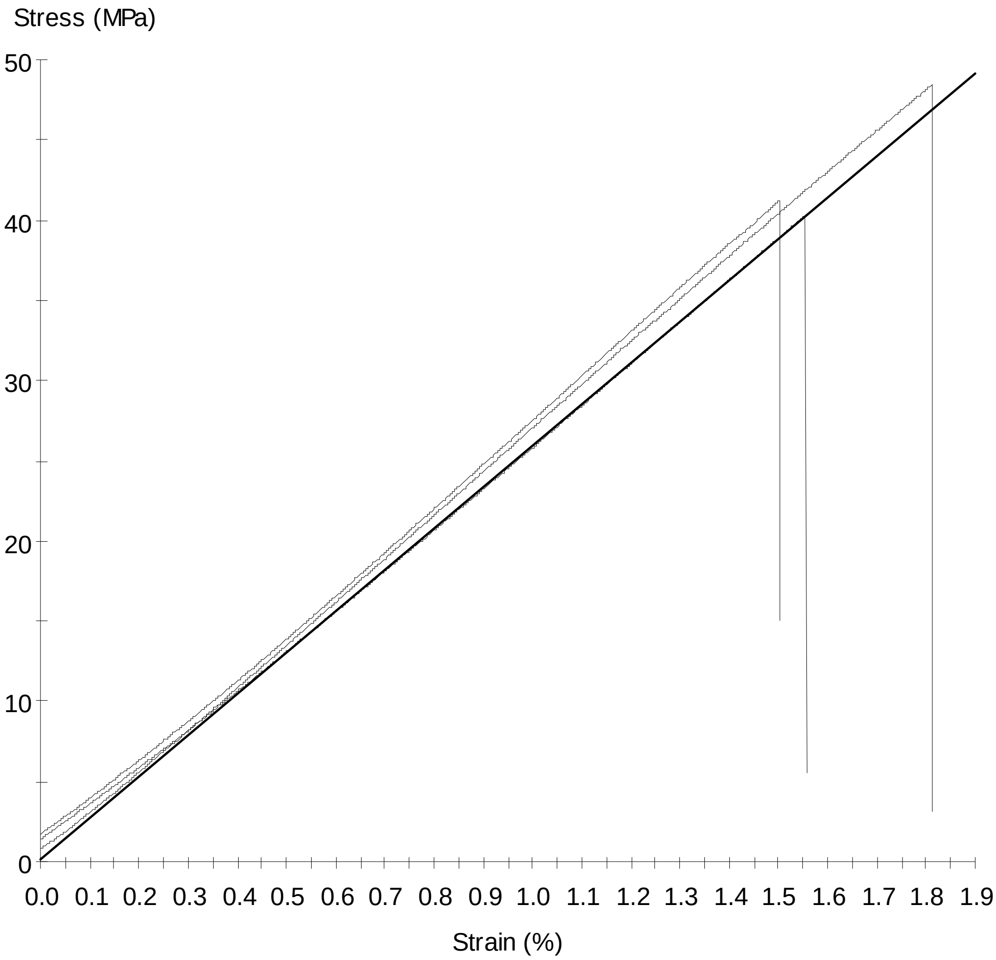
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.93	10.03	741	44.39	1.71	1.71	1.16	1.16	2590
2	15.26	10.17	705	42.88	1.71	1.71	1.15	1.15	2496
3	14.63	10.05	567	36.81	1.40	1.40	0.95	0.95	2626
Mean	**15.27**	**10.08**	**671**	**41.36**	**1.61**	**1.61**	**1.09**	**1.09**	**2570**
Std Dev	**0.65**	**0.08**	**92**	**4.01**	**0.18**	**0.18**	**0.12**	**0.12**	**67**



Stress vs Strain Plot

Sample 11

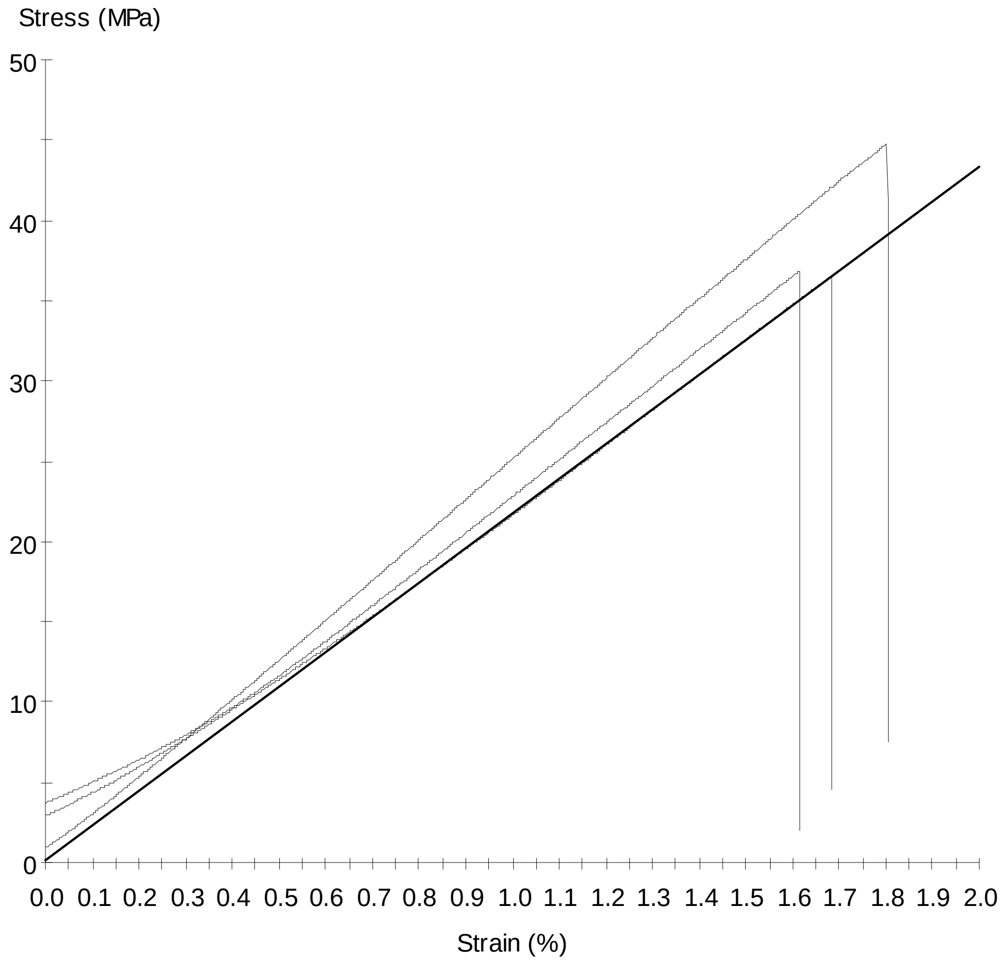
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.43	9.99	826	48.38	1.81	1.81	1.24	1.24	2698
2	15.31	9.95	651	41.21	1.50	1.50	1.03	1.03	2752
3	15.85	9.94	657	40.28	1.56	1.55	1.07	1.07	2586
Mean	**15.86**	**9.96**	**711**	**43.29**	**1.62**	**1.62**	**1.11**	**1.11**	**2679**
Std Dev	**0.56**	**0.03**	**100**	**4.43**	**0.17**	**0.17**	**0.11**	**0.11**	**85**



Stress vs Strain Plot

Sample 12

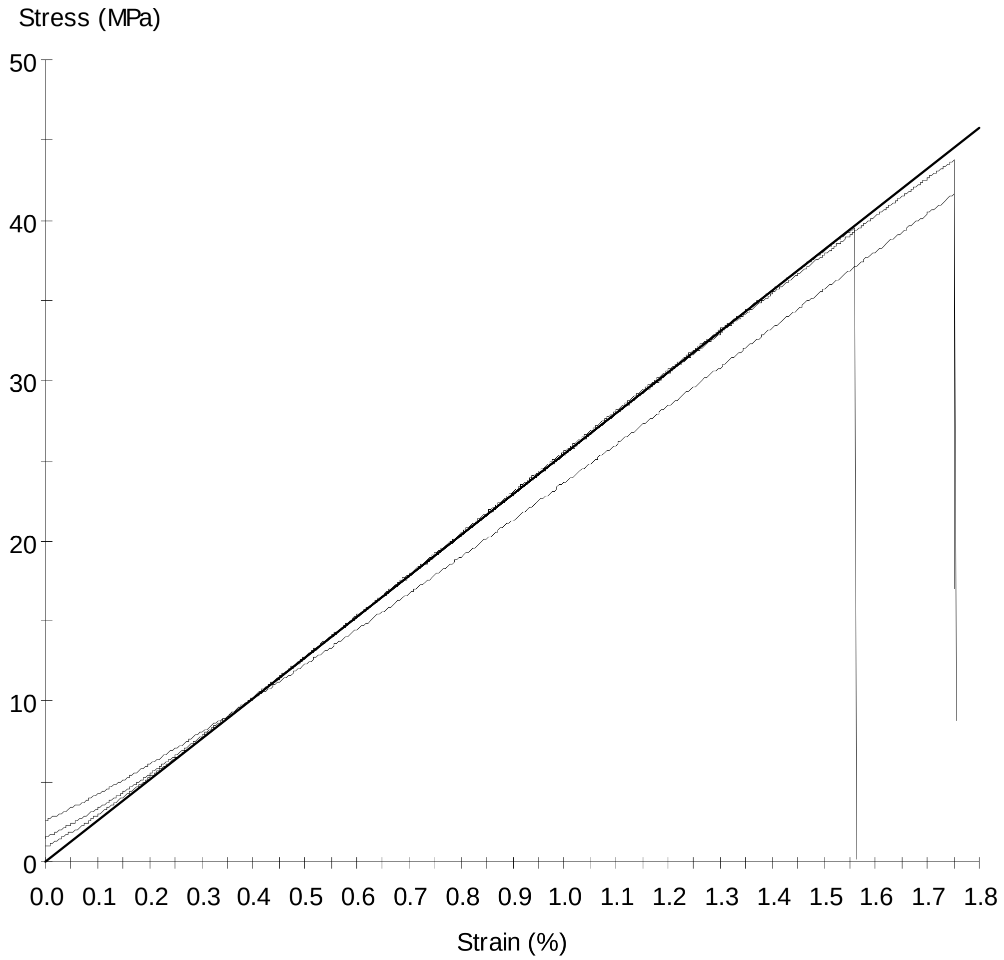
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.42	10.24	660	36.81	1.62	1.61	1.08	1.08	2282
2	16.77	10.09	796	44.78	1.80	1.80	1.22	1.22	2513
3	17.37	10.23	691	36.51	1.68	1.68	1.12	1.12	2169
Mean	**16.85**	**10.19**	**716**	**39.37**	**1.70**	**1.70**	**1.14**	**1.14**	**2321**
Std Dev	**0.48**	**0.08**	**71**	**4.69**	**0.10**	**0.10**	**0.07**	**0.07**	**175**



Stress vs Strain Plot

Sample 13

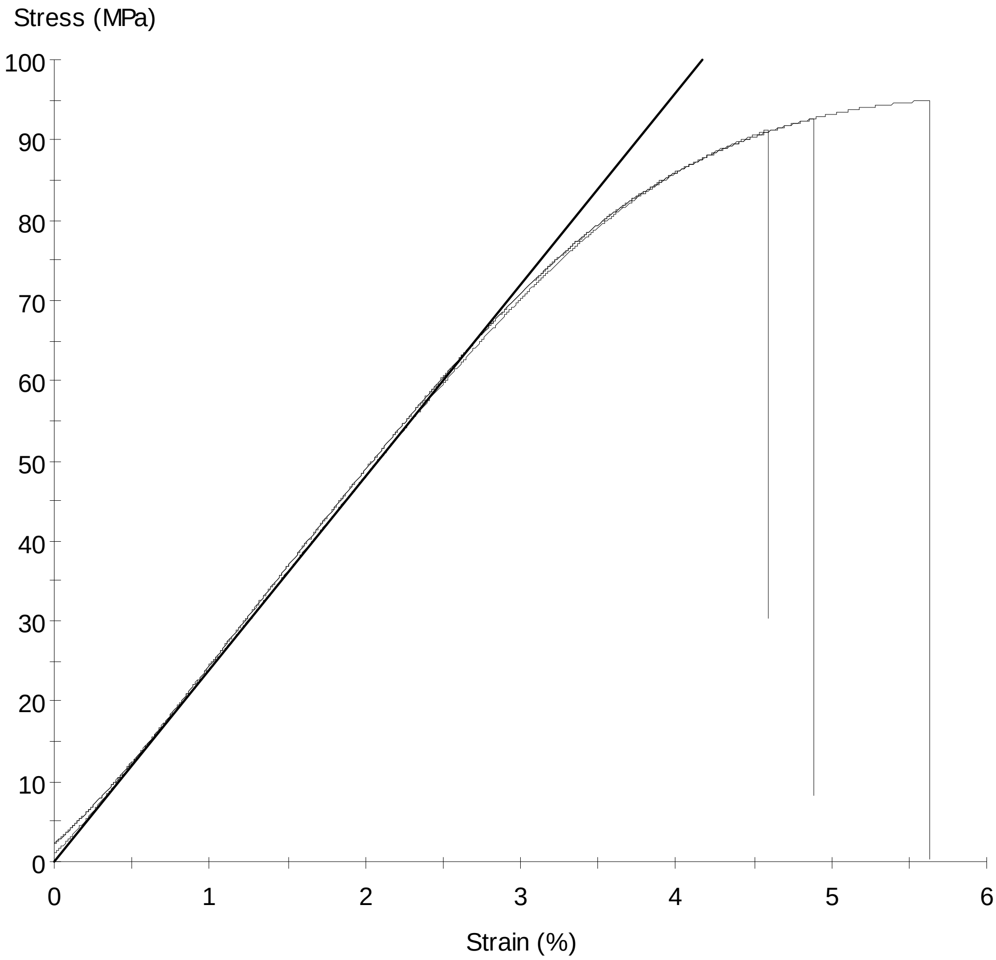
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.69	10.12	746	39.51	1.56	1.56	1.05	1.05	2558
2	18.27	10.09	806	41.62	1.76	1.75	1.19	1.19	2370
3	16.64	10.06	767	43.73	1.75	1.75	1.19	1.19	2537
Mean	**17.53**	**10.09**	**773**	**41.62**	**1.69**	**1.69**	**1.14**	**1.14**	**2488**
Std Dev	**0.83**	**0.03**	**31**	**2.11**	**0.11**	**0.11**	**0.08**	**0.08**	**103**



Stress vs Strain Plot

Sample 14

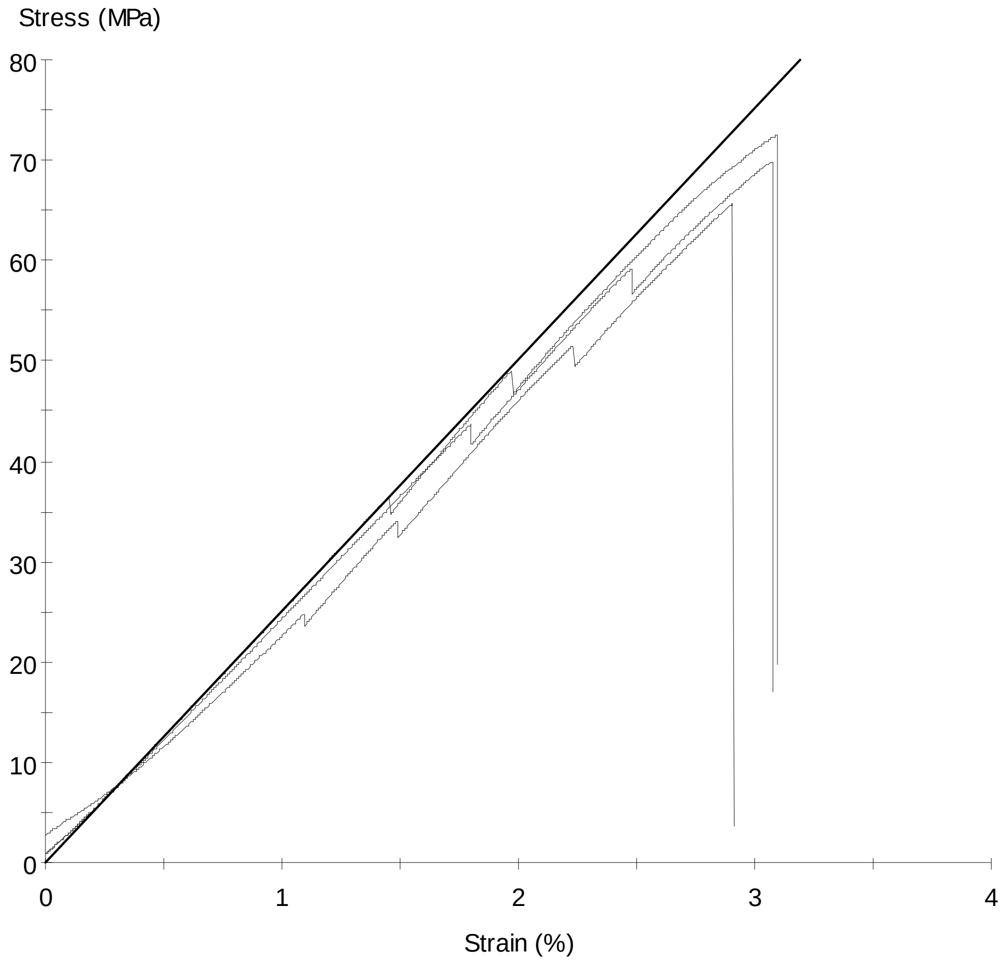
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.24	10.08	1494	92.60	4.89	4.88	3.31	3.31	2451
2	15.61	9.96	1531	94.91	5.63	5.63	3.86	3.86	2448
3	15.50	9.97	1464	91.24	4.60	4.59	3.14	3.14	2405
Mean	**15.45**	**10.00**	**1496**	**92.92**	**5.04**	**5.04**	**3.44**	**3.44**	**2435**
Std Dev	**0.19**	**0.07**	**33**	**1.85**	**0.53**	**0.54**	**0.37**	**0.37**	**26**



Stress vs Strain Plot

Sample 15

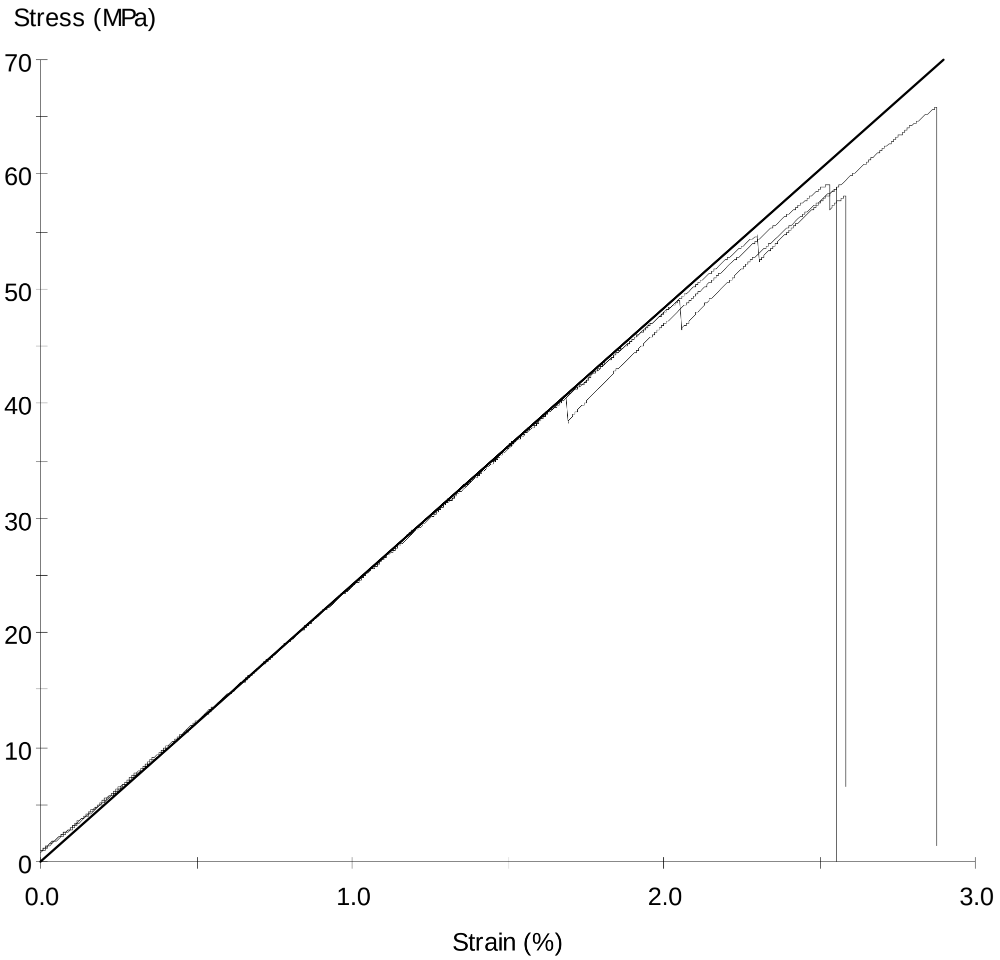
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.29	10.02	1190	69.87	3.08	3.07	2.09	2.09	2431
2	15.76	10.06	1093	65.76	2.91	2.91	1.97	1.97	2260
3	15.92	9.94	1189	72.55	3.10	3.09	2.12	2.12	2507
Mean	**15.99**	**10.01**	**1157**	**69.40**	**3.03**	**3.03**	**2.06**	**2.06**	**2399**
Std Dev	**0.27**	**0.06**	**56**	**3.42**	**0.10**	**0.10**	**0.08**	**0.08**	**127**



Stress vs Strain Plot

Sample 16

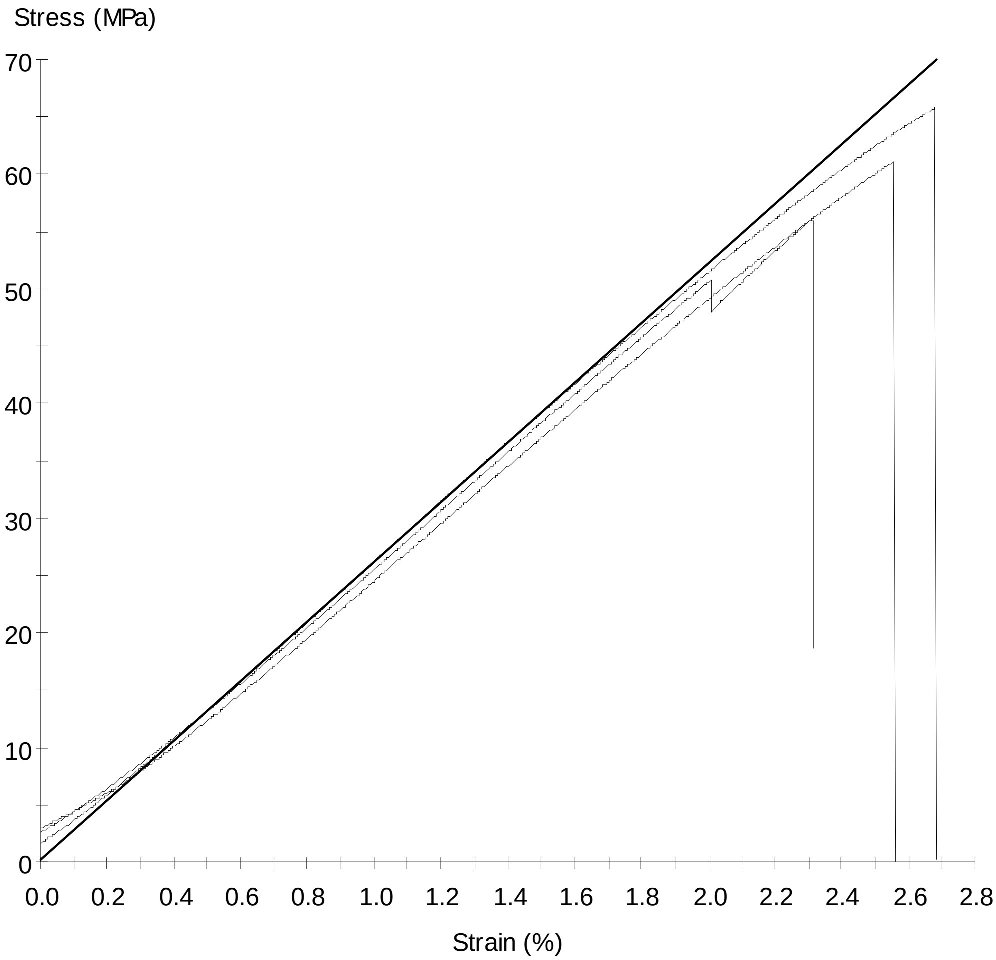
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.33	10.13	1221	65.89	2.88	2.87	1.94	1.94	2400
2	16.90	10.13	1063	58.85	2.56	2.56	1.72	1.72	2409
3	17.15	10.01	1059	59.16	2.58	2.53	1.73	1.73	2417
Mean	**17.13**	**10.09**	**1114**	**61.30**	**2.67**	**2.65**	**1.80**	**1.80**	**2409**
Std Dev	**0.22**	**0.07**	**92**	**3.98**	**0.18**	**0.19**	**0.12**	**0.12**	**8**



Stress vs Strain Plot

Sample 17

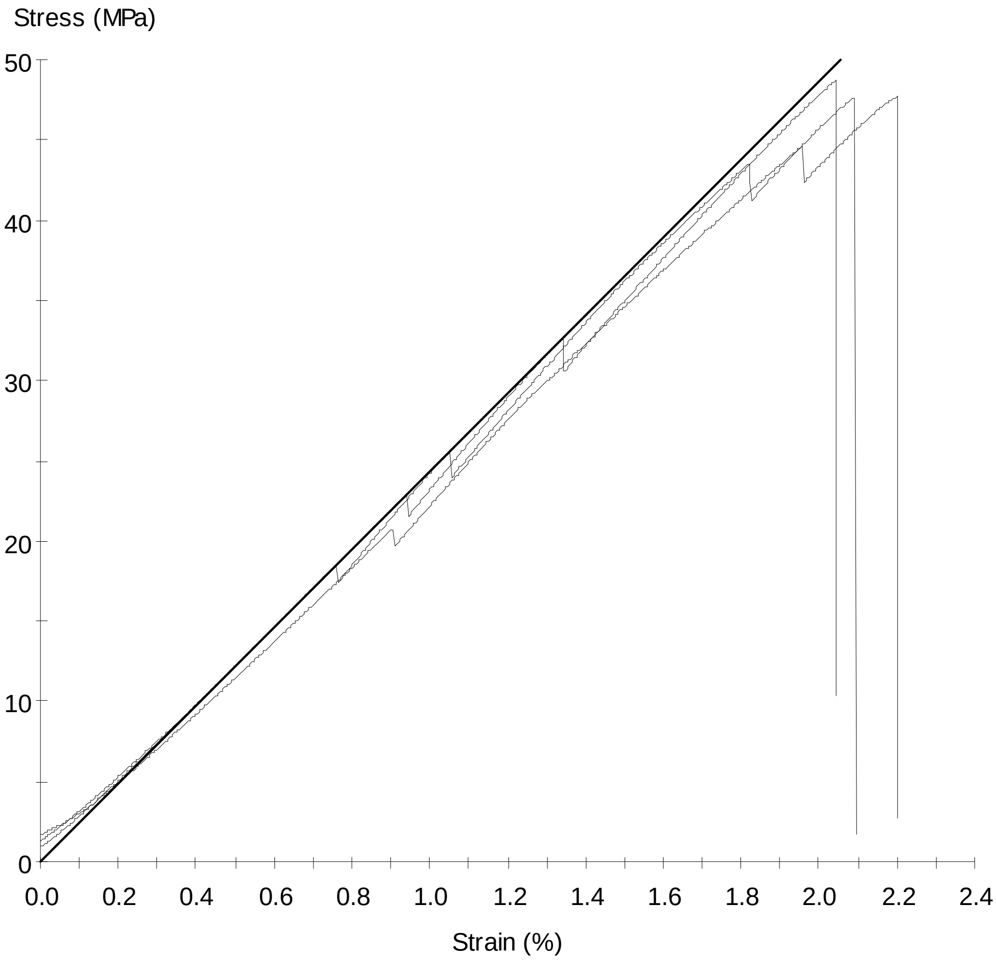
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.44	10.05	1121	61.09	2.56	2.56	1.74	1.74	2463
2	17.30	10.05	1020	56.02	2.32	2.31	1.57	1.57	2554
3	17.86	9.87	1192	65.76	2.68	2.68	1.85	1.85	2620
Mean	**17.53**	**9.99**	**1111**	**60.96**	**2.52**	**2.52**	**1.72**	**1.72**	**2546**
Std Dev	**0.29**	**0.10**	**87**	**4.87**	**0.19**	**0.19**	**0.14**	**0.14**	**79**



Stress vs Strain Plot

Sample 18

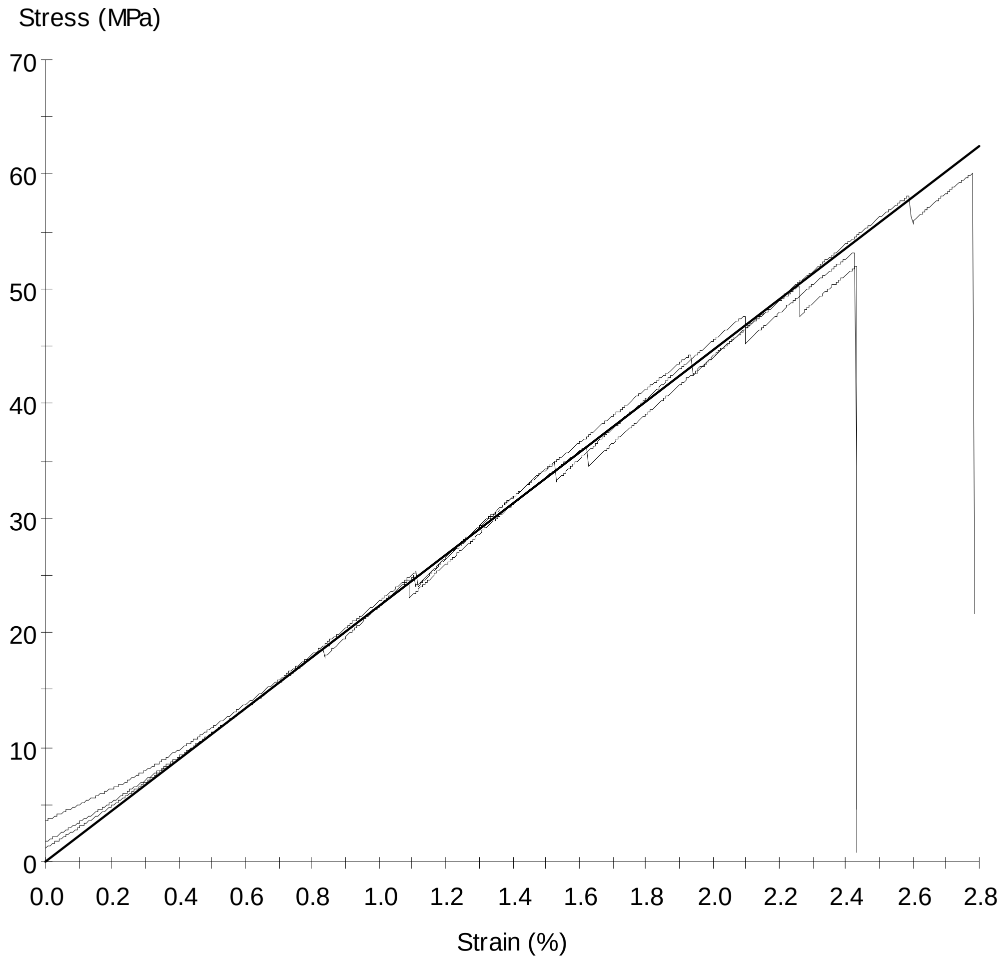
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.44	9.98	912	47.69	2.20	2.20	1.51	1.51	2288
2	18.13	10.07	912	47.65	2.09	2.09	1.42	1.42	2434
3	18.50	10.03	944	48.72	2.05	2.04	1.39	1.39	2429
Mean	**18.36**	**10.03**	**923**	**48.02**	**2.12**	**2.11**	**1.44**	**1.44**	**2384**
Std Dev	**0.20**	**0.05**	**19**	**0.61**	**0.08**	**0.08**	**0.06**	**0.06**	**83**



Stress vs Strain Plot

Sample 19

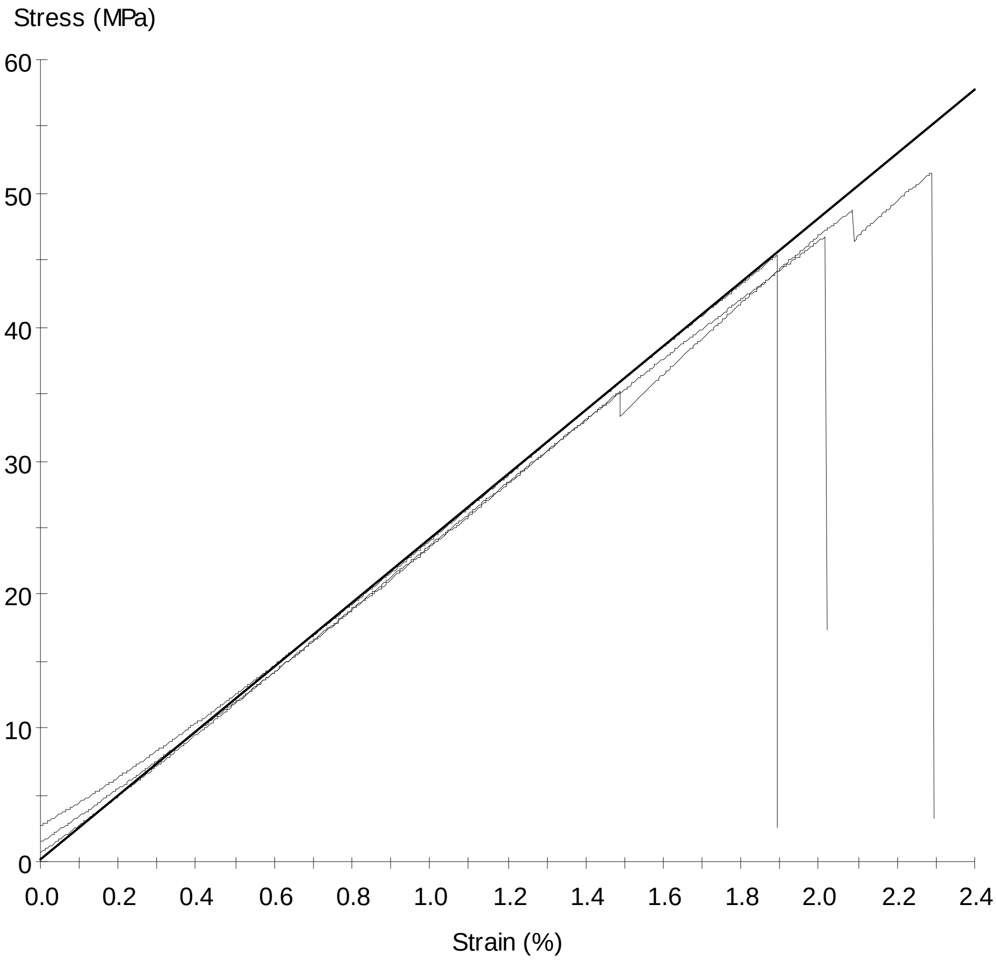
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.98	10.18	953	51.97	2.43	2.43	1.63	1.63	2228
2	16.78	10.18	964	53.23	2.43	2.43	1.63	1.63	2268
3	16.99	10.09	1084	60.14	2.78	2.78	1.88	1.88	2232
Mean	**16.92**	**10.15**	**1000**	**55.11**	**2.55**	**2.55**	**1.71**	**1.71**	**2243**
Std Dev	**0.12**	**0.05**	**72**	**4.40**	**0.20**	**0.20**	**0.15**	**0.15**	**22**



Stress vs Strain Plot

Sample 20

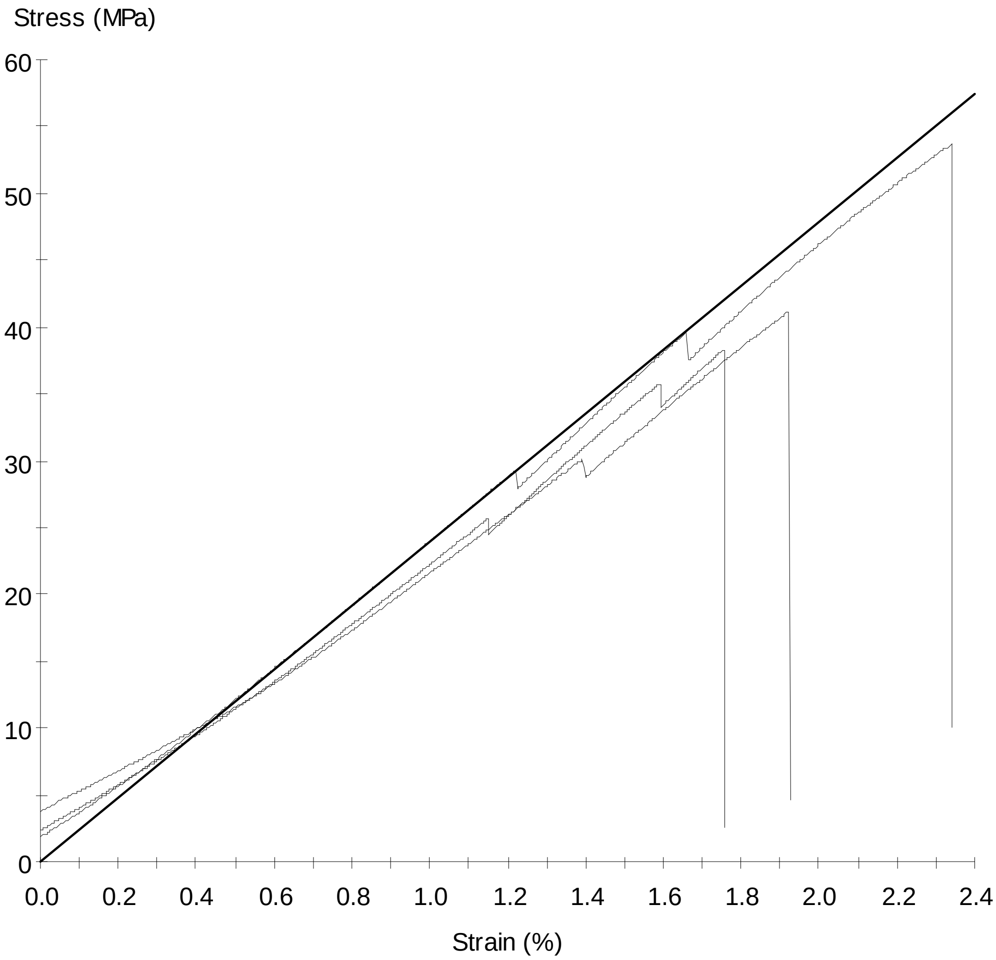
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.48	10.15	912	51.59	2.29	2.29	1.54	1.54	2350
2	17.35	10.15	871	46.78	2.02	2.02	1.36	1.36	2364
3	17.22	10.04	820	45.33	1.89	1.89	1.29	1.29	2406
Mean	**17.02**	**10.11**	**868**	**47.90**	**2.07**	**2.07**	**1.39**	**1.39**	**2373**
Std Dev	**0.47**	**0.06**	**46**	**3.28**	**0.20**	**0.20**	**0.13**	**0.13**	**29**



Stress vs Strain Plot

Sample 21

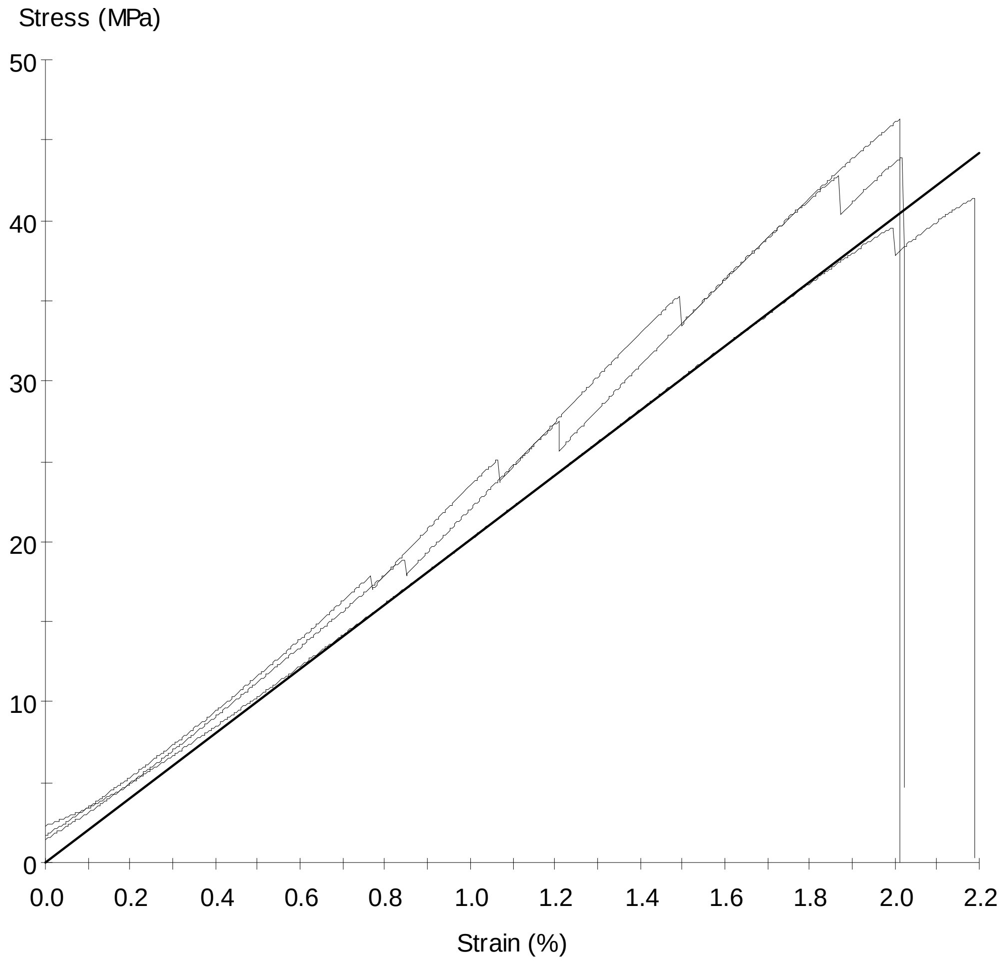
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.39	10.09	804	41.21	1.92	1.92	1.30	1.30	2158
2	18.10	10.11	738	38.31	1.76	1.75	1.18	1.18	2222
3	18.58	10.06	1052	53.70	2.34	2.34	1.59	1.59	2397
Mean	**18.36**	**10.09**	**865**	**44.41**	**2.01**	**2.01**	**1.36**	**1.36**	**2259**
Std Dev	**0.24**	**0.03**	**165**	**8.17**	**0.30**	**0.30**	**0.21**	**0.21**	**124**



Stress vs Strain Plot

Sample 22

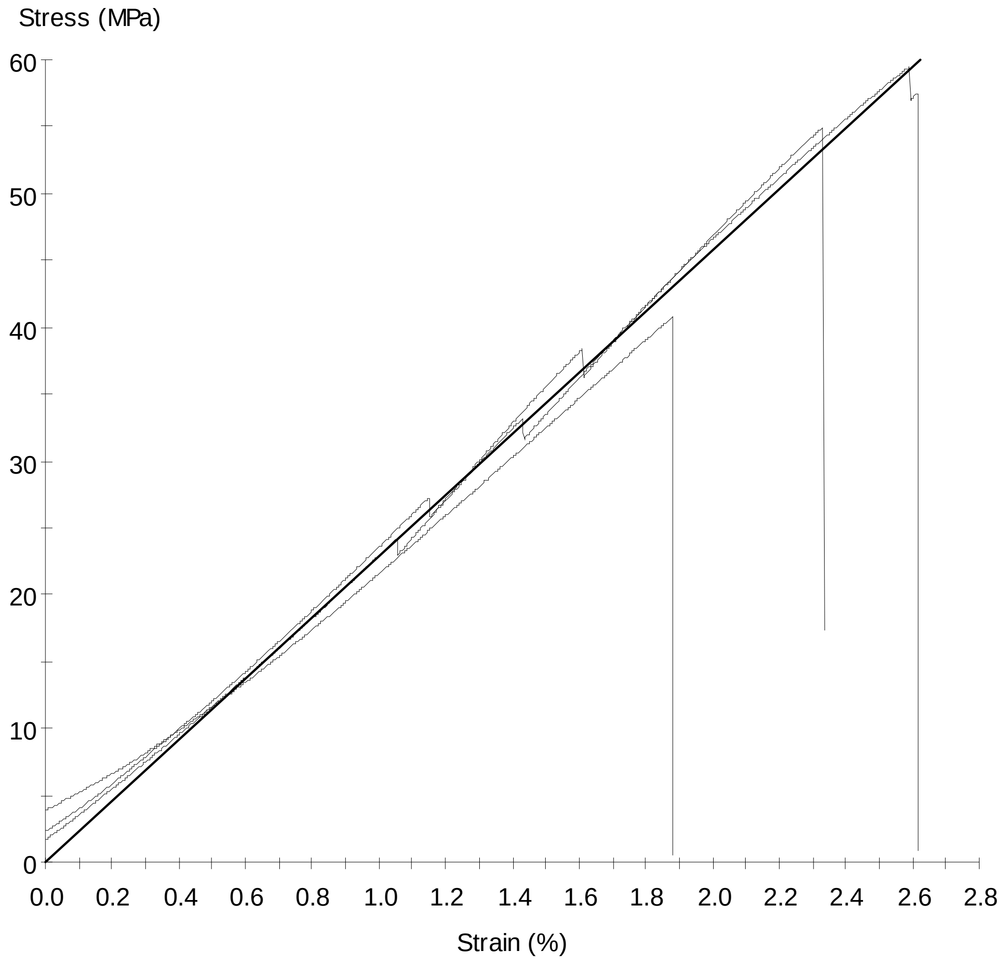
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	19.23	9.99	878	43.93	2.02	2.02	1.38	1.38	2237
2	18.54	10.00	893	46.26	2.01	2.01	1.37	1.37	2322
3	18.08	10.54	866	41.38	2.19	2.19	1.42	1.42	2012
Mean	**18.62**	**10.18**	**879**	**43.86**	**2.08**	**2.07**	**1.39**	**1.39**	**2190**
Std Dev	**0.58**	**0.31**	**14**	**2.44**	**0.10**	**0.10**	**0.02**	**0.02**	**160**



Stress vs Strain Plot

Sample 23

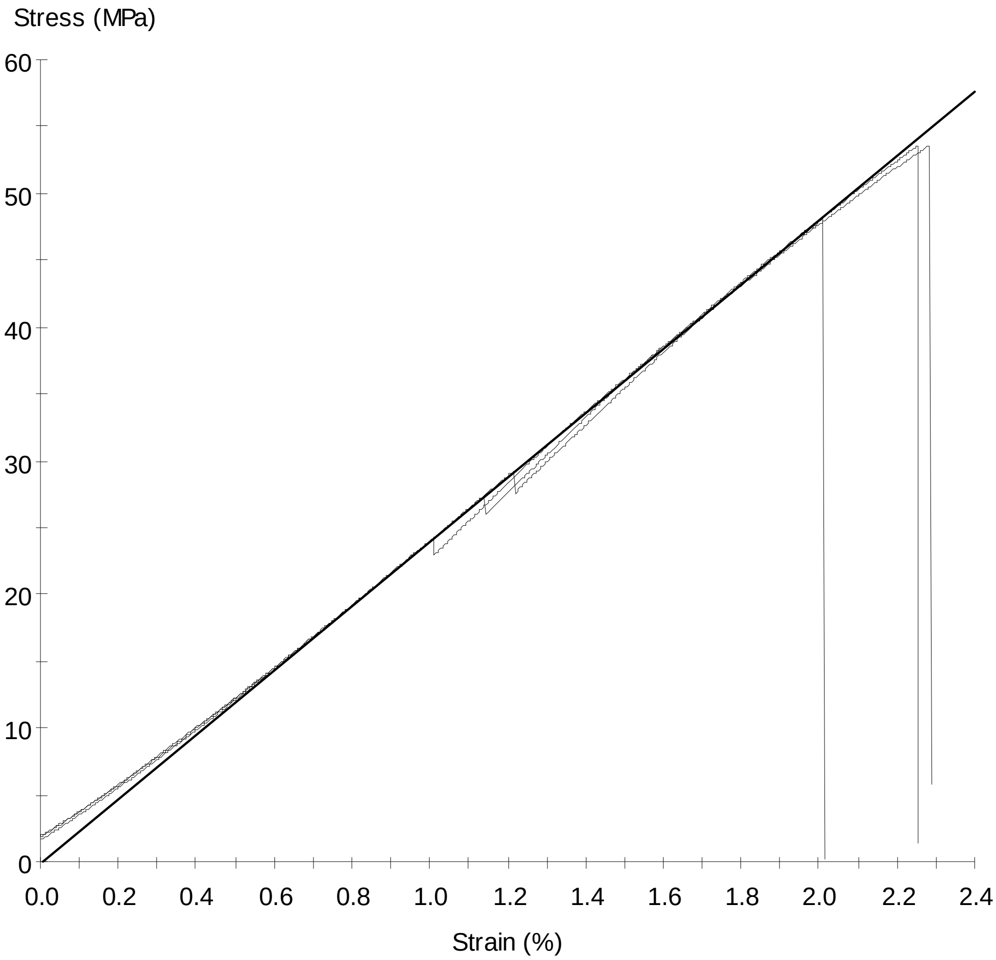
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.55	10.21	733	40.77	1.88	1.88	1.26	1.26	2162
2	16.20	9.98	924	54.97	2.33	2.33	1.59	1.59	2355
3	16.10	10.01	999	59.44	2.62	2.59	1.77	1.77	2285
Mean	**16.28**	**10.07**	**885**	**51.72**	**2.28**	**2.27**	**1.54**	**1.54**	**2267**
Std Dev	**0.24**	**0.13**	**137**	**9.75**	**0.37**	**0.36**	**0.26**	**0.26**	**98**



Stress vs Strain Plot

Sample 24

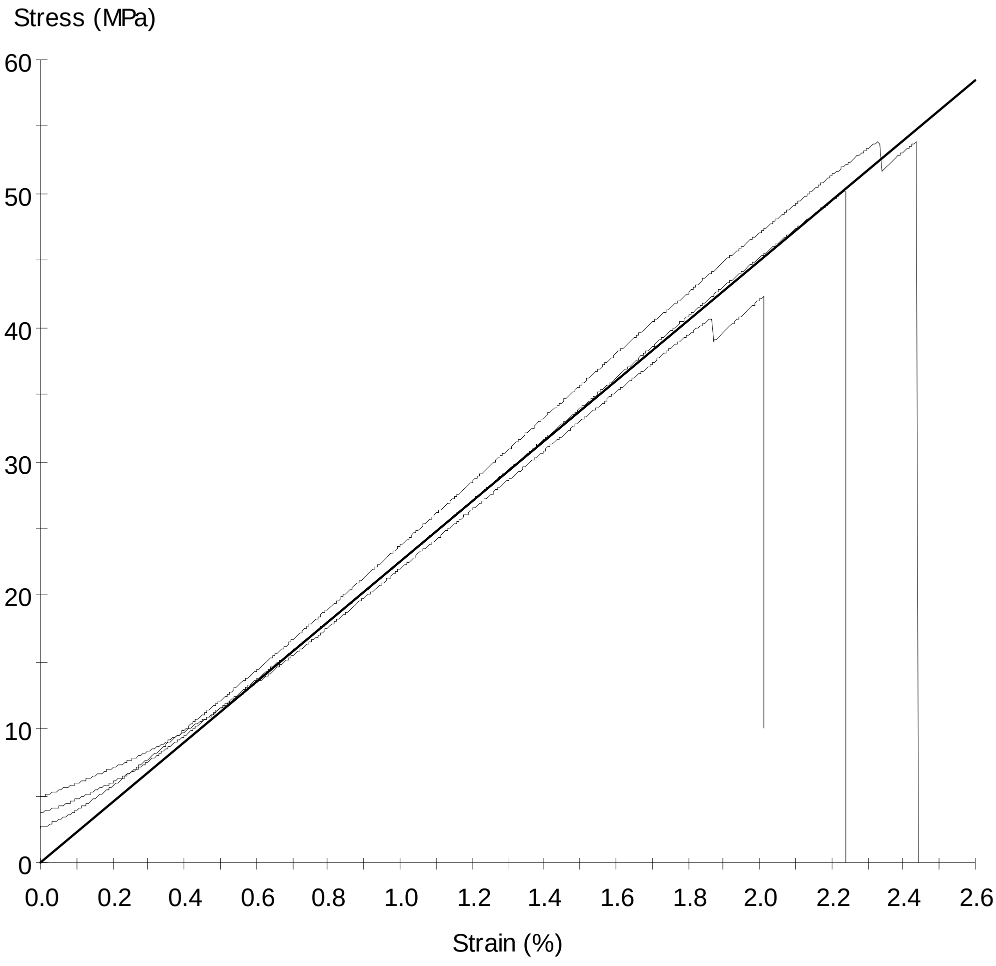
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.96	10.06	1015	53.61	2.29	2.28	1.55	1.55	2401
2	17.58	10.03	987	53.59	2.25	2.25	1.53	1.53	2397
3	17.43	9.99	872	48.12	2.01	2.01	1.37	1.37	2393
Mean	**17.66**	**10.03**	**958**	**51.77**	**2.19**	**2.18**	**1.49**	**1.49**	**2397**
Std Dev	**0.27**	**0.04**	**76**	**3.16**	**0.15**	**0.15**	**0.10**	**0.10**	**4**



Stress vs Strain Plot

Sample 25

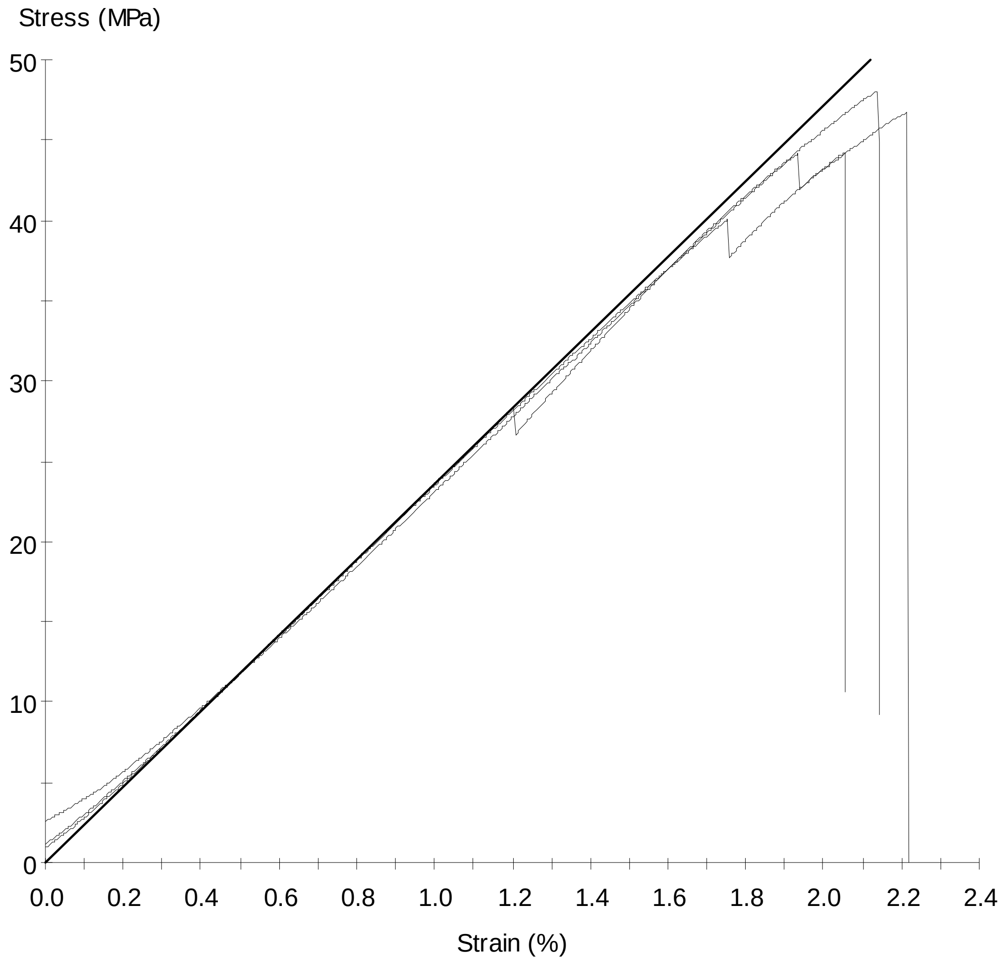
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.38	10.42	879	42.28	2.01	2.01	1.32	1.32	2197
2	18.00	10.12	1035	53.91	2.44	2.33	1.57	1.57	2370
3	18.10	10.12	969	50.21	2.24	2.24	1.51	1.51	2251
Mean	**18.16**	**10.22**	**961**	**48.80**	**2.23**	**2.19**	**1.47**	**1.47**	**2273**
Std Dev	**0.20**	**0.17**	**78**	**5.94**	**0.21**	**0.17**	**0.13**	**0.13**	**89**



Stress vs Strain Plot

Sample 26

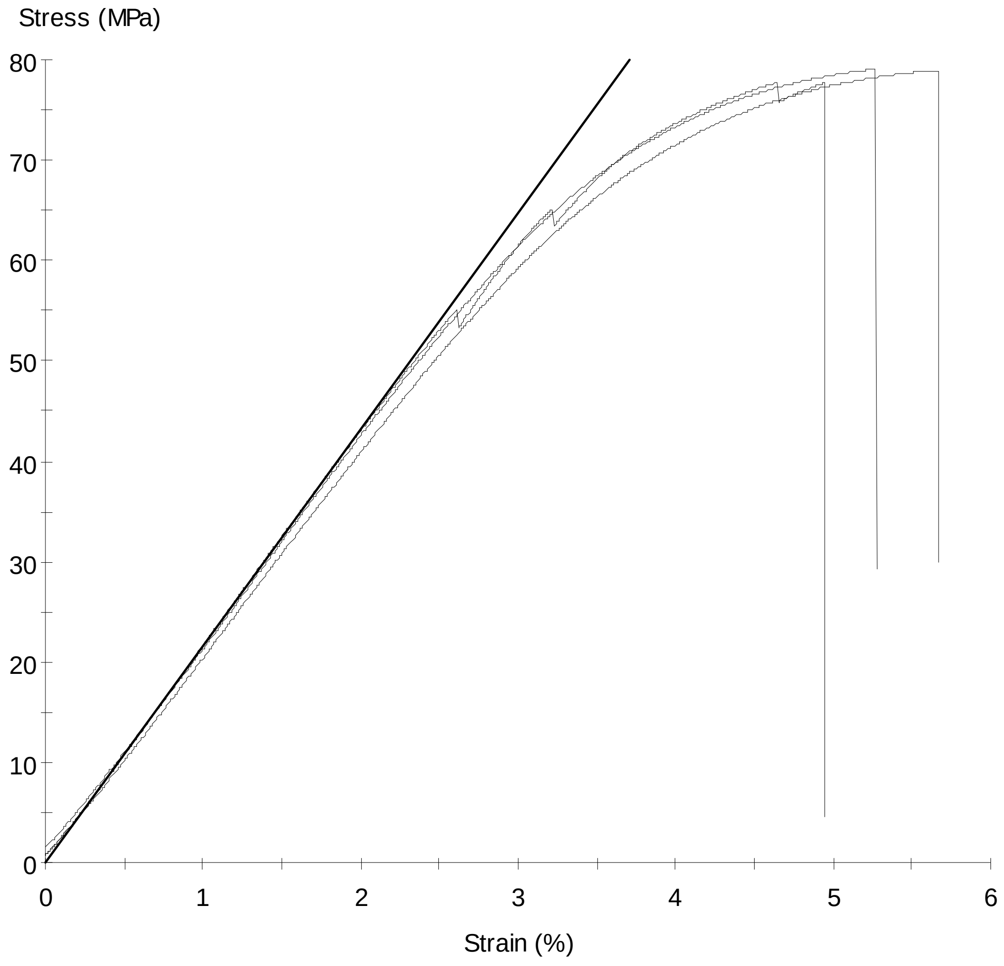
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.81	10.15	891	44.13	2.06	2.06	1.38	1.38	2347
2	18.78	10.12	936	46.72	2.22	2.21	1.49	1.49	2308
3	18.46	10.20	962	48.07	2.14	2.14	1.43	1.43	2358
Mean	**18.68**	**10.16**	**930**	**46.31**	**2.14**	**2.14**	**1.44**	**1.44**	**2338**
Std Dev	**0.19**	**0.04**	**36**	**2.00**	**0.08**	**0.08**	**0.06**	**0.06**	**26**



Stress vs Strain Plot

Sample 27

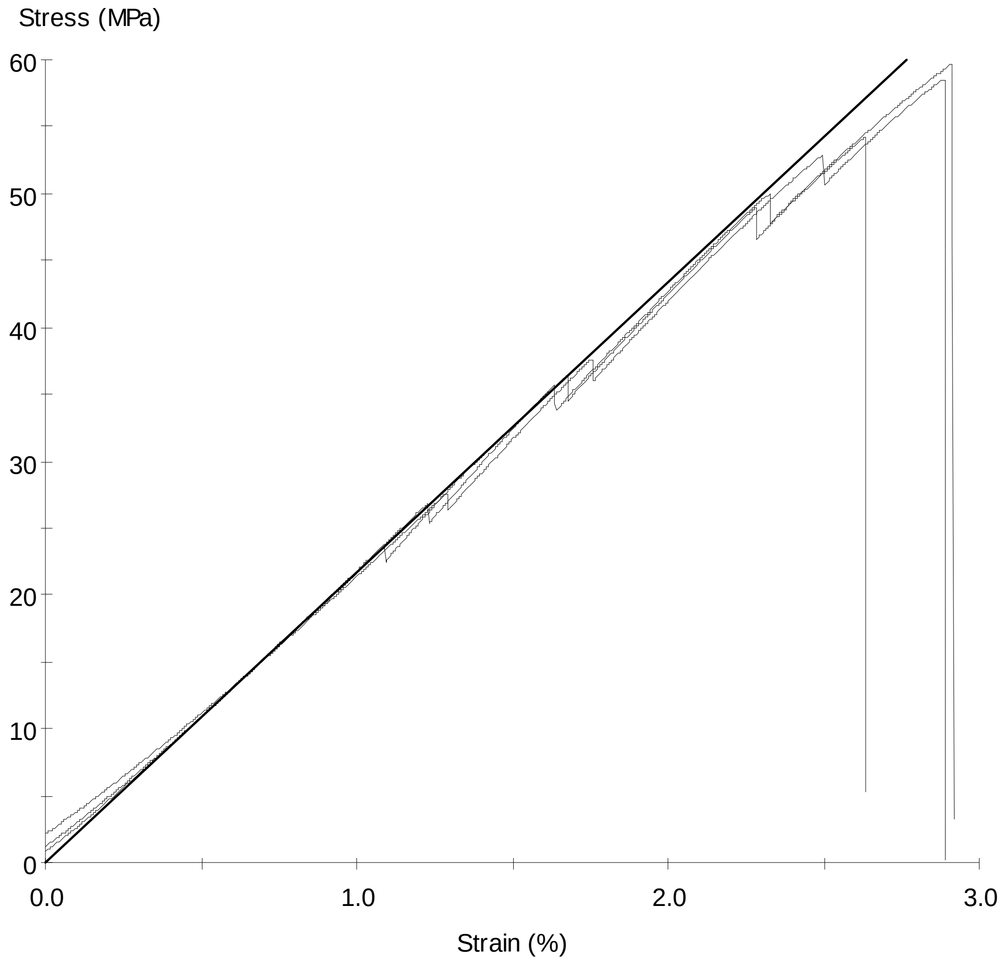
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.80	10.00	1219	79.09	5.28	5.27	3.60	3.60	2132
2	15.10	10.00	1242	78.95	5.67	5.66	3.86	3.86	2045
3	15.60	10.00	1263	77.70	4.95	4.64	3.17	3.17	2163
Mean	**15.17**	**10.00**	**1241**	**78.58**	**5.30**	**5.19**	**3.54**	**3.54**	**2113**
Std Dev	**0.40**	**0.00**	**22**	**0.77**	**0.36**	**0.51**	**0.35**	**0.35**	**61**



Stress vs Strain Plot

Sample 28

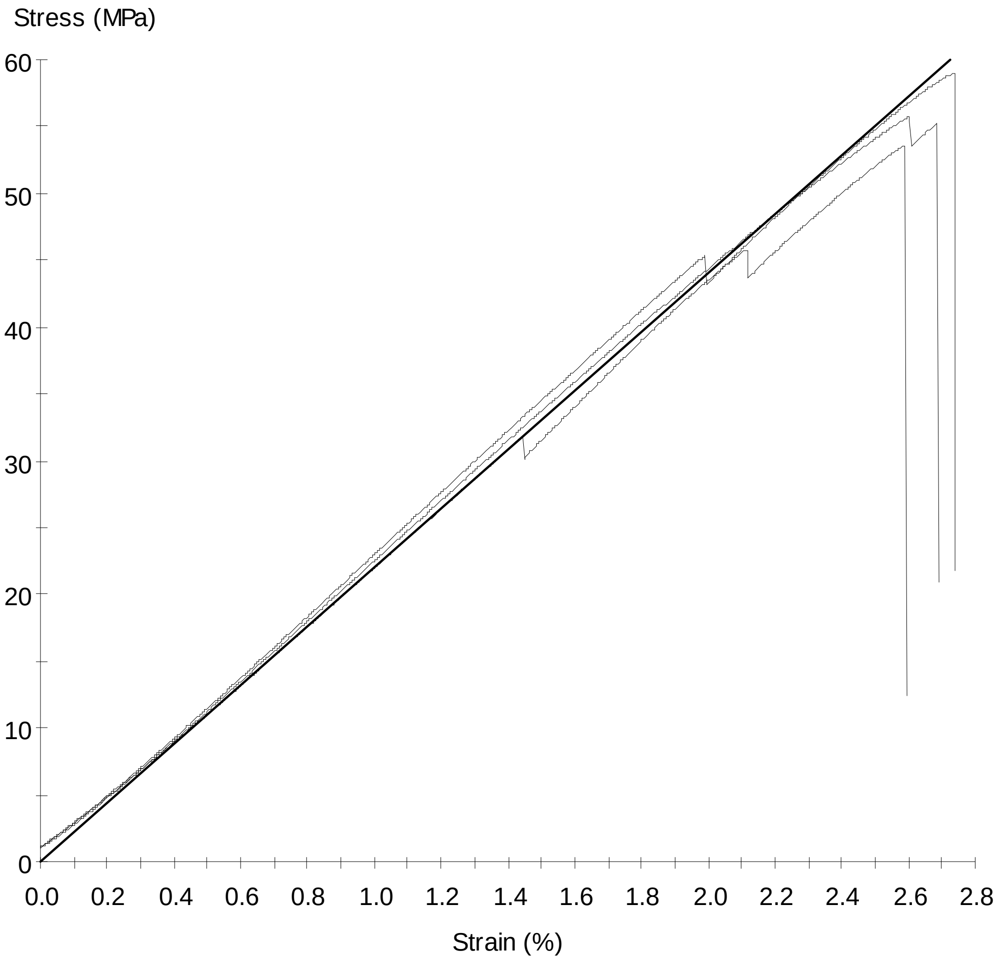
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.59	10.09	1029	58.50	2.89	2.89	1.95	1.95	2141
2	16.86	10.00	1048	59.69	2.92	2.91	1.99	1.99	2171
3	16.81	10.10	969	54.25	2.64	2.63	1.78	1.78	2161
Mean	**16.75**	**10.06**	**1016**	**57.48**	**2.81**	**2.81**	**1.91**	**1.91**	**2158**
Std Dev	**0.14**	**0.06**	**41**	**2.86**	**0.15**	**0.15**	**0.11**	**0.11**	**16**



Stress vs Strain Plot

Sample 29

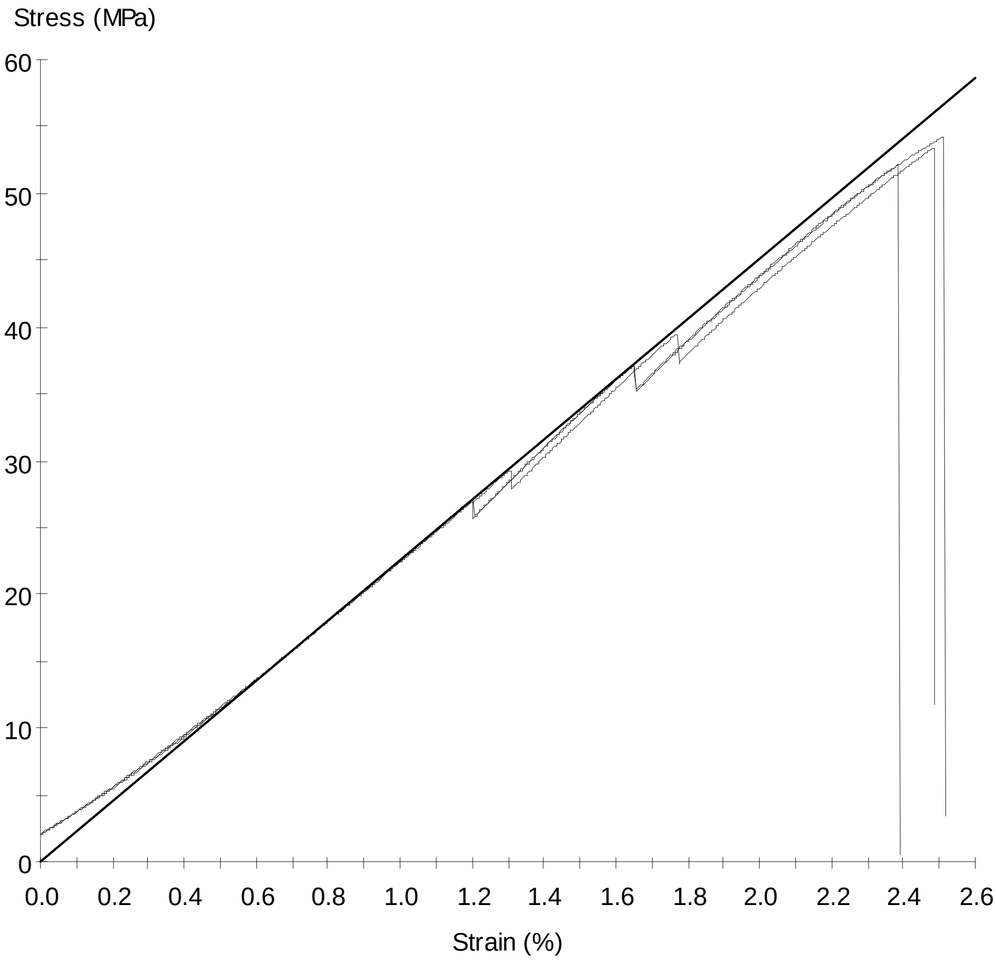
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.97	10.01	1045	55.73	2.69	2.60	1.77	1.77	2249
2	17.35	9.96	1058	59.00	2.74	2.74	1.88	1.88	2294
3	18.27	10.07	1034	53.58	2.59	2.59	1.75	1.75	2199
Mean	**17.86**	**10.01**	**1046**	**56.10**	**2.67**	**2.64**	**1.80**	**1.80**	**2248**
Std Dev	**0.47**	**0.06**	**12**	**2.73**	**0.08**	**0.08**	**0.07**	**0.07**	**48**



Stress vs Strain Plot

Sample 30

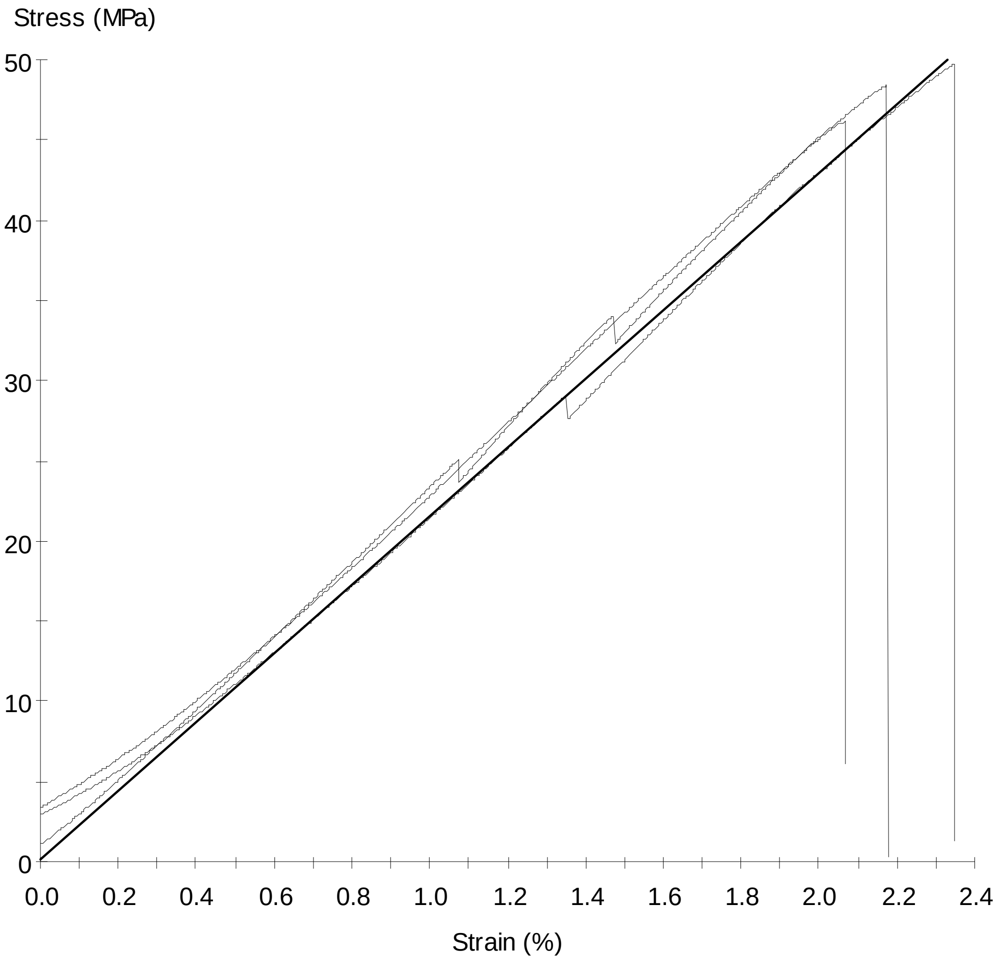
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.48	10.10	1066	54.28	2.52	2.51	1.70	1.70	2255
2	18.51	10.03	1035	53.38	2.49	2.48	1.69	1.69	2241
3	19.13	10.07	1053	52.10	2.39	2.38	1.62	1.62	2251
Mean	**18.71**	**10.07**	**1051**	**53.25**	**2.46**	**2.46**	**1.67**	**1.67**	**2249**
Std Dev	**0.37**	**0.04**	**15**	**1.10**	**0.07**	**0.07**	**0.05**	**0.05**	**7**



Stress vs Strain Plot

Sample 31

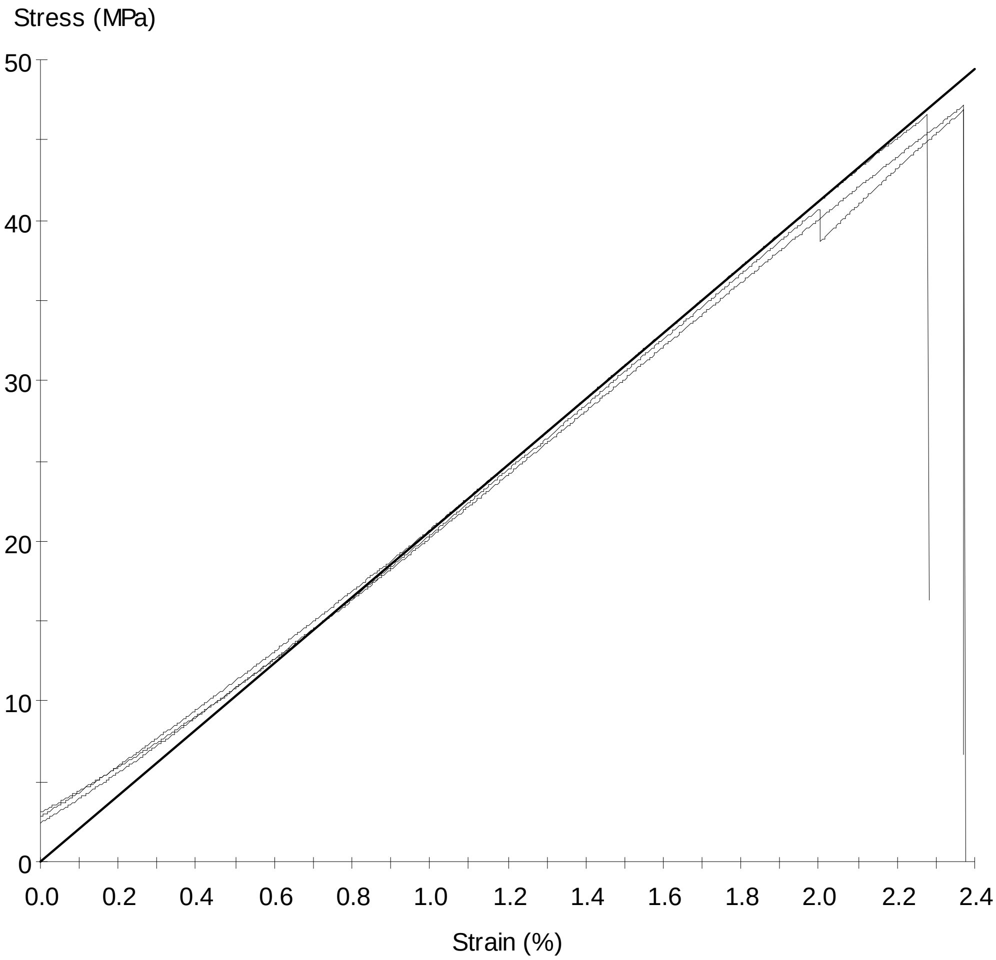
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.90	10.05	962	48.38	2.18	2.17	1.48	1.48	2333
2	19.06	10.17	947	46.13	2.07	2.07	1.39	1.39	2281
3	19.50	10.17	1044	49.67	2.35	2.35	1.58	1.58	2144
Mean	**19.15**	**10.13**	**984**	**48.06**	**2.20**	**2.20**	**1.48**	**1.48**	**2253**
Std Dev	**0.31**	**0.07**	**52**	**1.79**	**0.14**	**0.14**	**0.09**	**0.09**	**98**



Stress vs Strain Plot

Sample 32

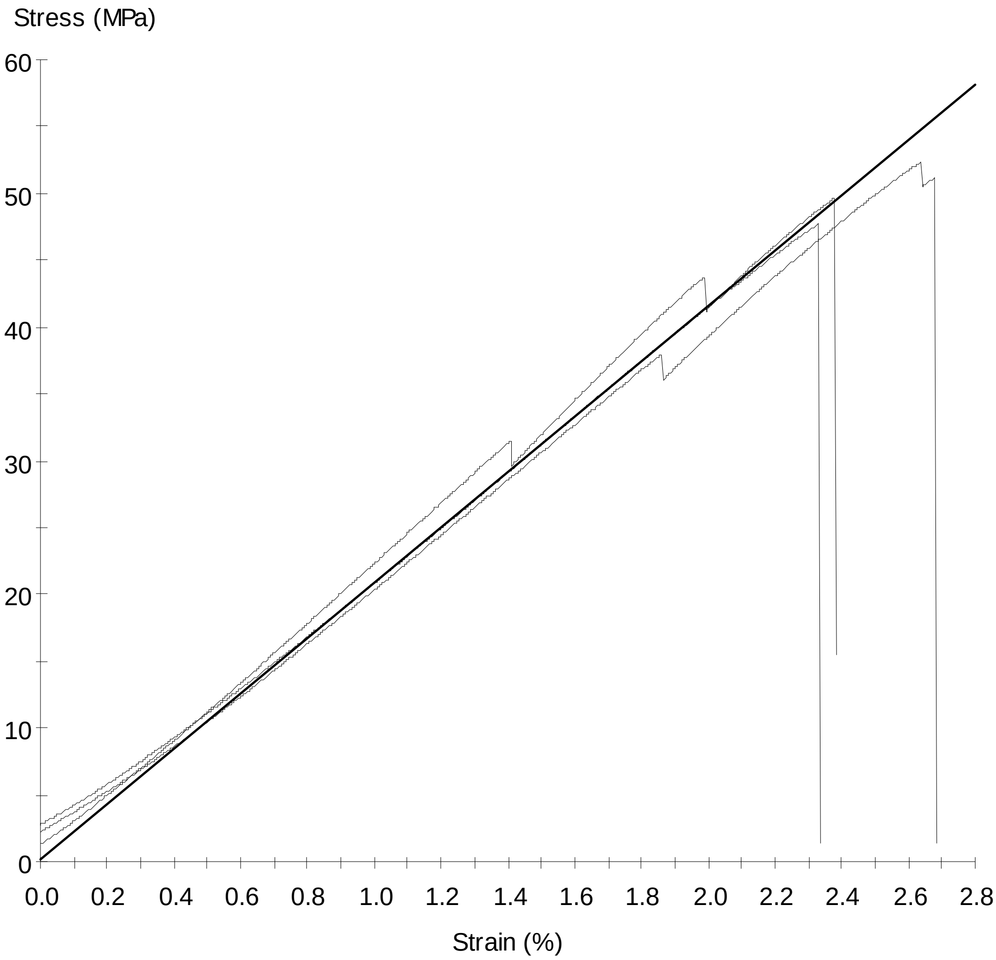
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.29	10.08	862	47.12	2.37	2.37	1.61	1.61	2006
2	16.88	10.02	827	46.84	2.37	2.37	1.61	1.61	2035
3	17.44	10.02	849	46.55	2.28	2.28	1.55	1.55	2061
Mean	**17.20**	**10.04**	**846**	**46.83**	**2.34**	**2.34**	**1.59**	**1.59**	**2034**
Std Dev	**0.29**	**0.03**	**18**	**0.29**	**0.05**	**0.05**	**0.03**	**0.03**	**27**



Stress vs Strain Plot

Sample 33

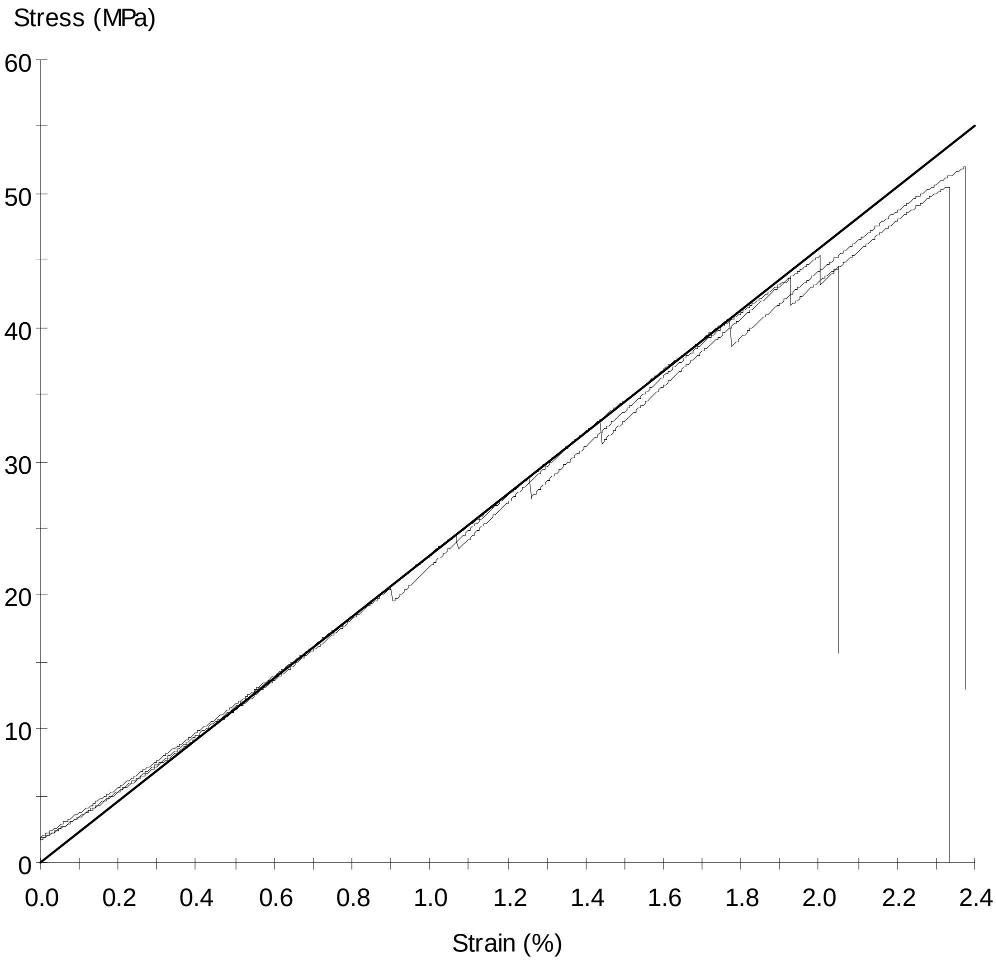
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.16	10.04	946	49.63	2.38	2.38	1.62	1.62	2230
2	18.36	10.04	1008	52.28	2.68	2.64	1.79	1.79	2036
3	18.42	10.11	937	47.77	2.33	2.33	1.58	1.58	2081
Mean	**18.31**	**10.06**	**964**	**49.89**	**2.47**	**2.45**	**1.66**	**1.66**	**2116**
Std Dev	**0.14**	**0.04**	**39**	**2.27**	**0.19**	**0.16**	**0.12**	**0.12**	**101**



Stress vs Strain Plot

Sample 34

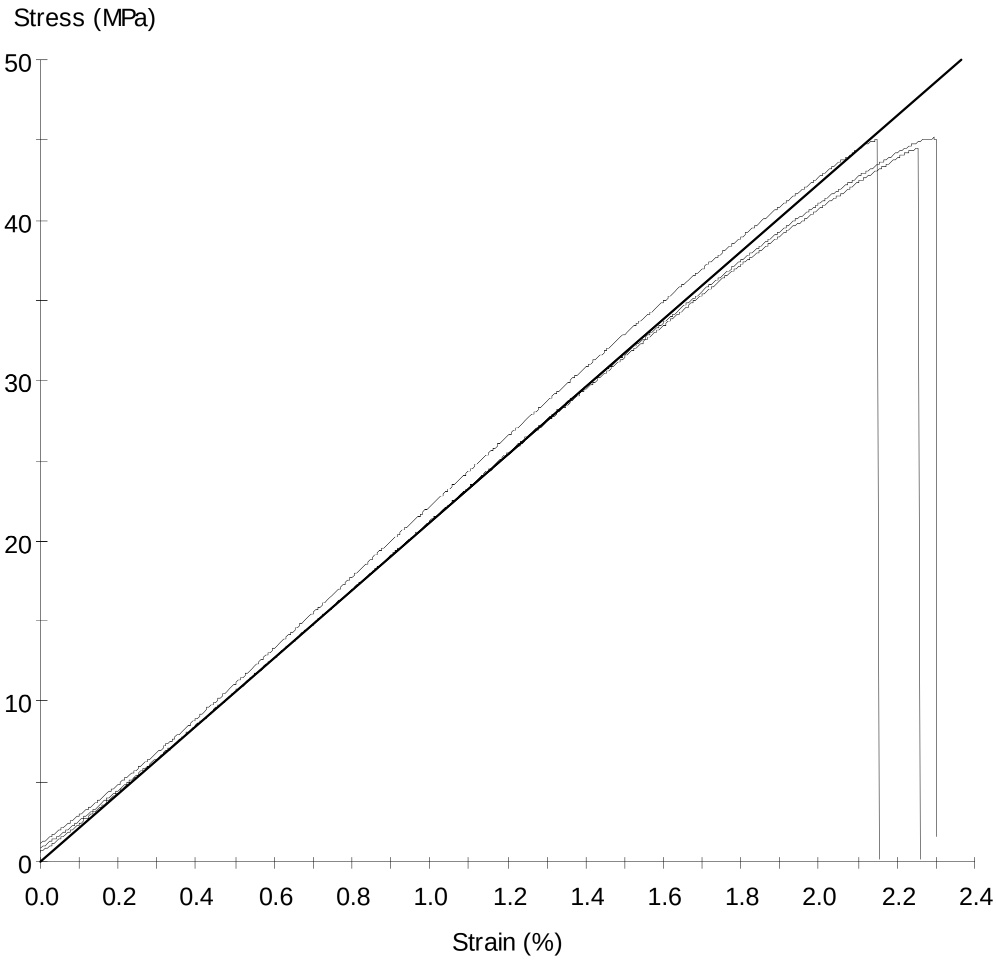
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.92	10.09	892	44.45	2.05	2.05	1.39	1.39	2268
2	18.29	10.00	990	51.98	2.38	2.38	1.62	1.62	2297
3	18.68	10.01	985	50.54	2.34	2.33	1.59	1.59	2293
Mean	**18.63**	**10.03**	**956**	**48.99**	**2.26**	**2.25**	**1.53**	**1.53**	**2286**
Std Dev	**0.32**	**0.05**	**55**	**4.00**	**0.18**	**0.18**	**0.13**	**0.13**	**16**



Stress vs Strain Plot

Sample 35

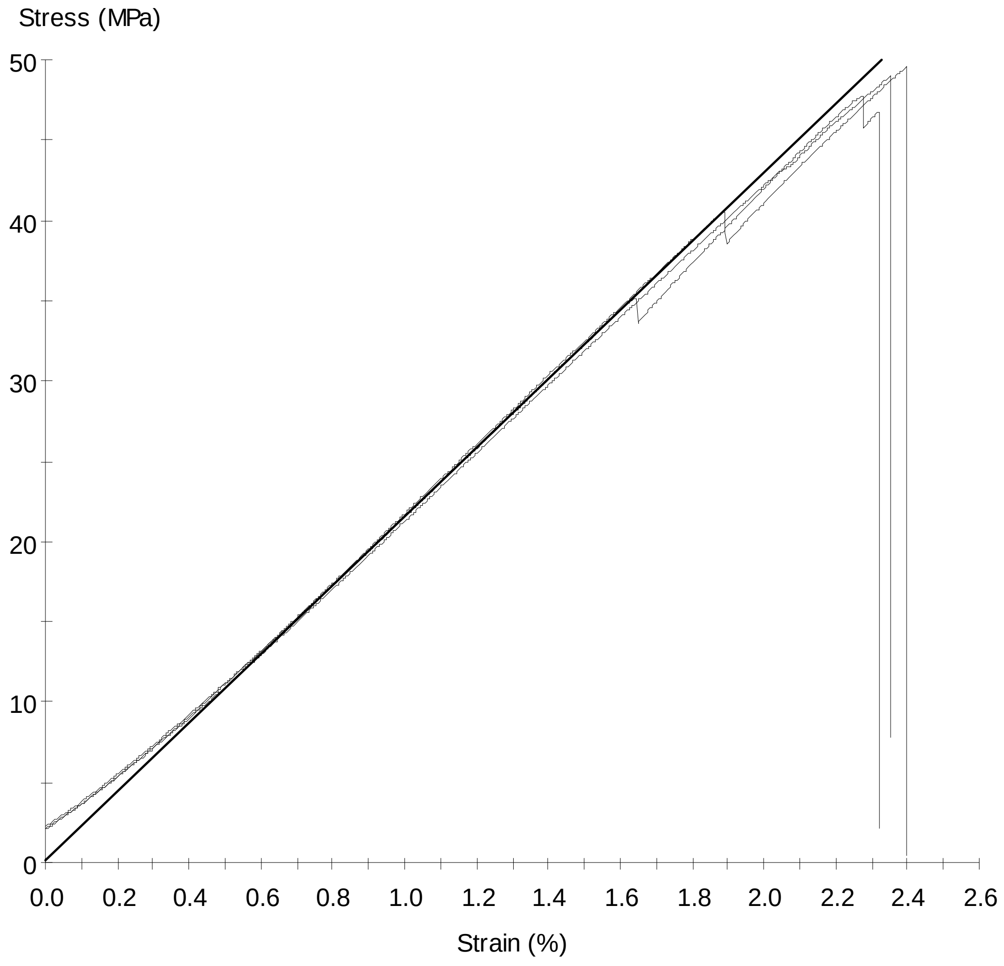
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.70	10.00	774	44.47	2.26	2.26	1.54	1.54	2117
2	15.70	10.00	737	45.04	2.15	2.15	1.47	1.47	2218
3	16.55	10.00	778	45.12	2.30	2.29	1.57	1.57	2121
Mean	**16.32**	**10.00**	**763**	**44.88**	**2.24**	**2.23**	**1.52**	**1.52**	**2152**
Std Dev	**0.54**	**0.00**	**23**	**0.35**	**0.08**	**0.08**	**0.05**	**0.05**	**57**



Stress vs Strain Plot

Sample 36

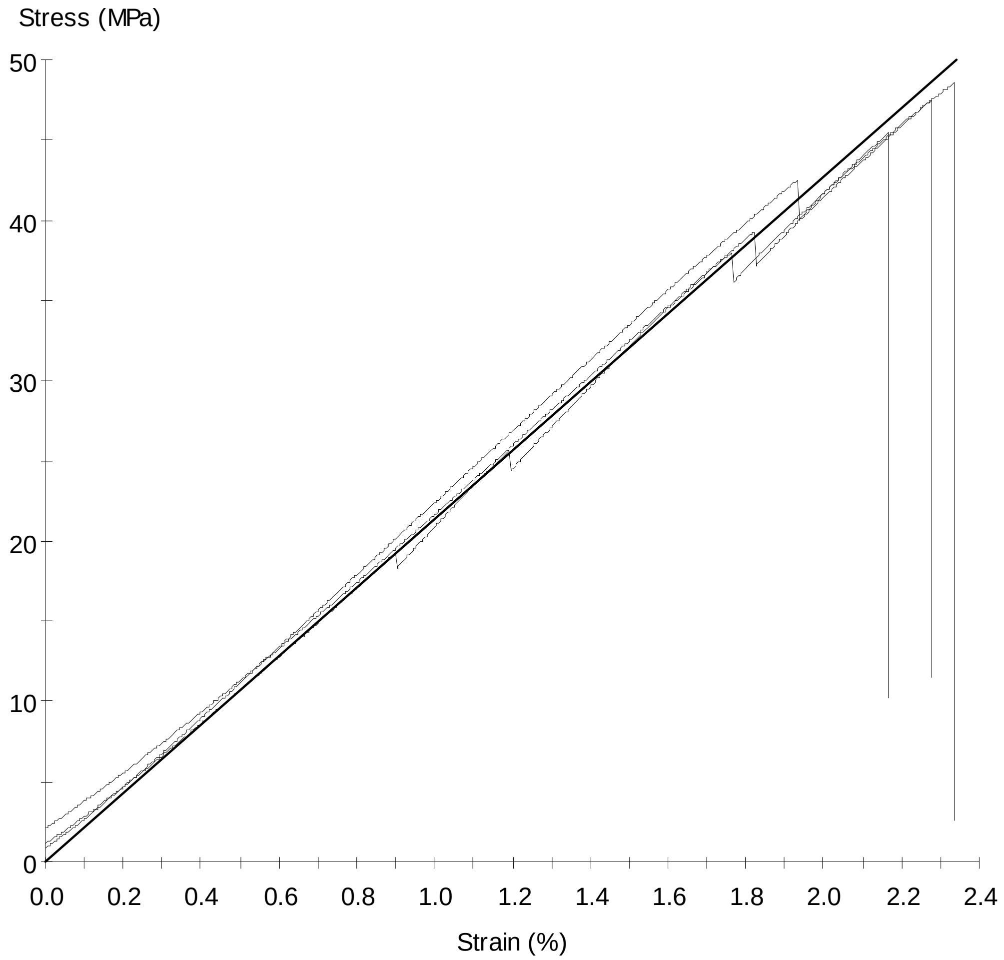
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.13	10.00	874	49.01	2.36	2.35	1.61	1.61	2125
2	17.50	10.04	911	49.55	2.40	2.40	1.63	1.63	2172
3	17.75	10.11	903	47.80	2.32	2.28	1.54	1.54	2151
Mean	**17.46**	**10.05**	**896**	**48.79**	**2.36**	**2.34**	**1.59**	**1.59**	**2149**
Std Dev	**0.31**	**0.06**	**19**	**0.90**	**0.04**	**0.06**	**0.05**	**0.05**	**24**



Stress vs Strain Plot

Sample 37

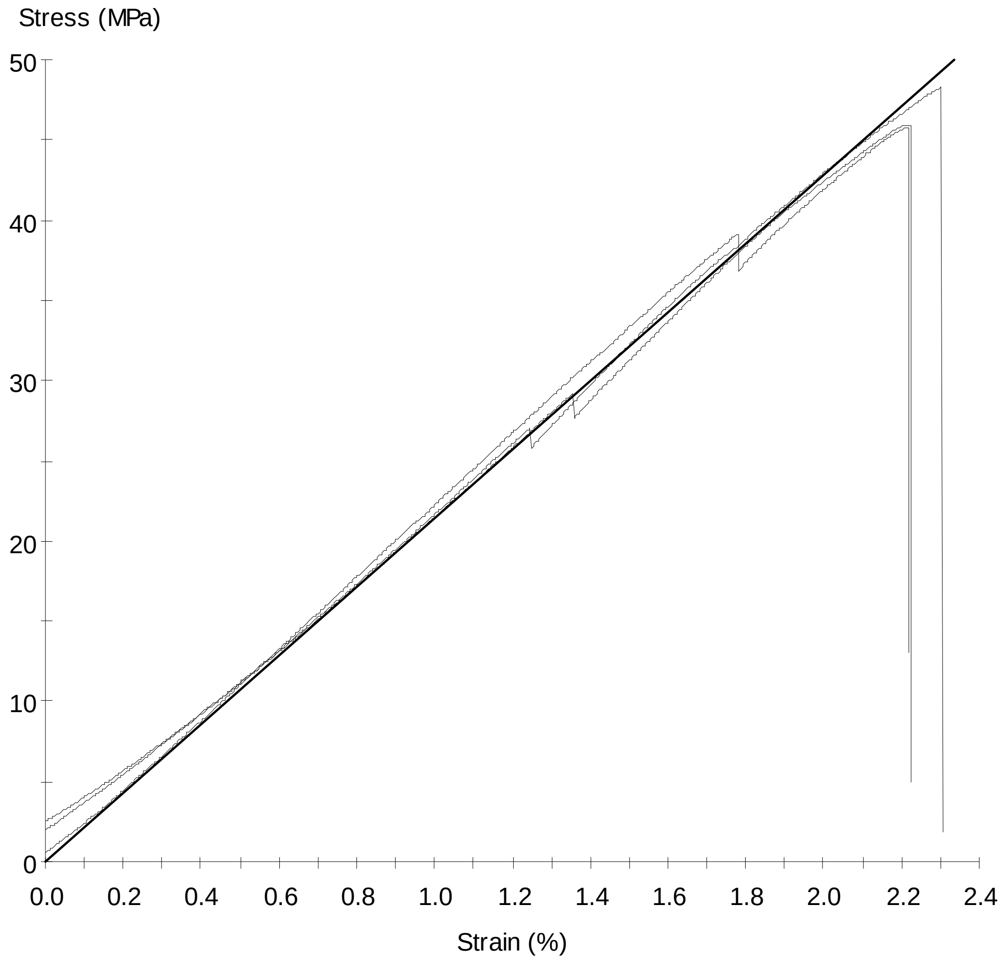
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.49	10.07	888	45.45	2.17	2.17	1.47	1.47	2234
2	17.98	10.07	901	47.43	2.28	2.27	1.54	1.54	2164
3	18.28	10.07	937	48.54	2.34	2.34	1.58	1.58	2129
Mean	**18.25**	**10.07**	**909**	**47.14**	**2.26**	**2.26**	**1.53**	**1.53**	**2176**
Std Dev	**0.26**	**0.00**	**26**	**1.56**	**0.09**	**0.09**	**0.06**	**0.06**	**54**



Stress vs Strain Plot

Sample 38

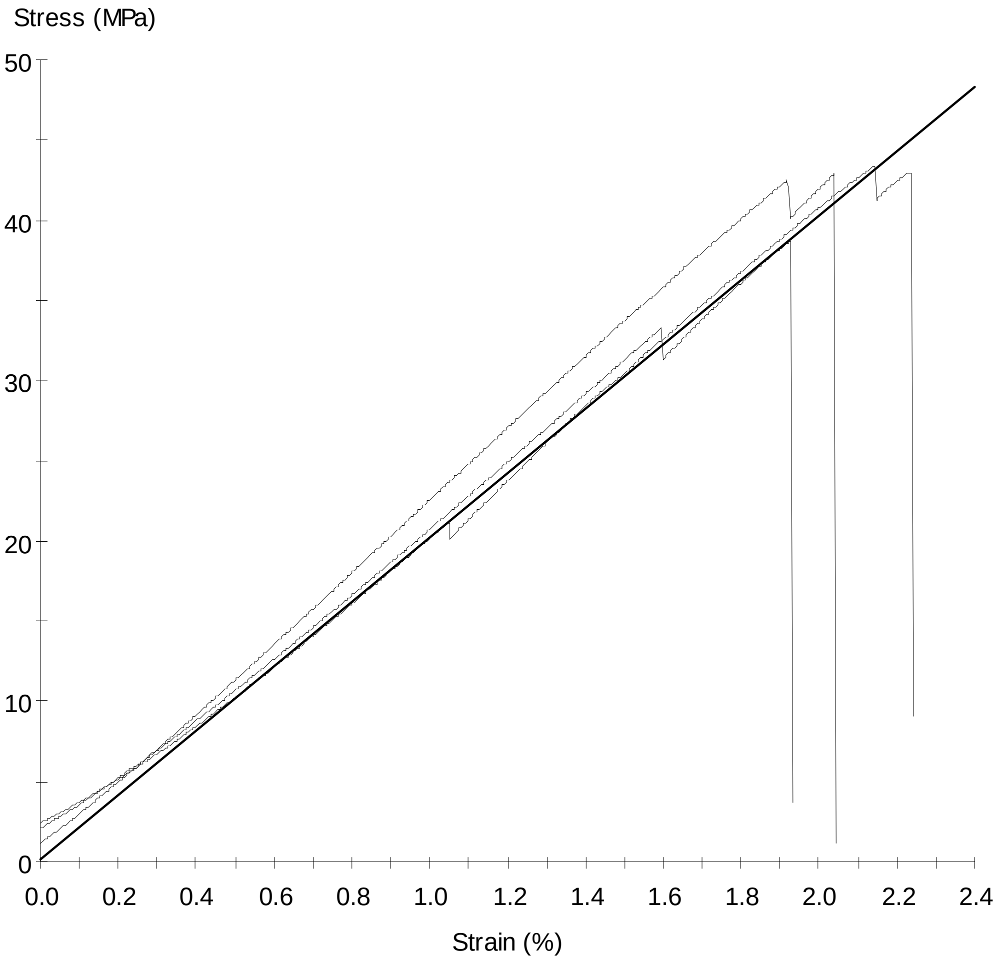
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	18.98	10.10	974	48.30	2.30	2.30	1.56	1.56	2166
2	18.29	10.11	892	45.82	2.22	2.21	1.49	1.49	2224
3	18.82	10.04	908	45.93	2.23	2.22	1.51	1.51	2146
Mean	**18.70**	**10.08**	**925**	**46.69**	**2.25**	**2.24**	**1.52**	**1.52**	**2179**
Std Dev	**0.36**	**0.04**	**44**	**1.40**	**0.05**	**0.05**	**0.03**	**0.03**	**41**



Stress vs Strain Plot

Sample 39

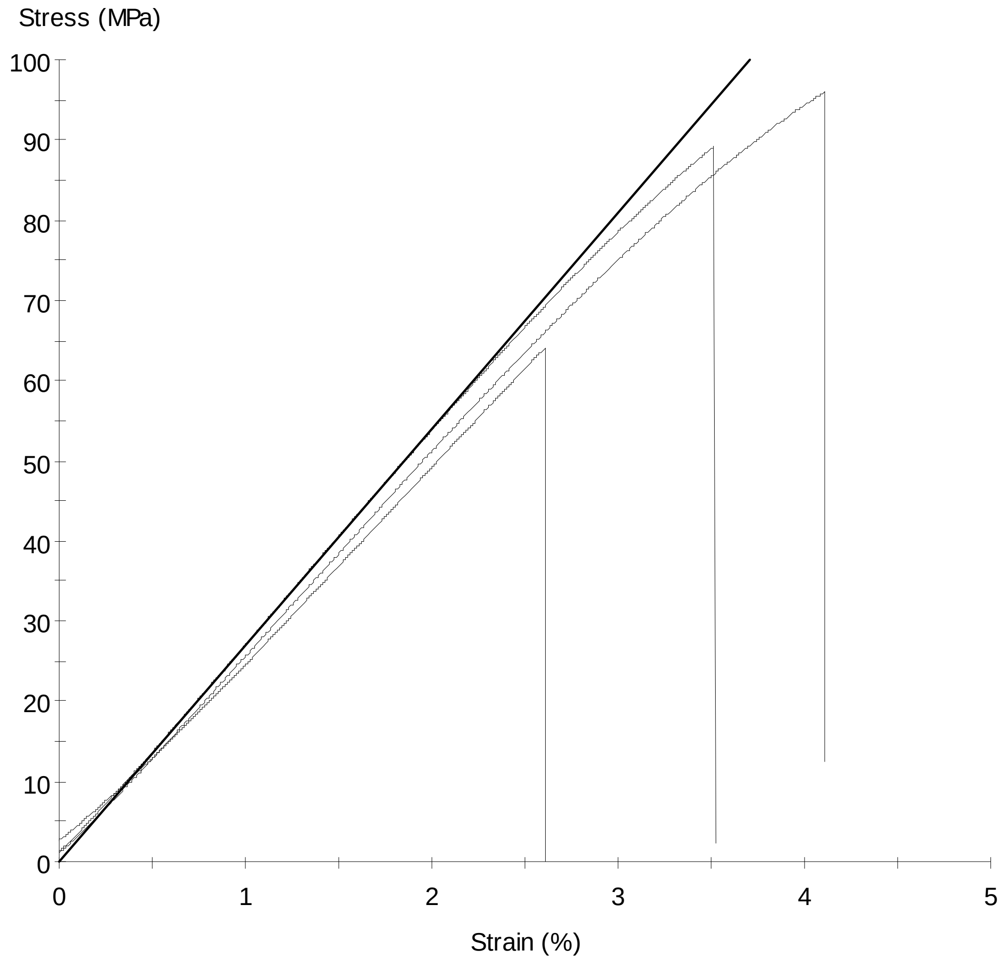
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	20.22	10.06	914	42.88	2.04	2.04	1.38	1.38	2255
2	19.70	10.08	806	38.67	1.93	1.93	1.31	1.31	2077
3	20.04	10.18	937	43.33	2.24	2.14	1.44	1.44	2014
Mean	**19.99**	**10.11**	**886**	**41.63**	**2.07**	**2.04**	**1.38**	**1.38**	**2115**
Std Dev	**0.26**	**0.06**	**70**	**2.57**	**0.16**	**0.11**	**0.07**	**0.07**	**125**



Stress vs Strain Plot

Sample 40

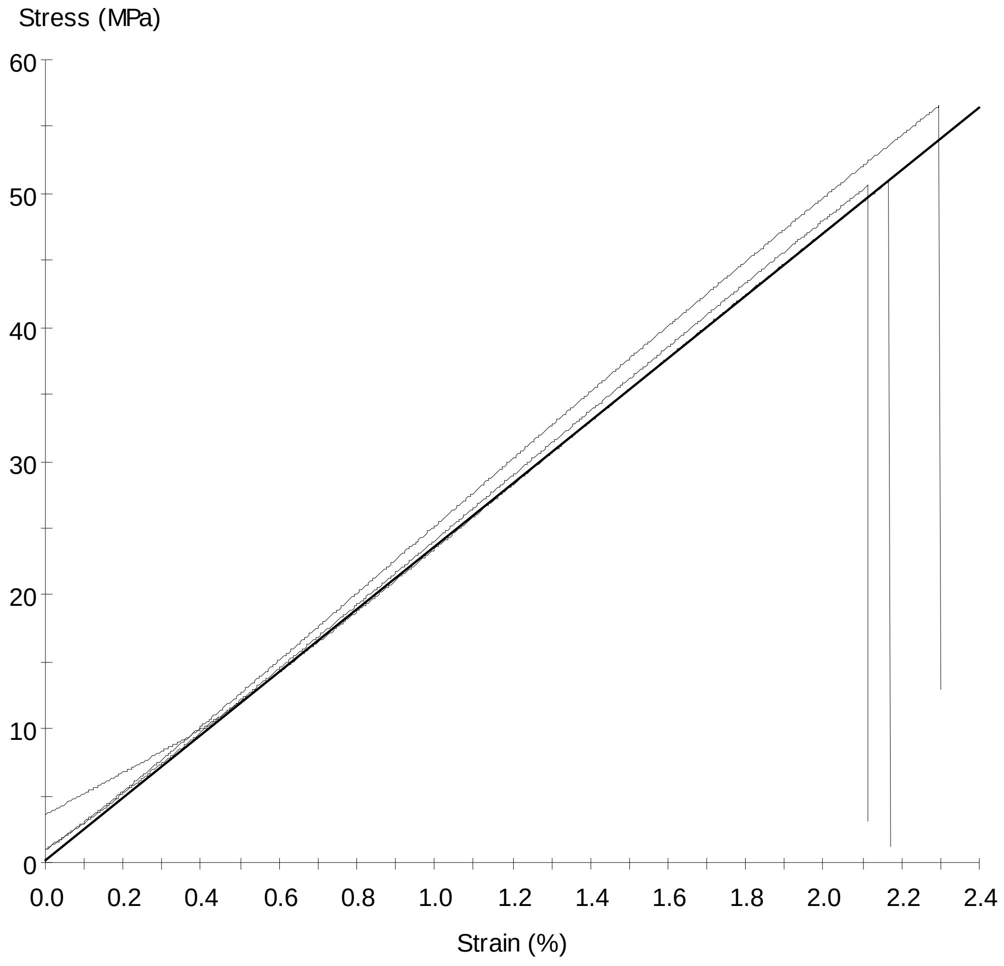
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	13.75	10.00	917	64.05	2.61	2.61	1.78	1.78	2456
2	13.00	10.00	1300	96.03	4.11	4.11	2.81	2.81	2562
3	13.20	10.00	1227	89.26	3.52	3.52	2.40	2.40	2705
Mean	**13.32**	**10.00**	**1148**	**83.12**	**3.42**	**3.41**	**2.33**	**2.33**	**2574**
Std Dev	**0.39**	**0.00**	**203**	**16.85**	**0.76**	**0.76**	**0.52**	**0.52**	**125**



Stress vs Strain Plot

Sample 41

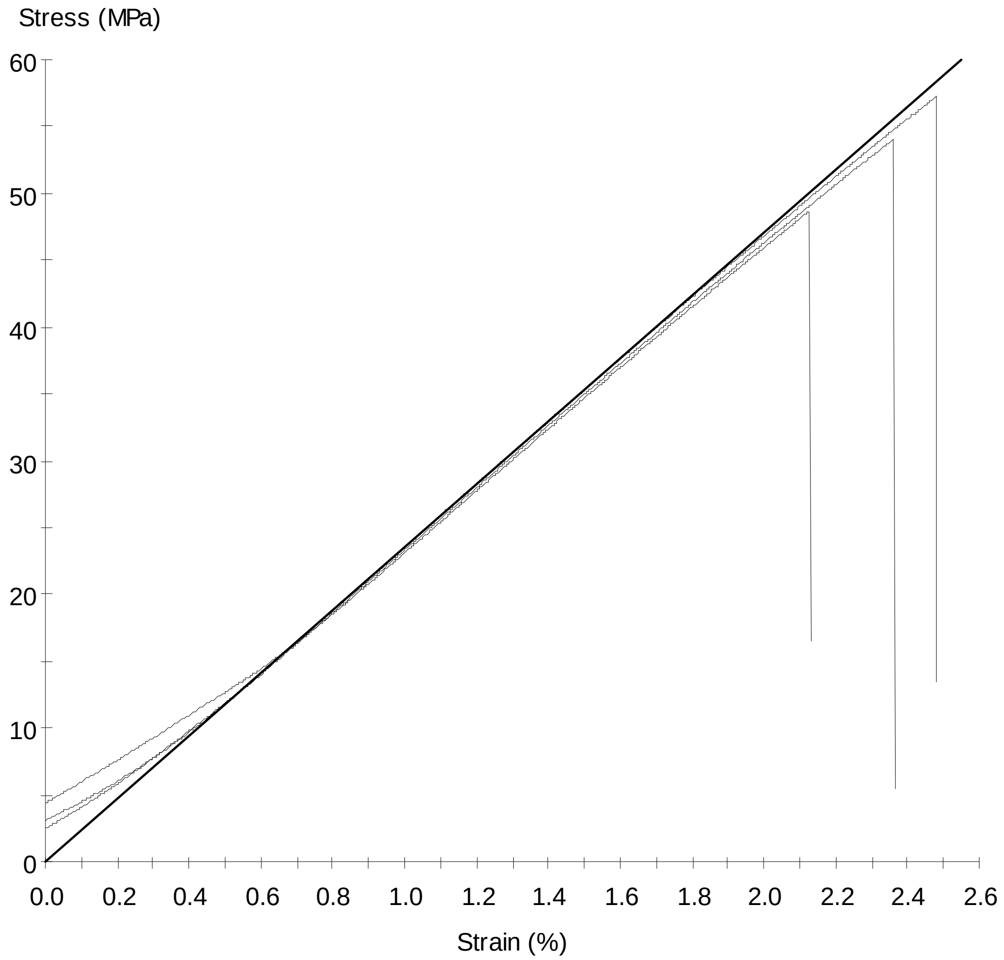
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.90	10.00	785	50.59	2.11	2.11	1.44	1.44	2408
2	15.13	10.00	891	56.56	2.30	2.30	1.57	1.57	2514
3	14.30	10.00	759	50.93	2.17	2.17	1.48	1.48	2348
Mean	**14.78**	**10.00**	**812**	**52.69**	**2.19**	**2.19**	**1.50**	**1.50**	**2424**
Std Dev	**0.43**	**0.00**	**70**	**3.36**	**0.10**	**0.09**	**0.06**	**0.06**	**84**



Stress vs Strain Plot

Sample 42

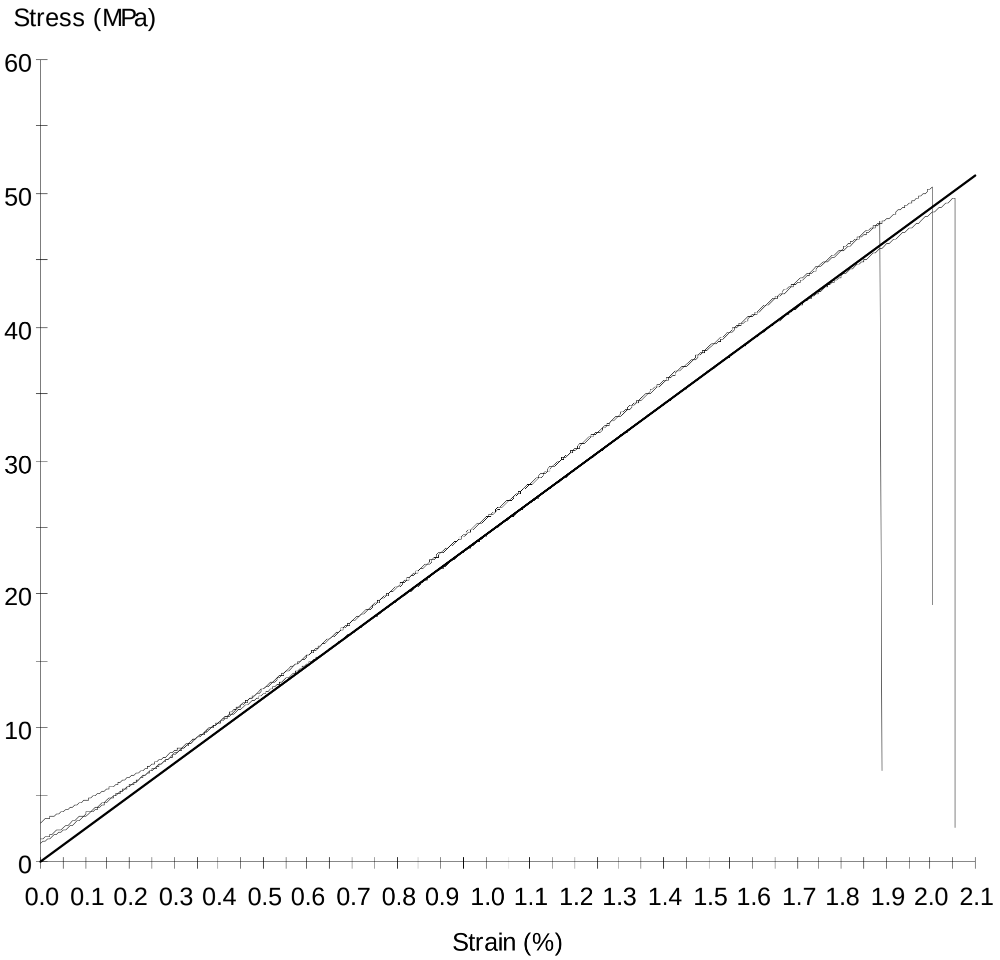
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.55	10.00	820	54.08	2.36	2.36	1.61	1.61	2332
2	15.60	10.00	791	48.68	2.13	2.13	1.45	1.45	2312
3	15.05	10.00	897	57.22	2.48	2.48	1.69	1.69	2354
Mean	**15.07**	**10.00**	**836**	**53.33**	**2.32**	**2.32**	**1.59**	**1.59**	**2332**
Std Dev	**0.53**	**0.00**	**55**	**4.32**	**0.18**	**0.18**	**0.12**	**0.12**	**21**



Stress vs Strain Plot

Sample 43

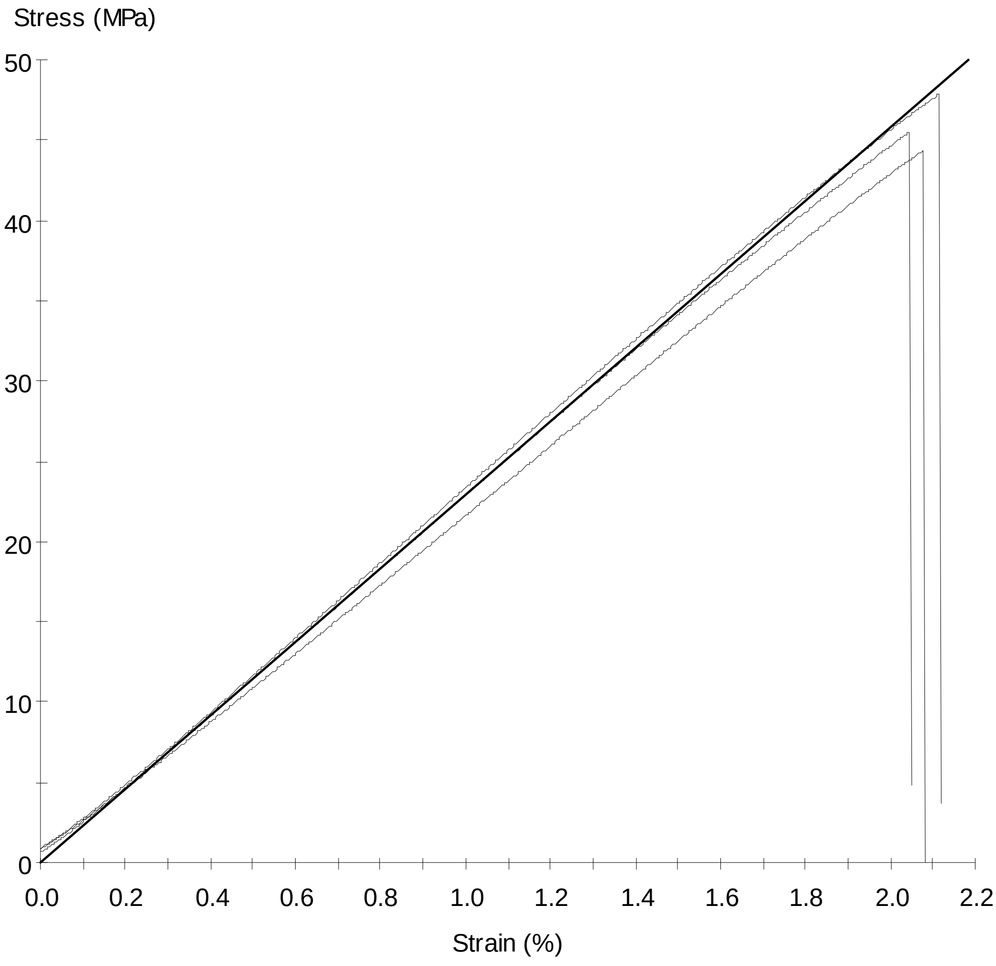
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.30	10.00	856	50.42	2.01	2.00	1.37	1.37	2563
2	16.50	10.00	824	47.94	1.89	1.89	1.29	1.29	2575
3	15.50	10.00	802	49.70	2.06	2.05	1.40	1.40	2440
Mean	**16.10**	**10.00**	**827**	**49.35**	**1.98**	**1.98**	**1.35**	**1.35**	**2526**
Std Dev	**0.53**	**0.00**	**27**	**1.27**	**0.08**	**0.09**	**0.06**	**0.06**	**75**



Stress vs Strain Plot

Sample 44

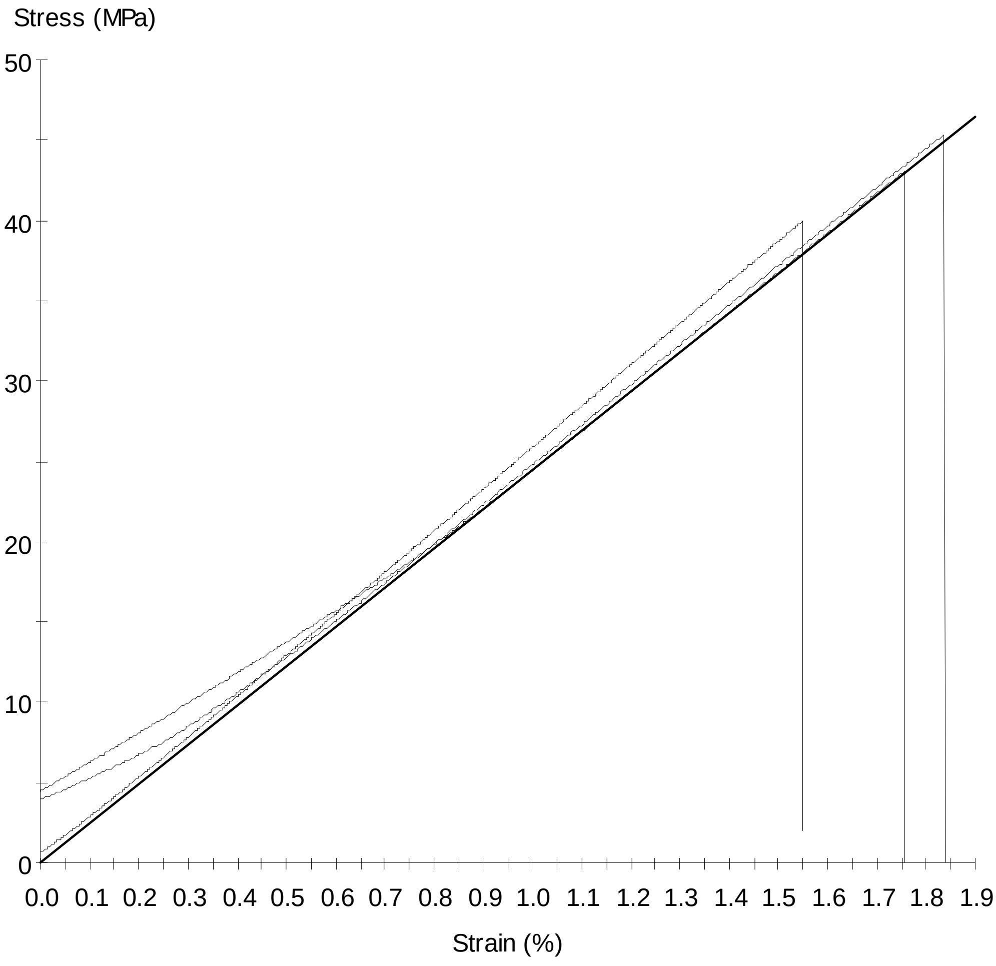
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.75	10.00	835	47.88	2.12	2.11	1.44	1.44	2334
2	17.10	10.00	789	44.29	2.08	2.07	1.42	1.42	2160
3	17.00	10.00	806	45.52	2.05	2.05	1.40	1.40	2290
Mean	**16.95**	**10.00**	**810**	**45.90**	**2.08**	**2.08**	**1.42**	**1.42**	**2261**
Std Dev	**0.18**	**0.00**	**24**	**1.83**	**0.04**	**0.04**	**0.02**	**0.02**	**90**



Stress vs Strain Plot

Sample 45

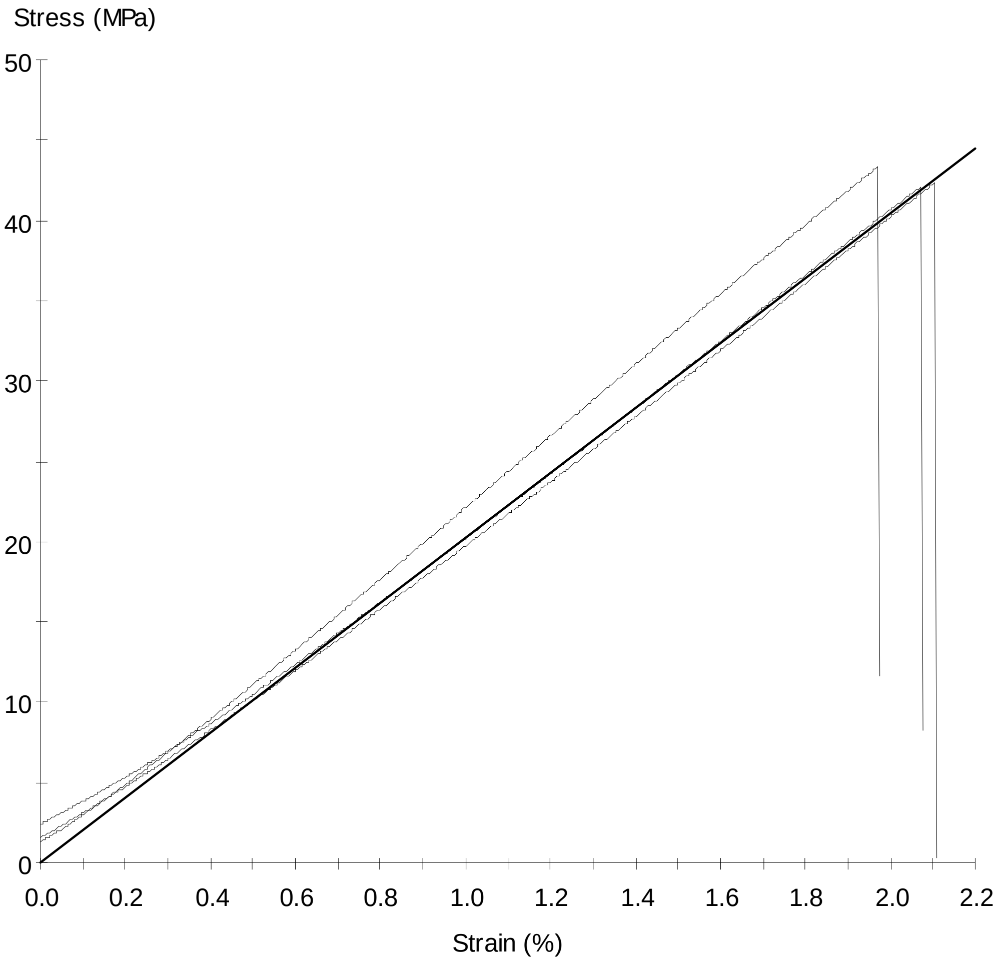
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.60	10.00	649	39.94	1.55	1.55	1.06	1.06	2584
2	15.40	10.00	728	45.37	1.84	1.84	1.25	1.25	2479
3	15.40	10.00	691	43.07	1.76	1.76	1.20	1.20	2443
Mean	**15.47**	**10.00**	**689**	**42.79**	**1.72**	**1.71**	**1.17**	**1.17**	**2502**
Std Dev	**0.12**	**0.00**	**39**	**2.73**	**0.15**	**0.15**	**0.10**	**0.10**	**73**



Stress vs Strain Plot

Sample 46

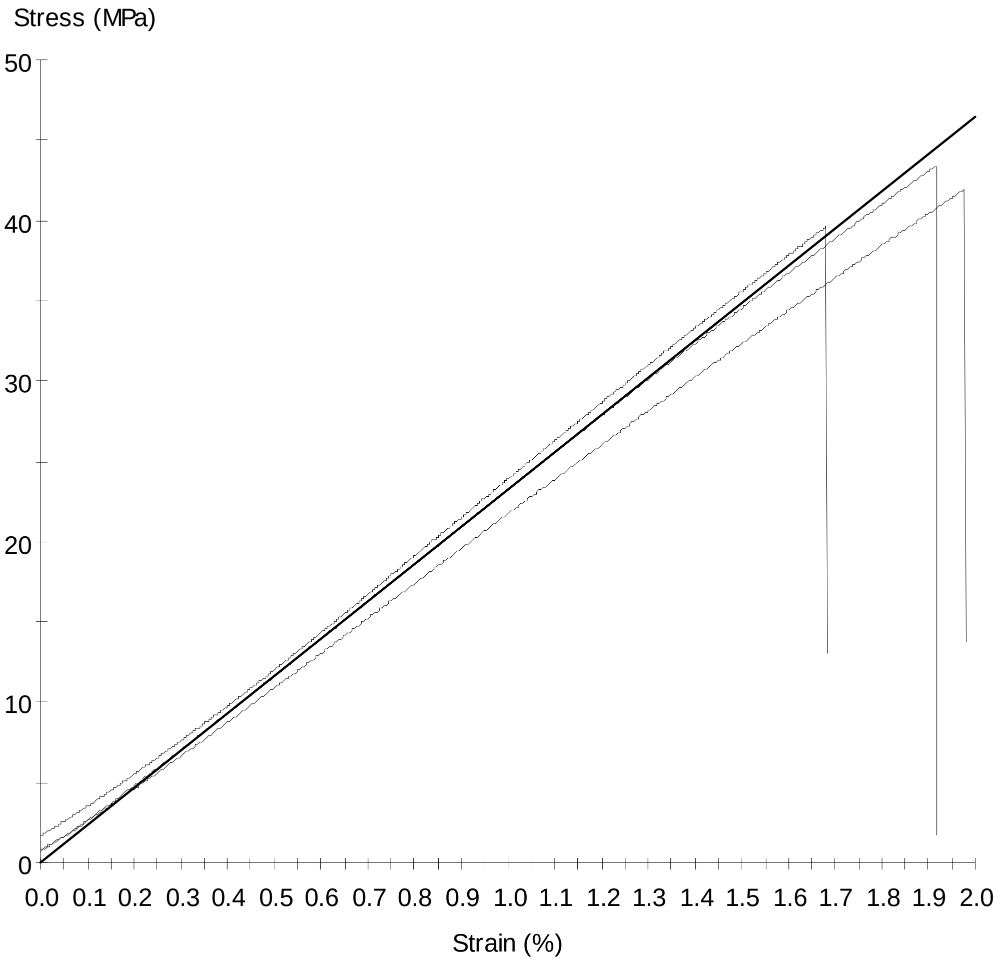
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.85	10.00	654	42.30	2.11	2.10	1.43	1.43	1974
2	14.60	10.00	659	43.32	1.97	1.97	1.34	1.34	2207
3	15.15	10.00	665	42.14	2.08	2.07	1.42	1.42	2020
Mean	**14.87**	**10.00**	**659**	**42.59**	**2.05**	**2.05**	**1.40**	**1.40**	**2067**
Std Dev	**0.28**	**0.00**	**5**	**0.64**	**0.07**	**0.07**	**0.05**	**0.05**	**123**



Stress vs Strain Plot

Sample 47

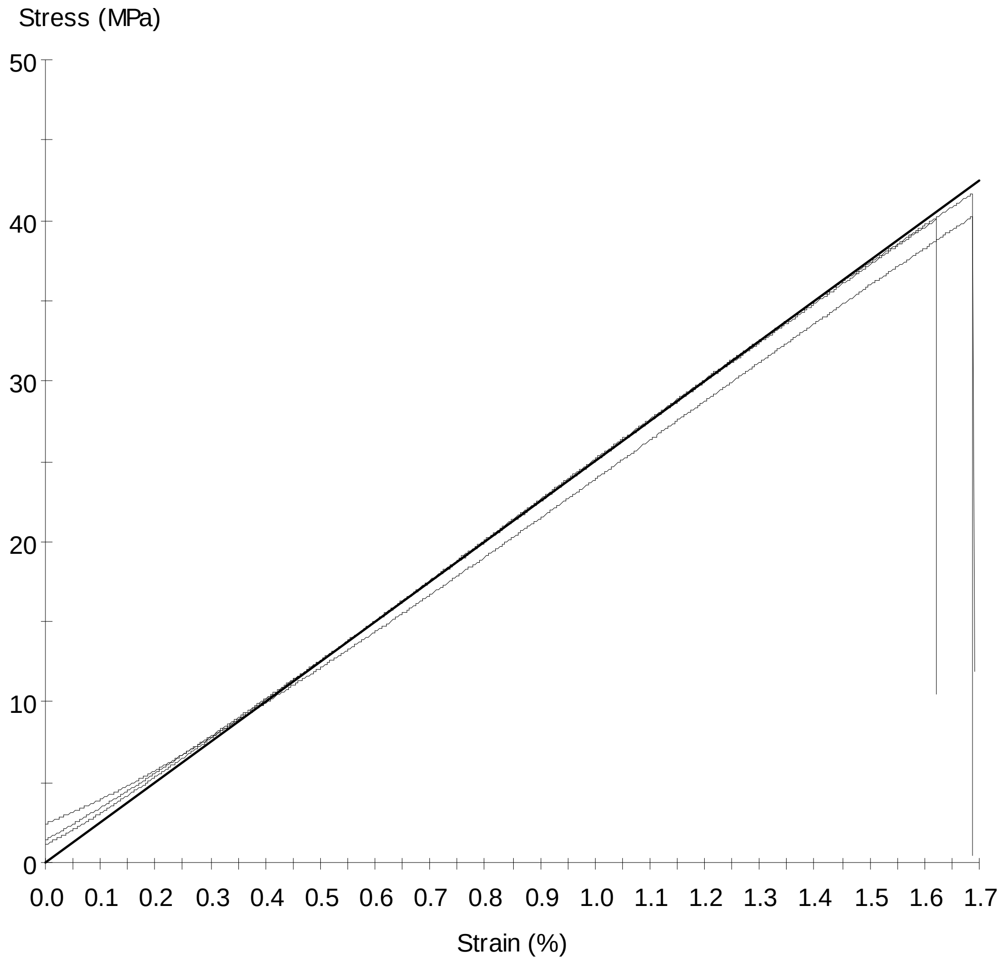
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.70	10.00	729	41.93	1.98	1.98	1.35	1.35	2173
2	15.90	10.00	656	39.63	1.68	1.68	1.15	1.15	2388
3	16.70	10.00	755	43.41	1.92	1.92	1.31	1.31	2324
Mean	**16.43**	**10.00**	**714**	**41.66**	**1.86**	**1.86**	**1.27**	**1.27**	**2295**
Std Dev	**0.46**	**0.00**	**51**	**1.90**	**0.16**	**0.16**	**0.11**	**0.11**	**110**



Stress vs Strain Plot

Sample 48

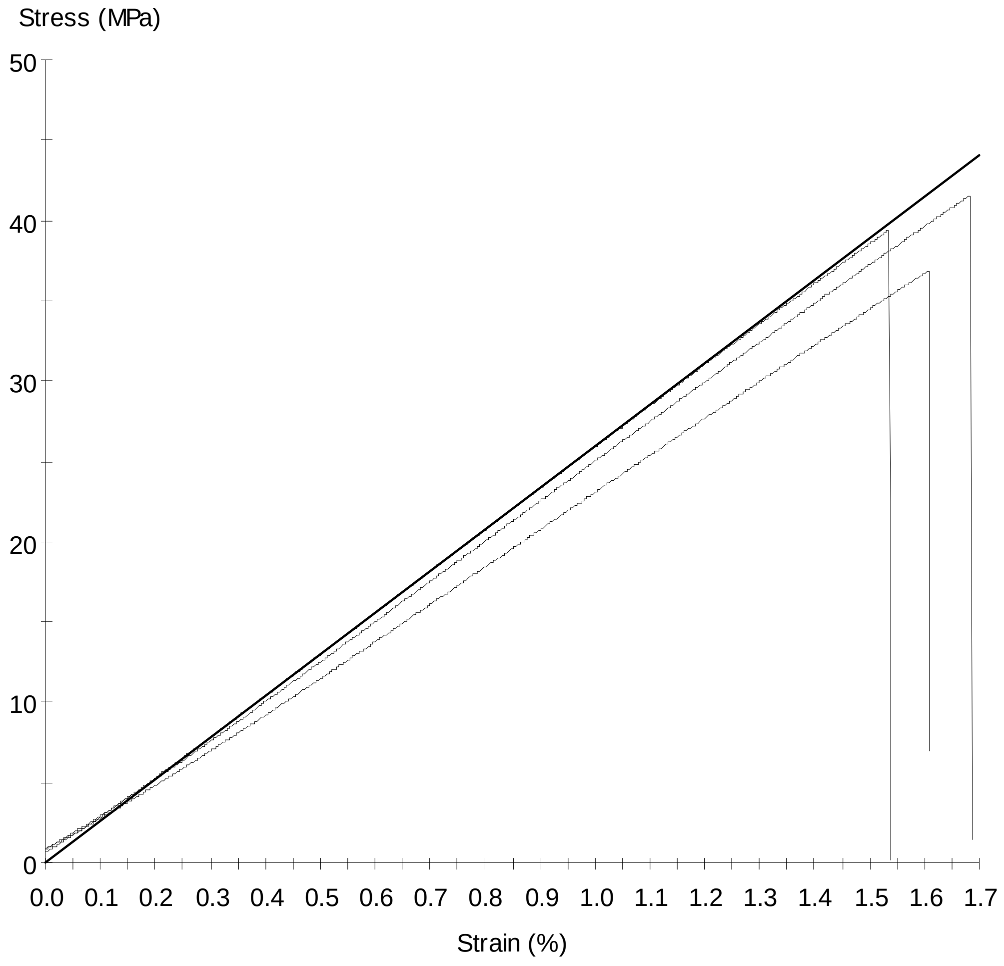
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.60	10.00	738	40.26	1.69	1.69	1.15	1.15	2381
2	17.80	10.00	773	41.67	1.69	1.69	1.15	1.15	2511
3	17.40	10.00	725	40.03	1.62	1.62	1.11	1.11	2496
Mean	**17.60**	**10.00**	**745**	**40.65**	**1.67**	**1.67**	**1.14**	**1.14**	**2463**
Std Dev	**0.20**	**0.00**	**24**	**0.89**	**0.04**	**0.04**	**0.03**	**0.03**	**71**



Stress vs Strain Plot

Sample 49

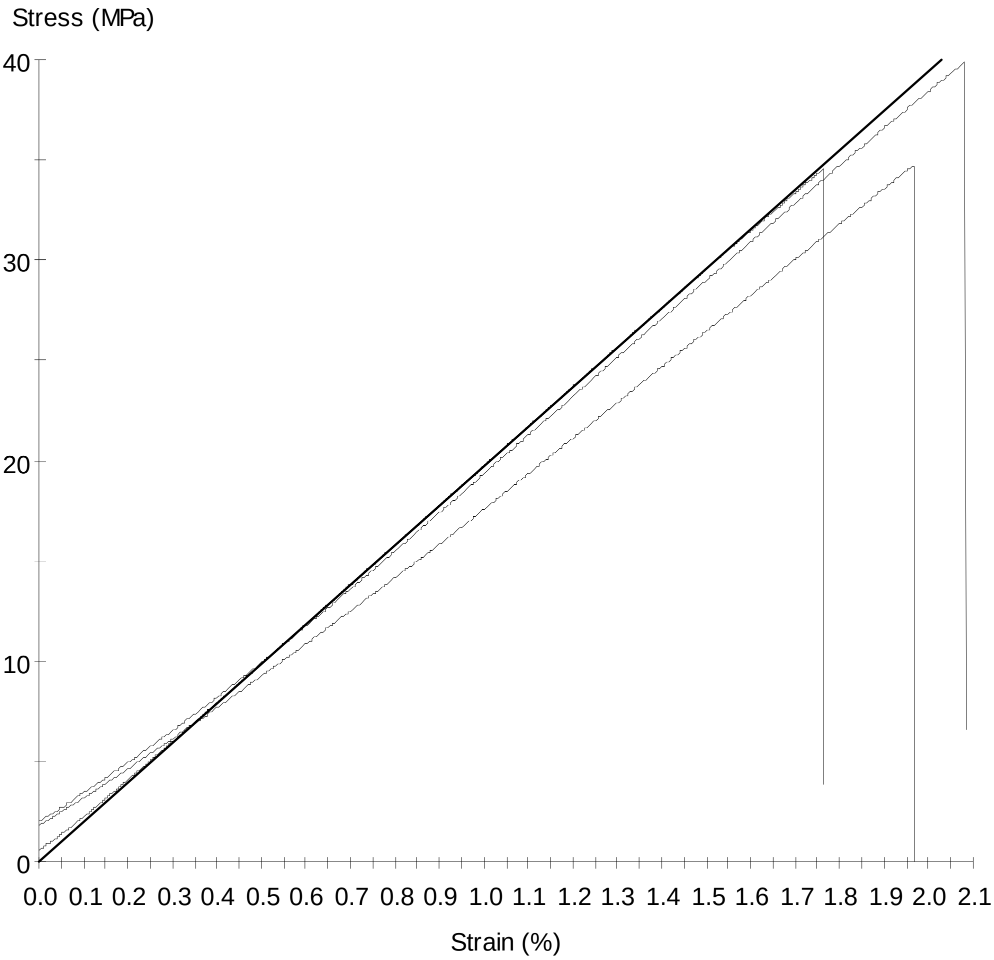
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.26	10.00	547	36.86	1.61	1.61	1.10	1.10	2293
2	14.65	10.00	634	41.57	1.69	1.68	1.15	1.15	2501
3	14.75	10.00	605	39.39	1.54	1.54	1.05	1.05	2592
Mean	**14.55**	**10.00**	**596**	**39.27**	**1.61**	**1.61**	**1.10**	**1.10**	**2462**
Std Dev	**0.26**	**0.00**	**44**	**2.36**	**0.07**	**0.07**	**0.05**	**0.05**	**153**



Stress vs Strain Plot

Sample 50

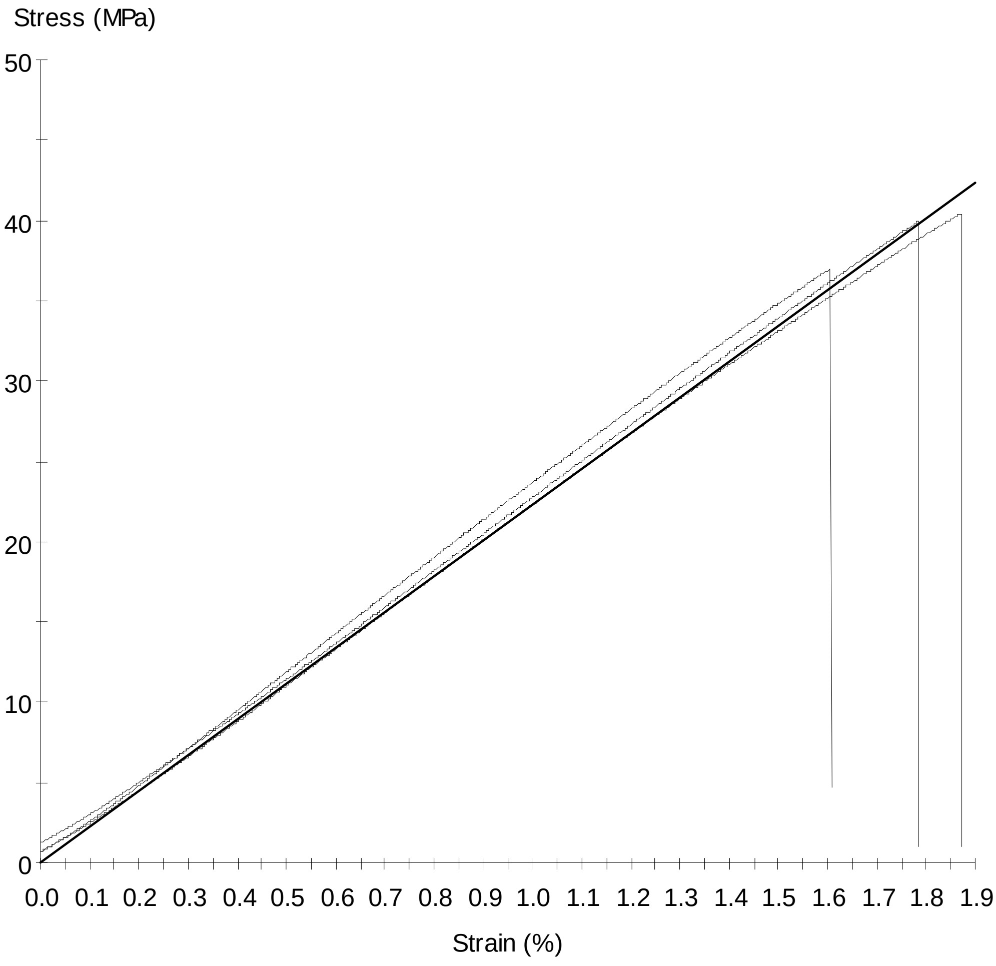
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.40	10.00	639	39.86	2.08	2.08	1.42	1.42	1935
2	13.00	10.00	470	34.73	1.97	1.97	1.34	1.34	1760
3	14.60	10.00	525	34.54	1.76	1.76	1.20	1.20	1974
Mean	**14.33**	**10.00**	**545**	**36.37**	**1.94**	**1.94**	**1.32**	**1.32**	**1890**
Std Dev	**1.22**	**0.00**	**86**	**3.02**	**0.16**	**0.16**	**0.11**	**0.11**	**114**



Stress vs Strain Plot

Sample 51

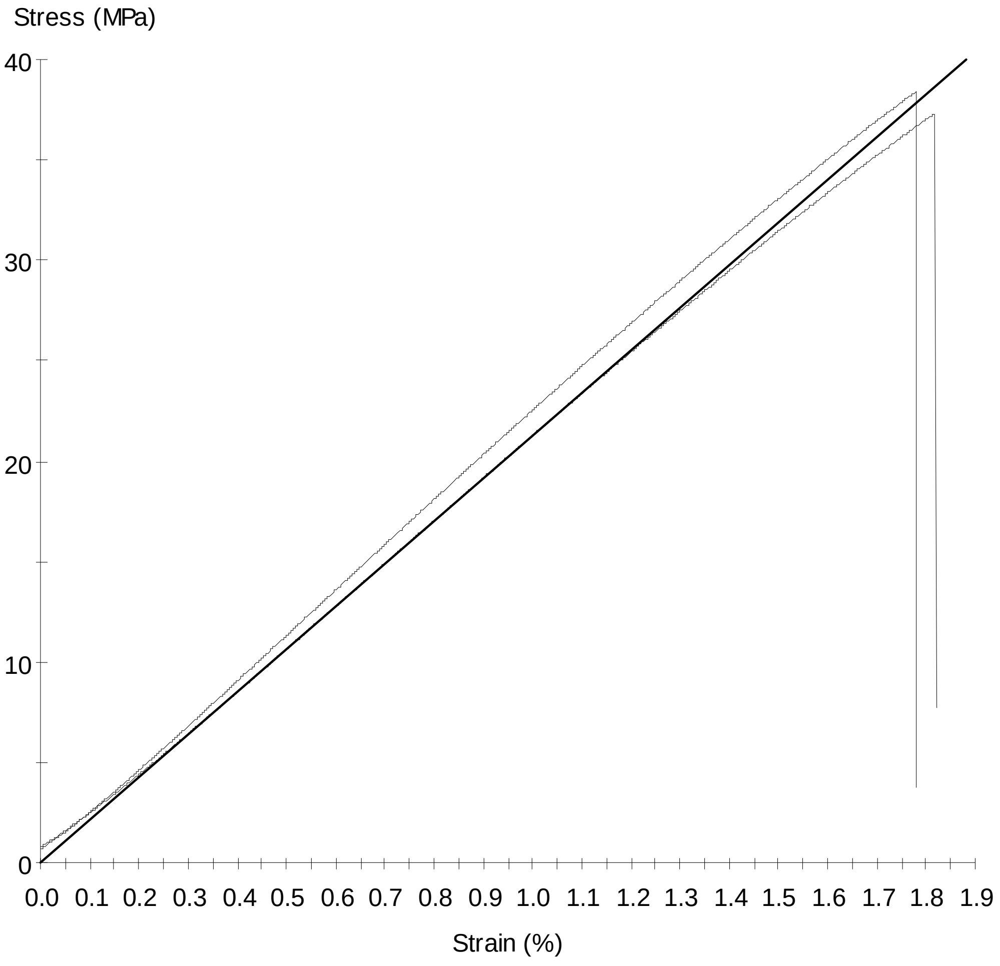
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.40	10.00	682	39.93	1.79	1.78	1.22	1.22	2274
2	16.25	10.00	625	36.94	1.61	1.61	1.10	1.10	2377
3	16.20	10.00	682	40.40	1.87	1.87	1.28	1.28	2230
Mean	**16.28**	**10.00**	**663**	**39.09**	**1.76**	**1.75**	**1.20**	**1.20**	**2294**
Std Dev	**0.10**	**0.00**	**33**	**1.88**	**0.14**	**0.14**	**0.09**	**0.09**	**76**



Stress vs Strain Plot

Sample 52

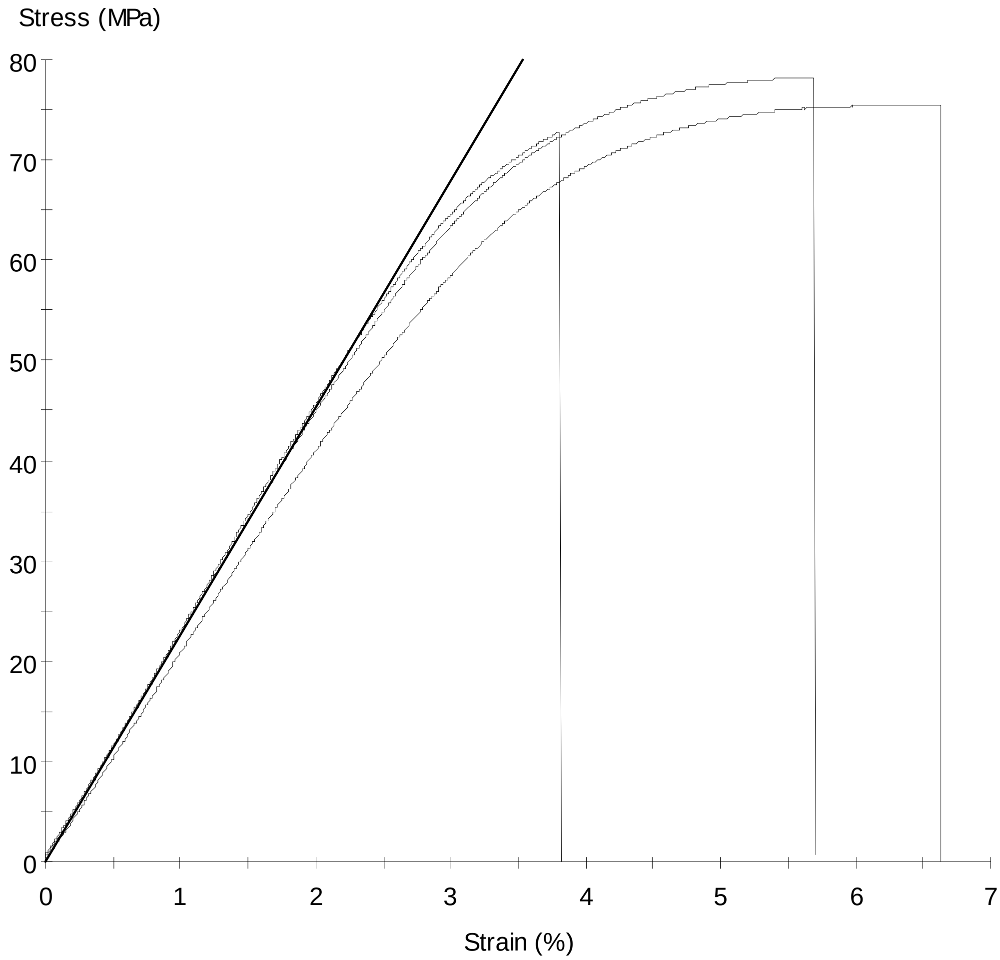
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.15	10.00	686	38.41	1.78	1.78	1.21	1.21	2264
2	17.68	10.00	687	37.31	1.82	1.82	1.24	1.24	2127
Mean	**17.42**	**10.00**	**687**	**37.86**	**1.80**	**1.80**	**1.23**	**1.23**	**2195**
Std Dev	**0.37**	**0.00**	**1**	**0.78**	**0.03**	**0.03**	**0.02**	**0.02**	**97**



Stress vs Strain Plot

Sample 53

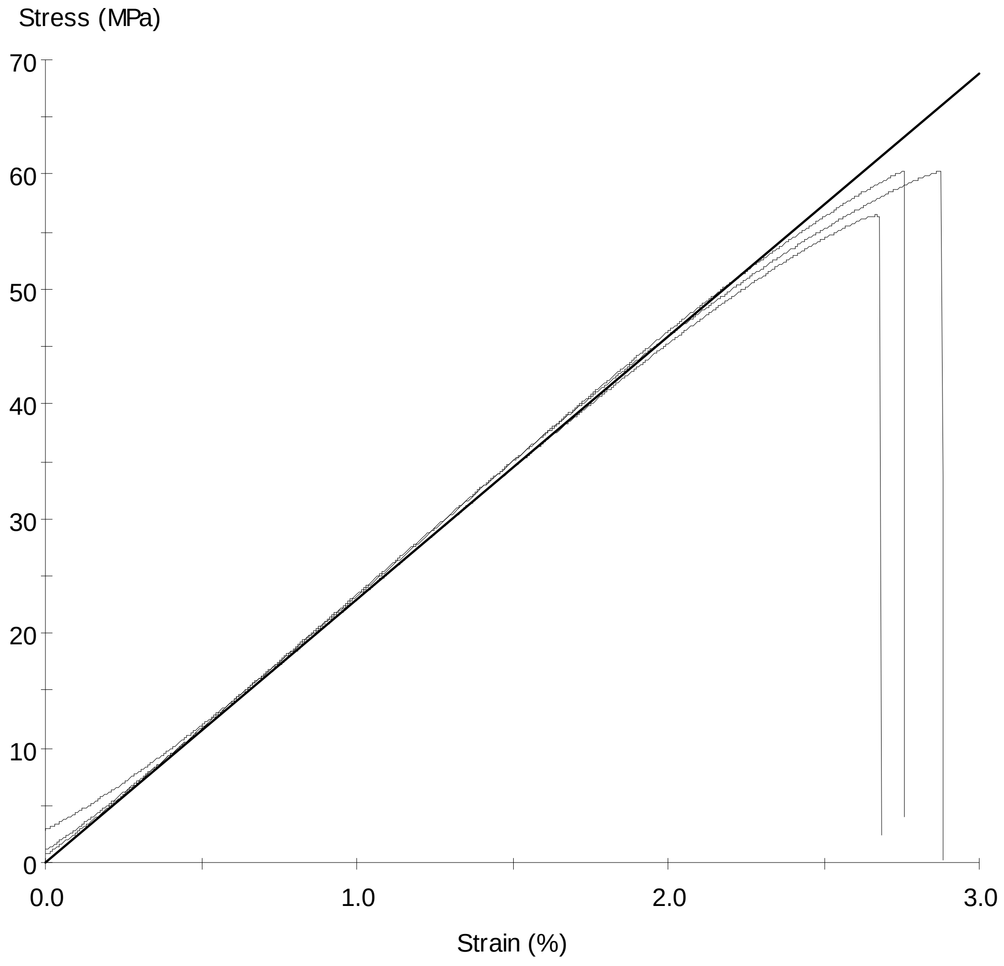
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	13.47	10.00	1058	75.43	6.64	6.22	4.25	4.25	2087
2	14.15	10.00	1074	72.84	3.81	3.81	2.60	2.60	2307
3	13.40	10.00	1092	78.26	5.70	5.66	3.86	3.86	2272
Mean	**13.67**	**10.00**	**1075**	**75.51**	**5.38**	**5.23**	**3.57**	**3.57**	**2222**
Std Dev	**0.41**	**0.00**	**17**	**2.71**	**1.44**	**1.26**	**0.86**	**0.86**	**118**



Stress vs Strain Plot

Sample 54

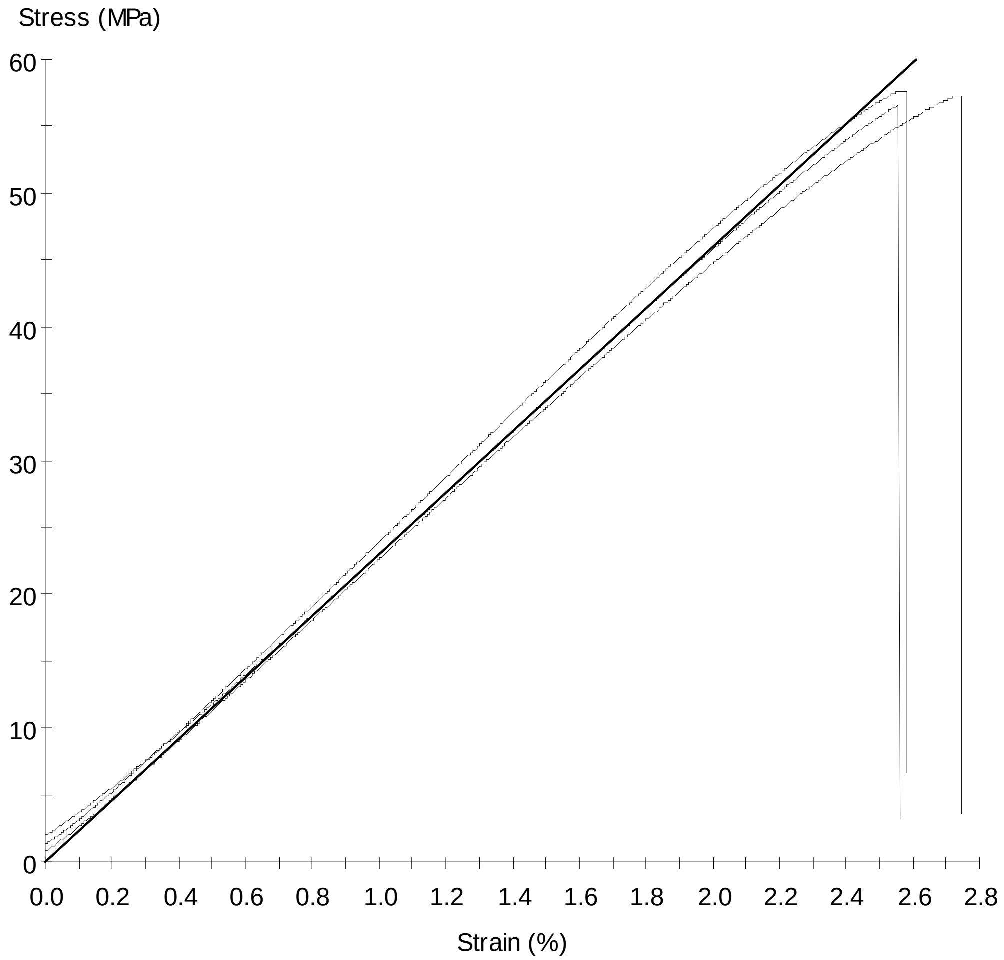
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.50	10.00	910	60.27	2.76	2.76	1.88	1.88	2327
2	13.00	10.00	815	60.22	2.88	2.87	1.96	1.96	2338
3	15.50	10.00	911	56.42	2.69	2.67	1.82	1.82	2293
Mean	**14.33**	**10.00**	**879**	**58.97**	**2.78**	**2.77**	**1.89**	**1.89**	**2320**
Std Dev	**1.26**	**0.00**	**55**	**2.21**	**0.10**	**0.10**	**0.07**	**0.07**	**23**



Stress vs Strain Plot

Sample 55

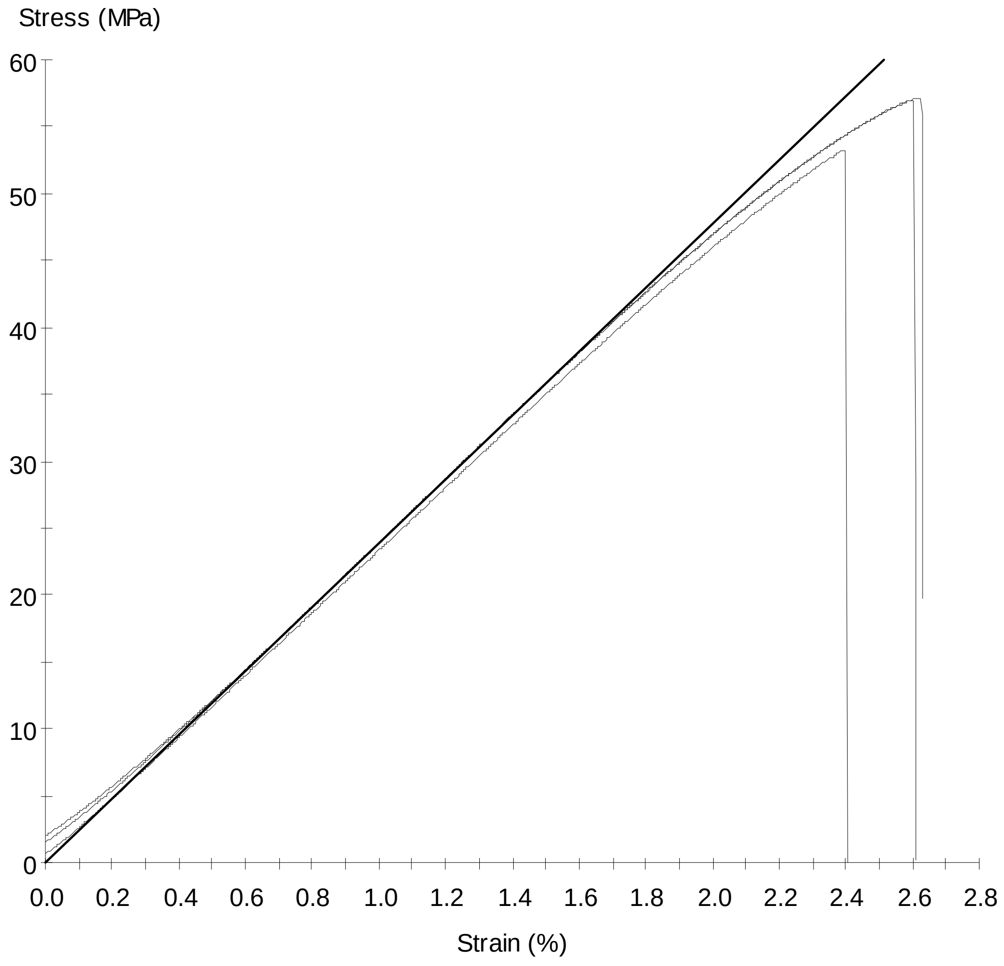
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.60	10.00	932	57.35	2.74	2.74	1.87	1.87	2261
2	16.25	10.00	977	57.70	2.58	2.57	1.75	1.75	2393
3	16.40	10.00	967	56.58	2.56	2.56	1.74	1.74	2298
Mean	**16.08**	**10.00**	**958**	**57.21**	**2.63**	**2.62**	**1.79**	**1.79**	**2317**
Std Dev	**0.43**	**0.00**	**23**	**0.58**	**0.10**	**0.10**	**0.07**	**0.07**	**68**



Stress vs Strain Plot

Sample 56

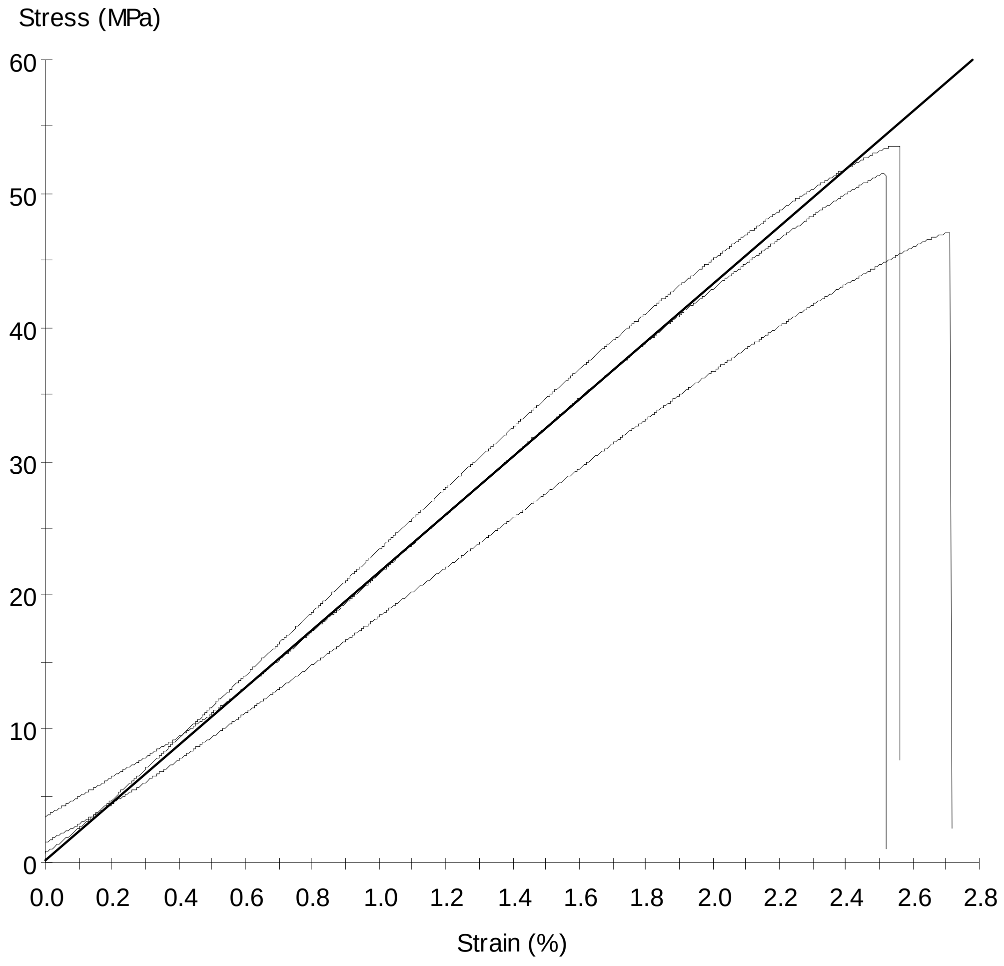
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.50	10.00	982	57.13	2.63	2.62	1.79	1.79	2392
2	17.00	10.00	943	53.23	2.40	2.40	1.64	1.64	2336
3	16.50	10.00	980	57.02	2.61	2.60	1.77	1.77	2390
Mean	**16.67**	**10.00**	**968**	**55.79**	**2.55**	**2.54**	**1.73**	**1.73**	**2373**
Std Dev	**0.29**	**0.00**	**22**	**2.22**	**0.12**	**0.12**	**0.08**	**0.08**	**32**



Stress vs Strain Plot

Sample 57

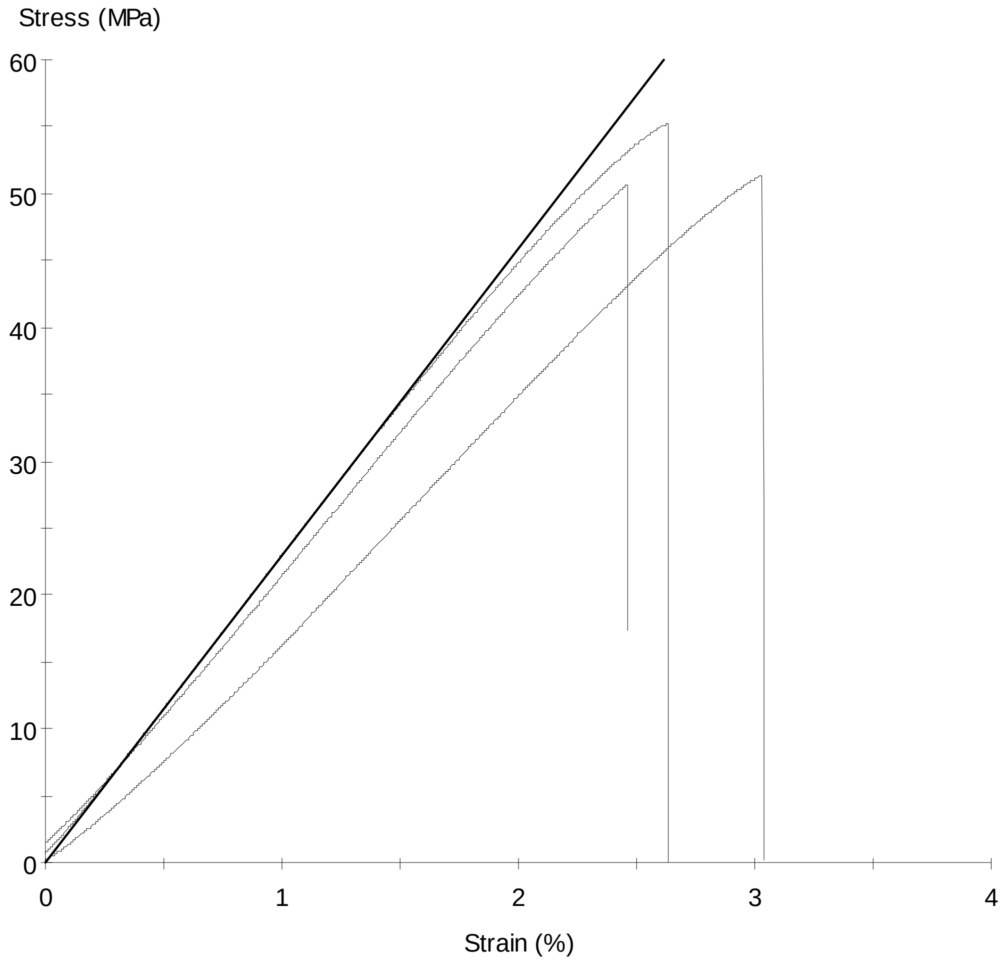
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.00	10.00	949	53.62	2.56	2.56	1.74	1.74	2339
2	18.00	10.00	883	47.09	2.72	2.71	1.85	1.85	1839
3	16.80	10.00	901	51.46	2.52	2.52	1.72	1.72	2163
Mean	**17.27**	**10.00**	**911**	**50.72**	**2.60**	**2.59**	**1.77**	**1.77**	**2114**
Std Dev	**0.64**	**0.00**	**35**	**3.33**	**0.10**	**0.10**	**0.07**	**0.07**	**254**



Stress vs Strain Plot

Sample 58

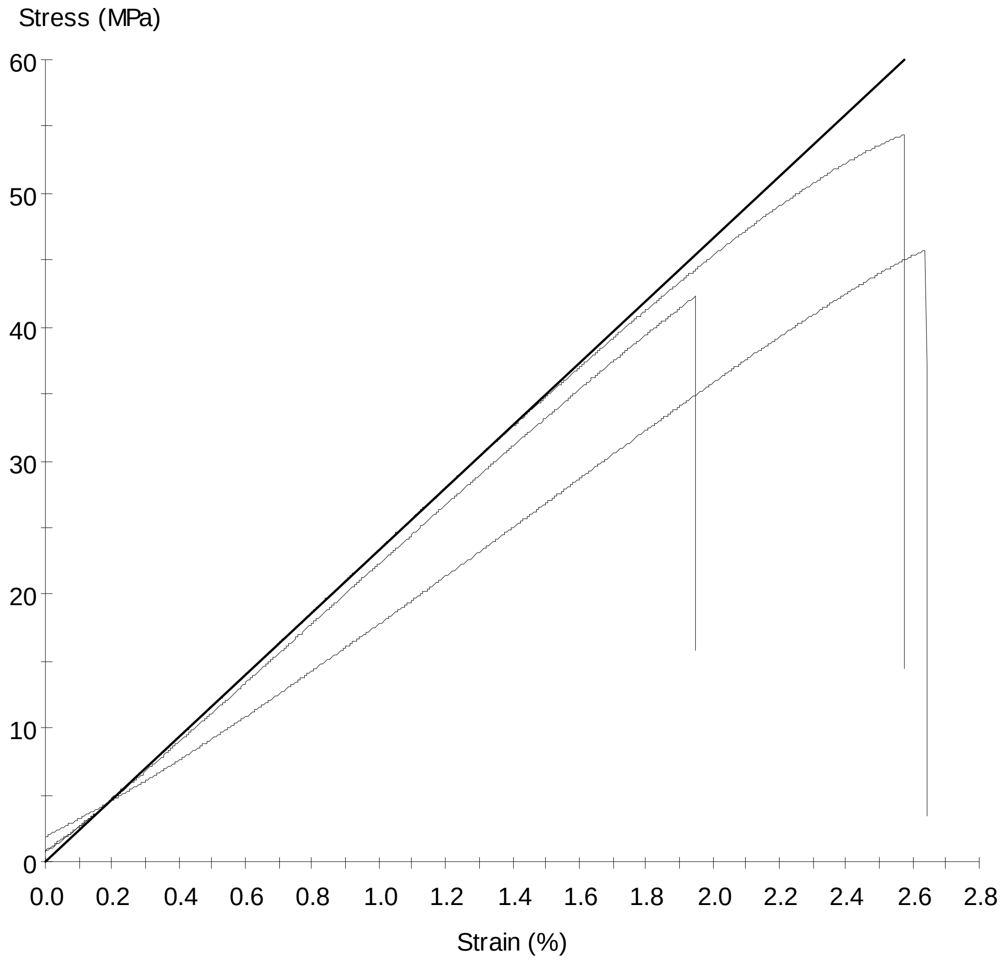
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.10	10.00	808	51.38	3.04	3.03	2.07	2.07	1407
2	16.50	10.00	872	50.71	2.47	2.46	1.68	1.68	2144
3	15.50	10.00	891	55.16	2.63	2.63	1.79	1.79	2298
Mean	**15.70**	**10.00**	**857**	**52.42**	**2.71**	**2.71**	**1.85**	**1.85**	**1950**
Std Dev	**0.72**	**0.00**	**43**	**2.40**	**0.29**	**0.29**	**0.20**	**0.20**	**477**



Stress vs Strain Plot

Sample 59

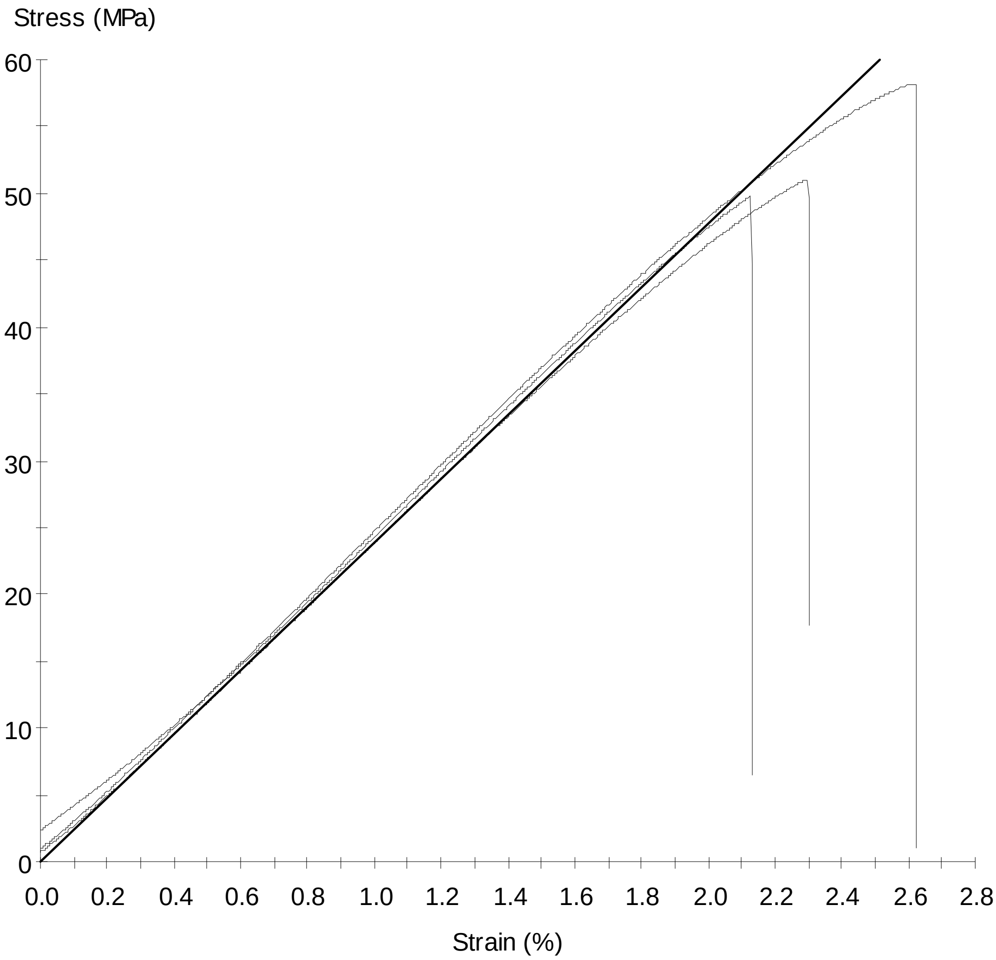
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.70	10.00	735	42.27	1.95	1.95	1.33	1.33	2228
2	16.20	10.00	772	45.73	2.64	2.64	1.80	1.80	1783
3	15.50	10.00	879	54.42	2.58	2.58	1.76	1.76	2334
Mean	**16.13**	**10.00**	**795**	**47.47**	**2.39**	**2.39**	**1.63**	**1.63**	**2115**
Std Dev	**0.60**	**0.00**	**74**	**6.26**	**0.38**	**0.38**	**0.26**	**0.26**	**292**



Stress vs Strain Plot

Sample 60

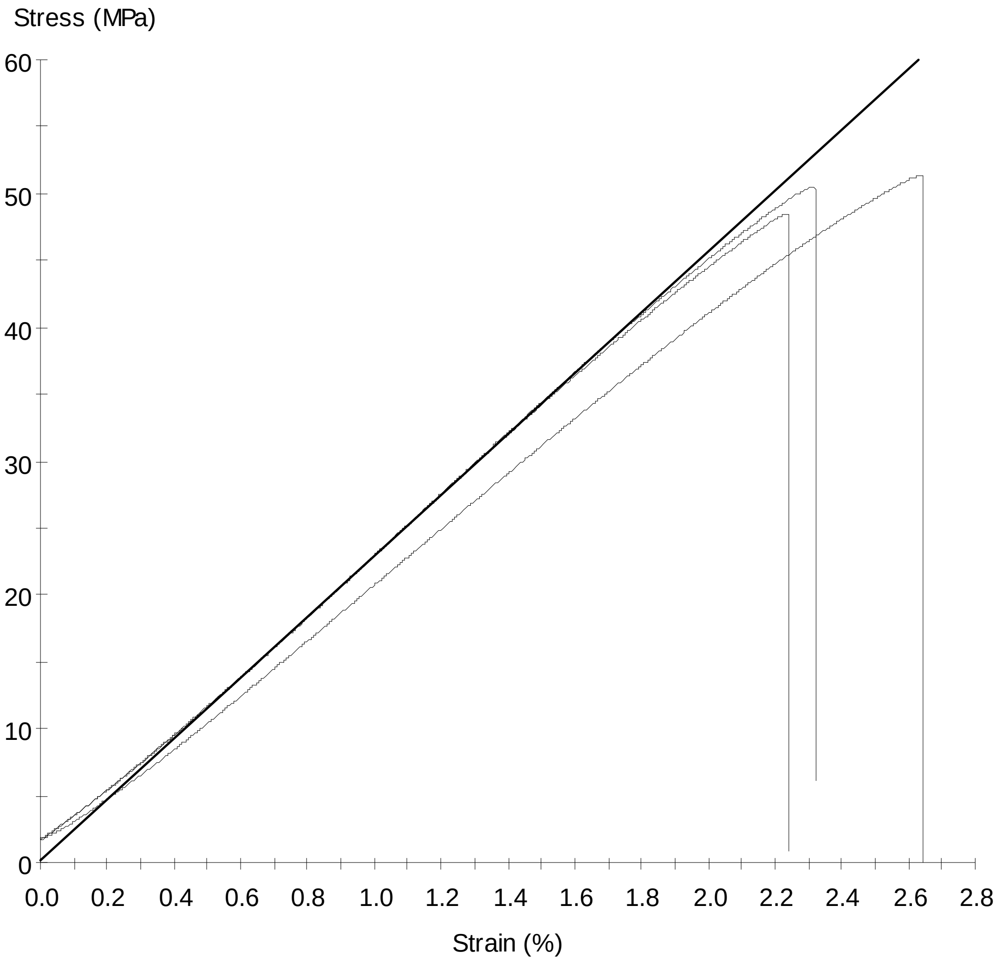
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.10	10.00	836	49.85	2.13	2.13	1.45	1.45	2429
2	16.30	10.00	988	58.17	2.63	2.62	1.79	1.79	2473
3	16.10	10.00	855	50.98	2.30	2.29	1.56	1.56	2384
Mean	**16.17**	**10.00**	**893**	**53.00**	**2.35**	**2.35**	**1.60**	**1.60**	**2429**
Std Dev	**0.12**	**0.00**	**83**	**4.51**	**0.25**	**0.25**	**0.17**	**0.17**	**44**



Stress vs Strain Plot

Sample 61

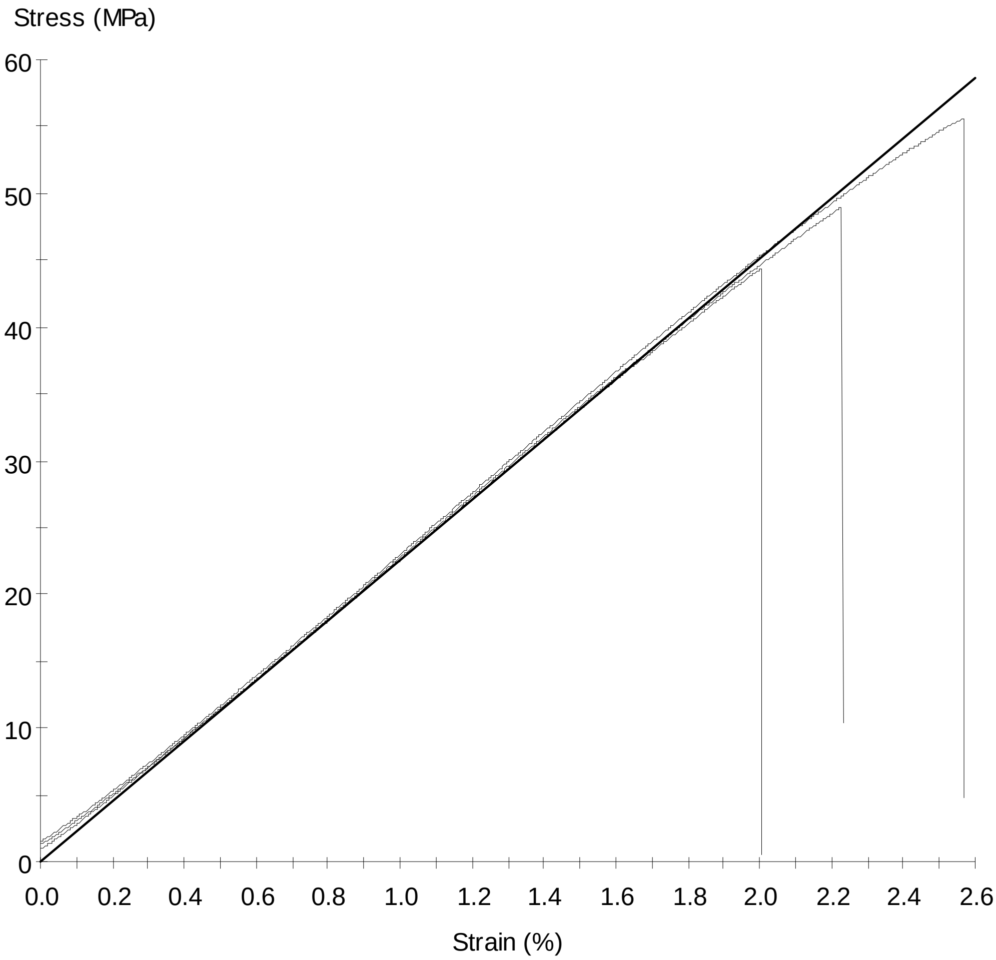
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.65	10.00	929	50.51	2.32	2.32	1.58	1.58	2297
2	16.00	10.00	856	51.36	2.65	2.64	1.80	1.80	2075
3	17.40	10.00	879	48.48	2.24	2.24	1.53	1.53	2290
Mean	**17.02**	**10.00**	**888**	**50.12**	**2.41**	**2.40**	**1.64**	**1.64**	**2220**
Std Dev	**0.89**	**0.00**	**37**	**1.48**	**0.21**	**0.21**	**0.14**	**0.14**	**126**



Stress vs Strain Plot

Sample 62

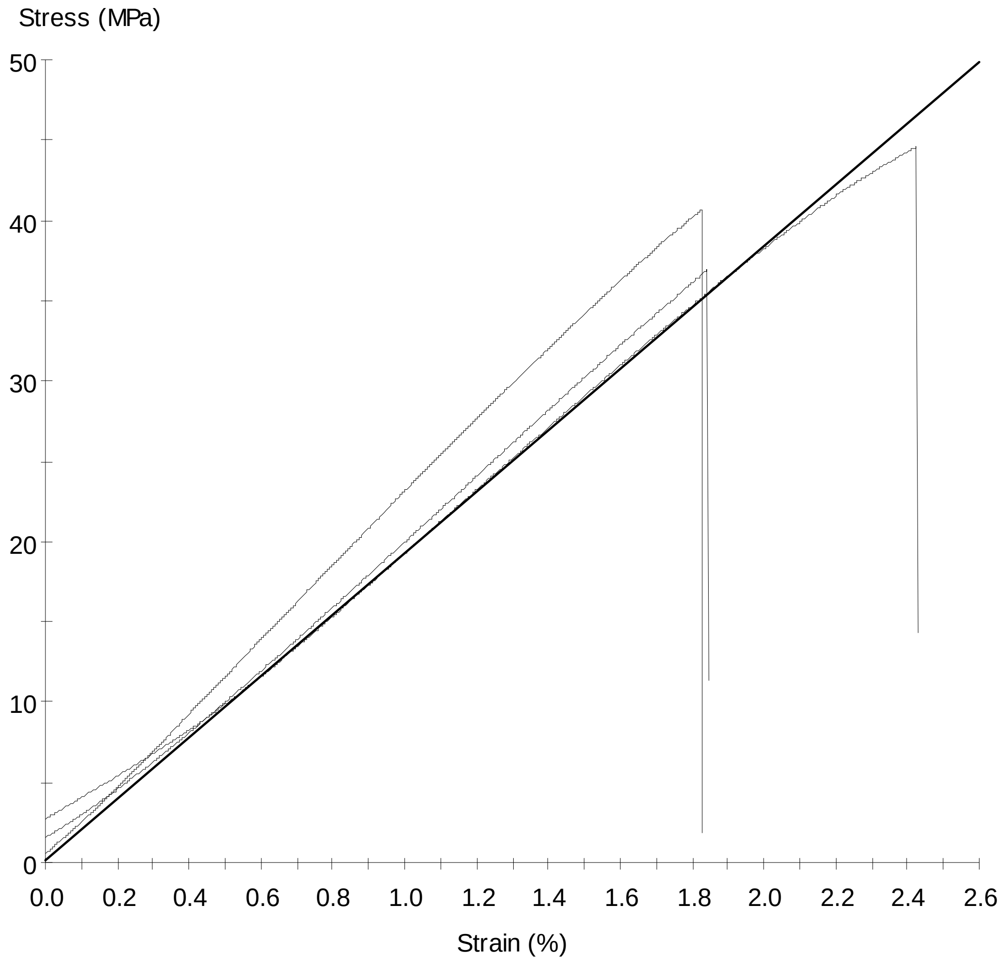
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.20	10.00	939	55.62	2.57	2.57	1.75	1.75	2299
2	14.65	10.00	748	48.99	2.23	2.23	1.52	1.52	2274
3	15.40	10.00	712	44.41	2.01	2.00	1.37	1.37	2259
Mean	**15.42**	**10.00**	**800**	**49.67**	**2.27**	**2.27**	**1.55**	**1.55**	**2277**
Std Dev	**0.78**	**0.00**	**122**	**5.64**	**0.28**	**0.28**	**0.19**	**0.19**	**20**



Stress vs Strain Plot

Sample 63

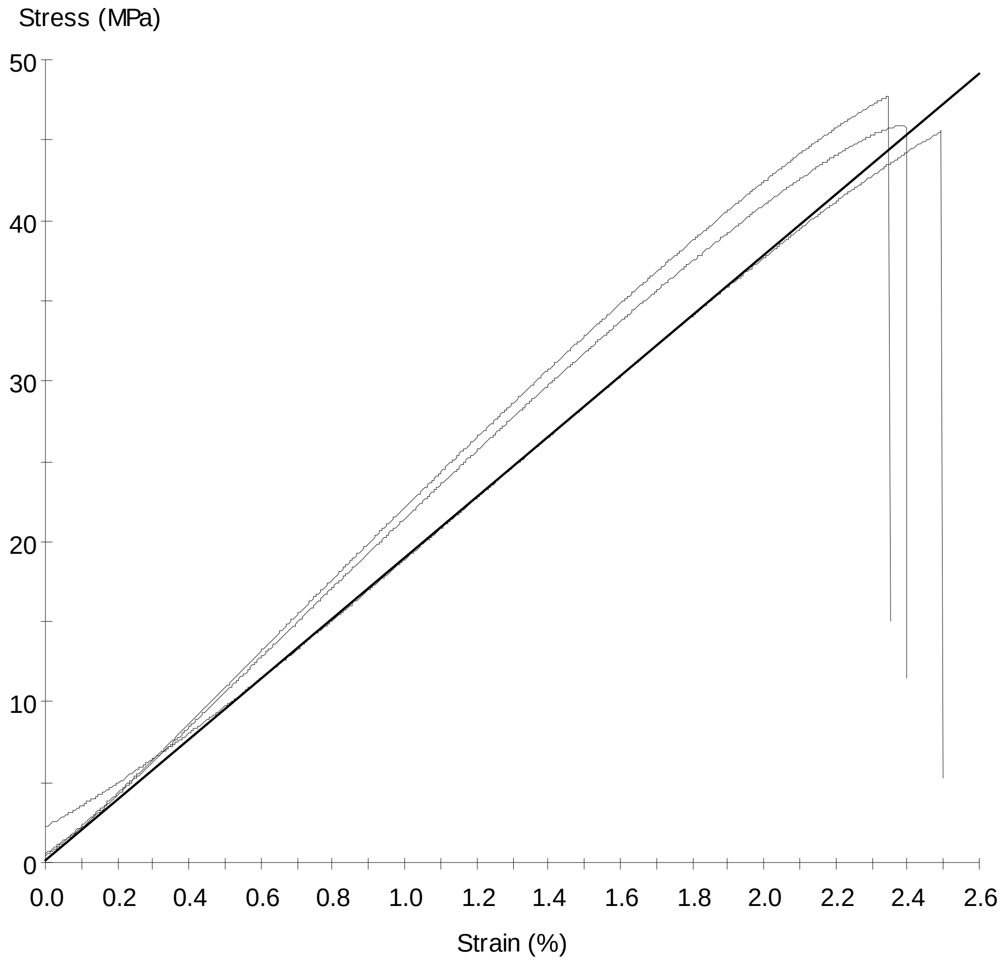
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.20	10.00	729	40.68	1.83	1.83	1.25	1.25	2317
2	16.25	10.00	625	36.92	1.85	1.84	1.26	1.26	1996
3	15.70	10.00	729	44.57	2.43	2.43	1.66	1.66	1924
Mean	**16.38**	**10.00**	**694**	**40.72**	**2.03**	**2.03**	**1.39**	**1.39**	**2079**
Std Dev	**0.76**	**0.00**	**60**	**3.82**	**0.34**	**0.34**	**0.23**	**0.23**	**209**



Stress vs Strain Plot

Sample 64

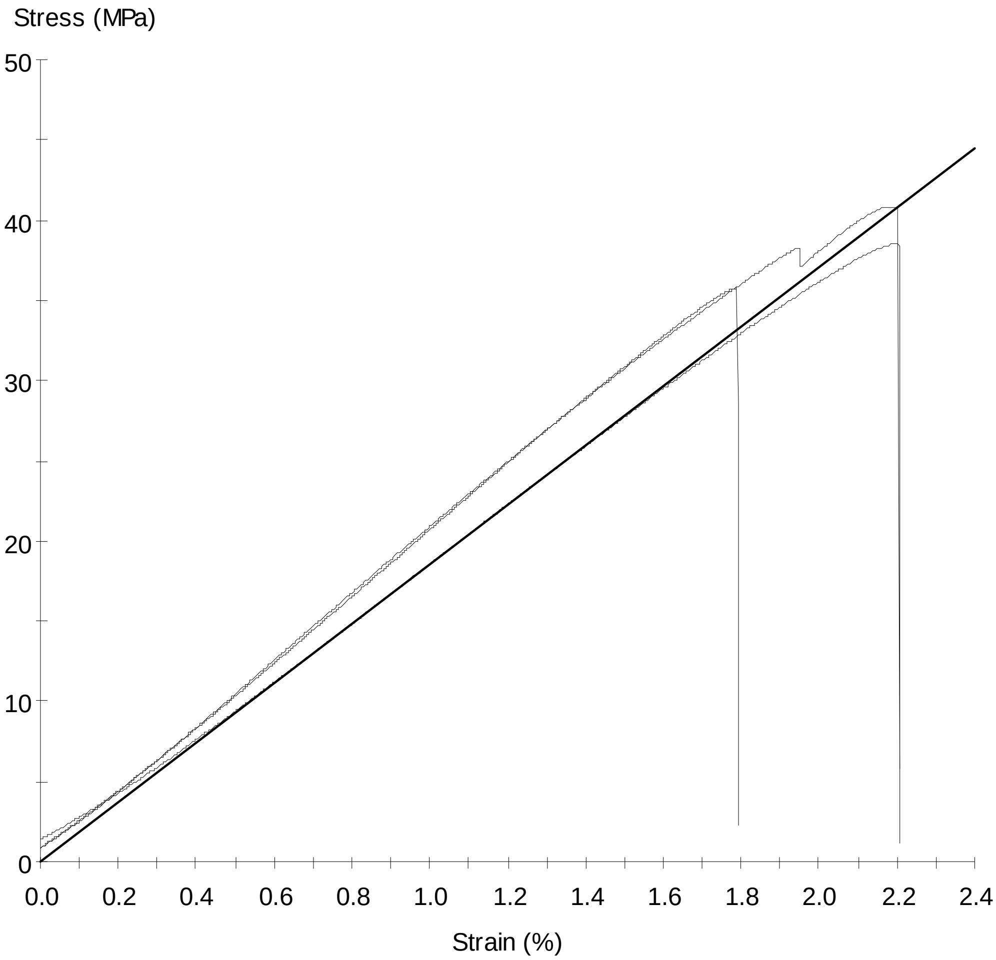
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.10	10.00	818	45.90	2.40	2.39	1.63	1.63	2138
2	17.50	10.00	870	47.72	2.35	2.35	1.60	1.60	2208
3	16.80	10.00	797	45.57	2.50	2.50	1.70	1.70	1891
Mean	**17.13**	**10.00**	**828**	**46.40**	**2.42**	**2.41**	**1.65**	**1.65**	**2079**
Std Dev	**0.35**	**0.00**	**37**	**1.16**	**0.07**	**0.08**	**0.05**	**0.05**	**166**



Stress vs Strain Plot

Sample 65

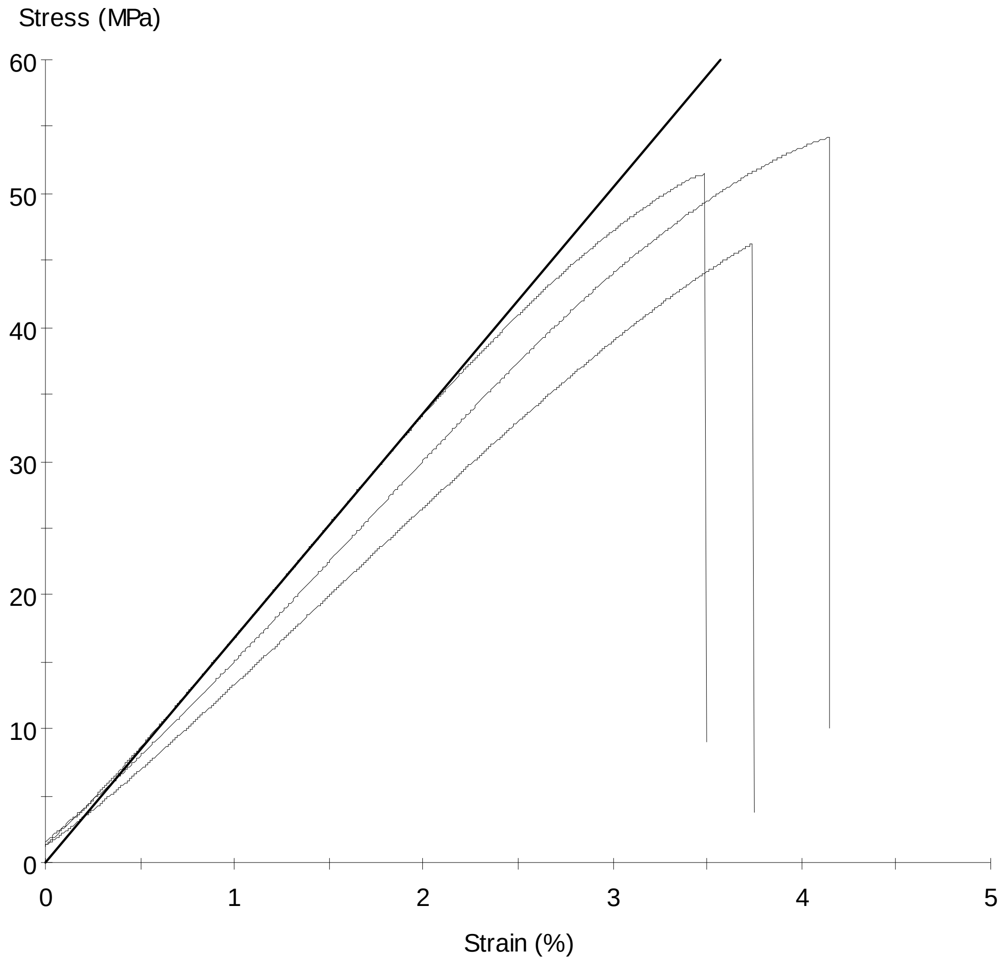
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.80	10.00	626	35.77	1.79	1.79	1.22	1.22	2062
2	17.30	10.00	736	40.85	2.21	2.18	1.49	1.49	2094
3	17.35	10.00	697	38.54	2.21	2.20	1.50	1.50	1856
Mean	**17.15**	**10.00**	**686**	**38.39**	**2.07**	**2.06**	**1.40**	**1.40**	**2004**
Std Dev	**0.30**	**0.00**	**56**	**2.55**	**0.24**	**0.23**	**0.16**	**0.16**	**129**



Stress vs Strain Plot

Sample 66

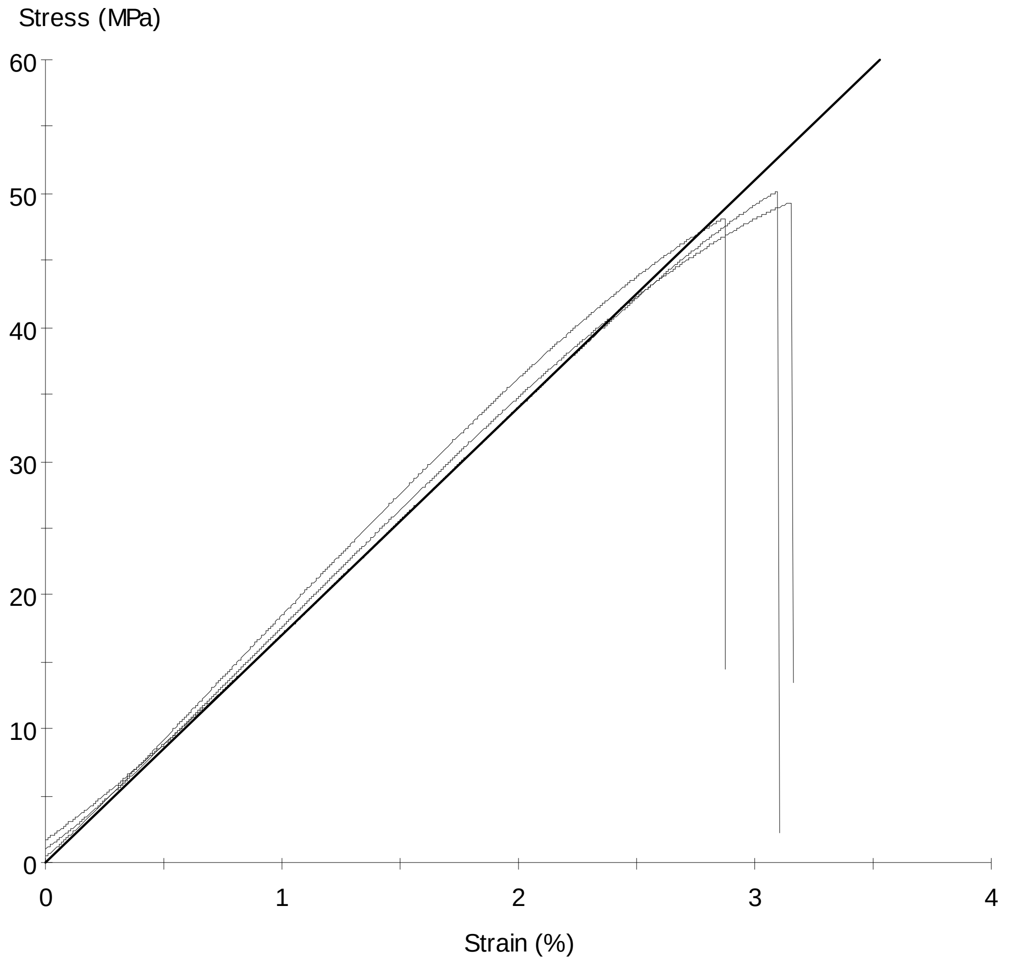
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.00	10.00	723	46.26	3.75	3.74	2.56	2.56	1329
2	15.10	10.00	852	54.16	4.15	4.14	2.83	2.83	1500
3	15.00	10.00	804	51.44	3.49	3.48	2.38	2.38	1684
Mean	**15.03**	**10.00**	**793**	**50.62**	**3.80**	**3.79**	**2.59**	**2.59**	**1504**
Std Dev	**0.06**	**0.00**	**65**	**4.01**	**0.33**	**0.33**	**0.23**	**0.23**	**177**



Stress vs Strain Plot

Sample 67

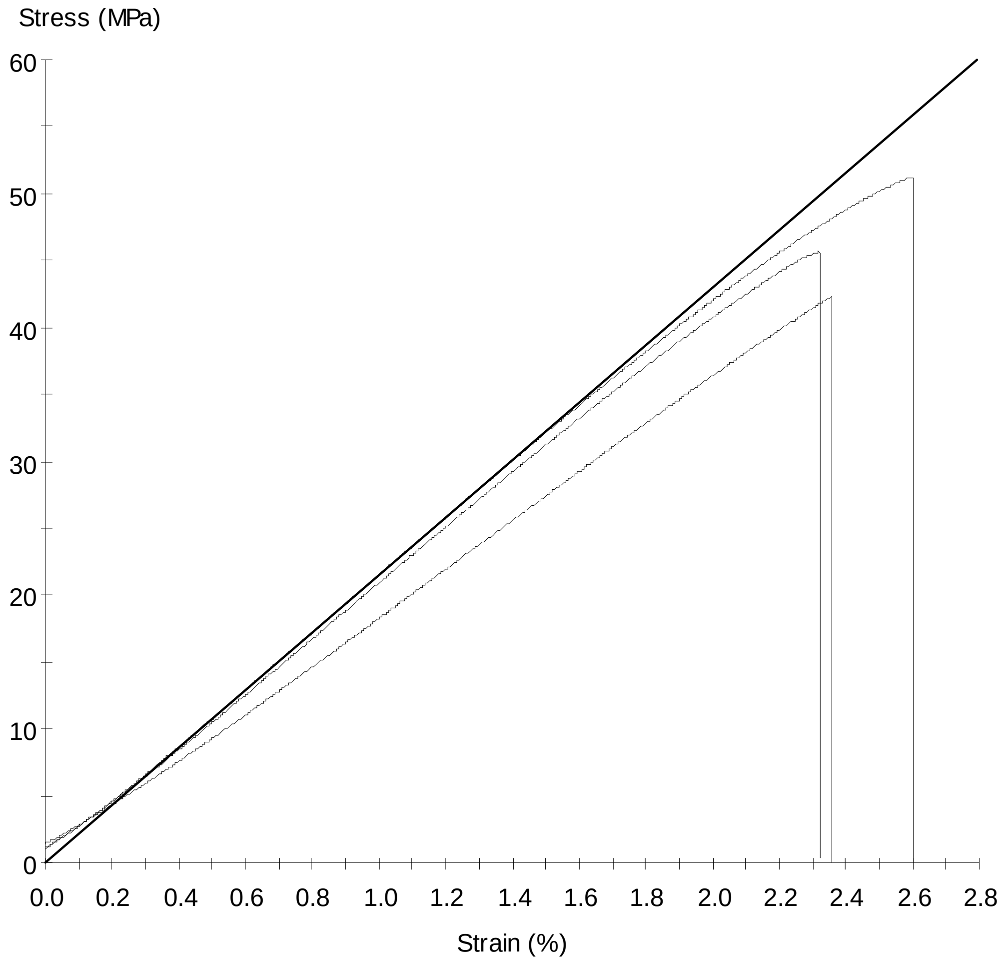
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.50	10.00	796	49.33	3.16	3.16	2.15	2.15	1758
2	16.40	10.00	823	48.15	2.88	2.87	1.96	1.96	1847
3	15.50	10.00	808	50.07	3.10	3.09	2.11	2.11	1703
Mean	**15.80**	**10.00**	**809**	**49.18**	**3.05**	**3.04**	**2.08**	**2.08**	**1769**
Std Dev	**0.52**	**0.00**	**13**	**0.97**	**0.15**	**0.15**	**0.10**	**0.10**	**73**



Stress vs Strain Plot

Sample 68

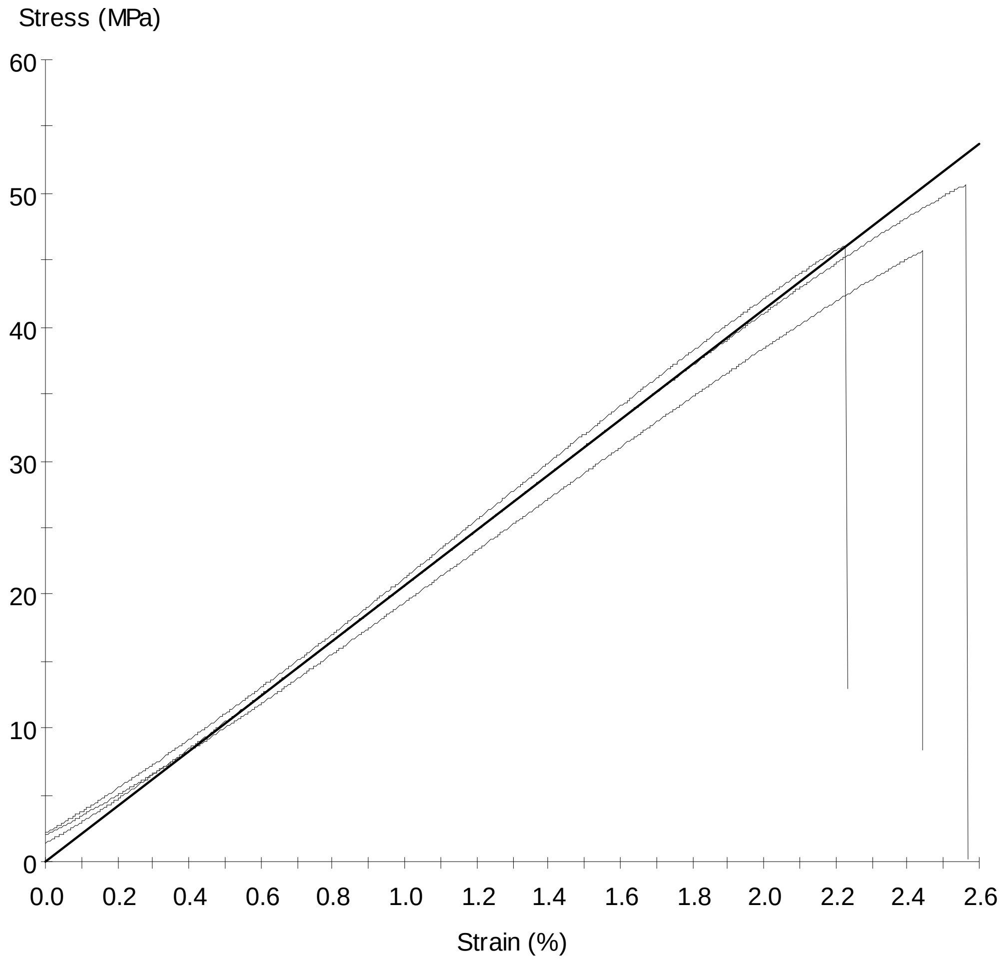
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.35	10.00	777	45.64	2.33	2.32	1.58	1.58	2091
2	16.00	10.00	704	42.24	2.36	2.36	1.61	1.61	1826
3	16.00	10.00	853	51.21	2.60	2.60	1.77	1.77	2150
Mean	**16.12**	**10.00**	**778**	**46.36**	**2.43**	**2.42**	**1.66**	**1.66**	**2023**
Std Dev	**0.20**	**0.00**	**75**	**4.53**	**0.15**	**0.15**	**0.10**	**0.10**	**173**



Stress vs Strain Plot

Sample 69

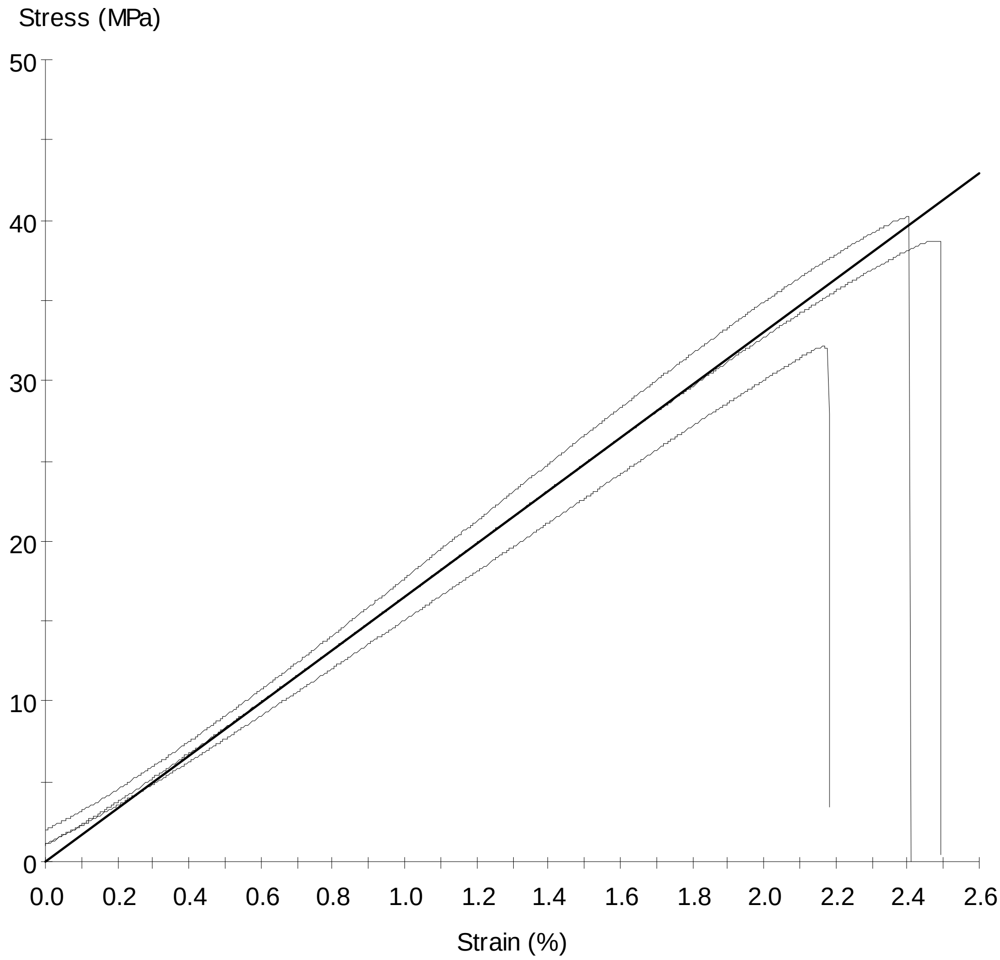
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.85	10.00	857	46.11	2.23	2.23	1.52	1.52	2126
2	17.55	10.00	835	45.70	2.45	2.44	1.67	1.67	1939
3	16.90	10.00	892	50.65	2.57	2.56	1.75	1.75	2066
Mean	**17.43**	**10.00**	**861**	**47.49**	**2.41**	**2.41**	**1.65**	**1.65**	**2044**
Std Dev	**0.49**	**0.00**	**28**	**2.75**	**0.17**	**0.17**	**0.12**	**0.12**	**96**



Stress vs Strain Plot

Sample 70

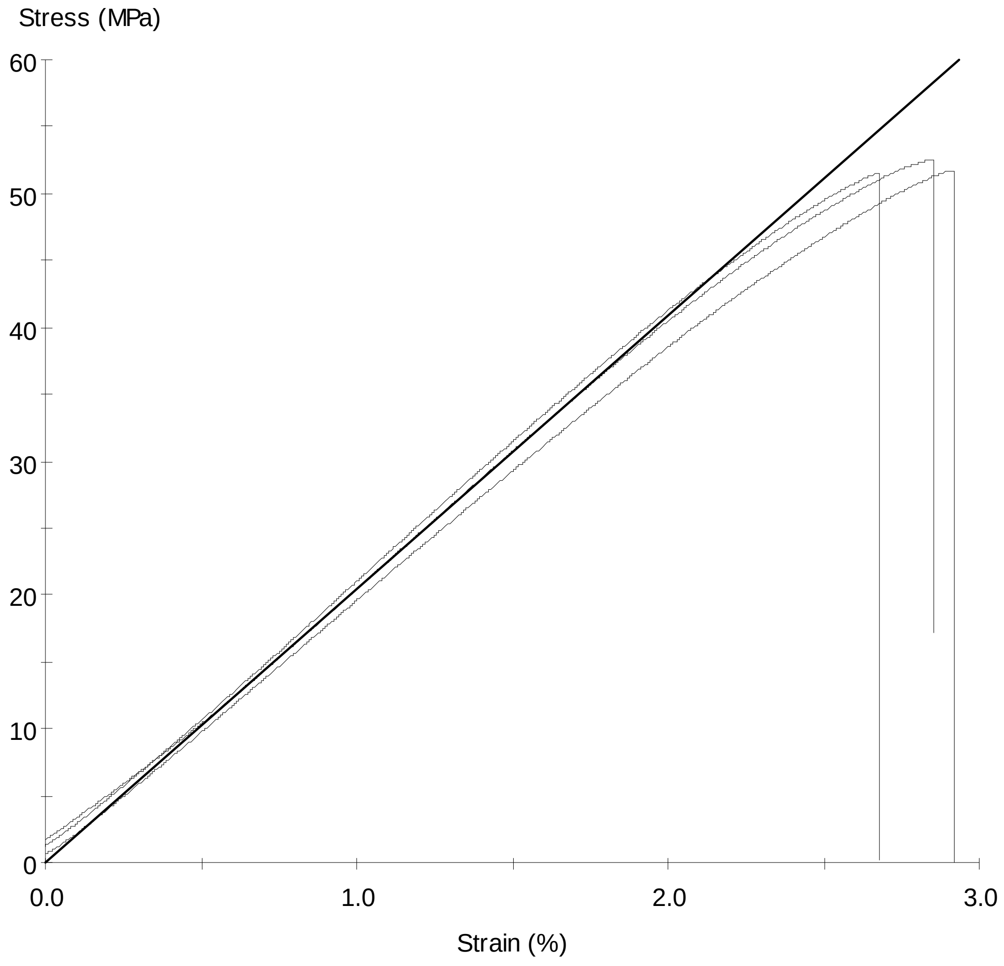
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.50	10.00	586	32.12	2.18	2.16	1.48	1.48	1507
2	16.90	10.00	708	40.21	2.41	2.40	1.64	1.64	1768
3	17.10	10.00	690	38.71	2.49	2.48	1.69	1.69	1653
Mean	**17.17**	**10.00**	**661**	**37.01**	**2.36**	**2.35**	**1.60**	**1.60**	**1643**
Std Dev	**0.31**	**0.00**	**66**	**4.30**	**0.16**	**0.16**	**0.11**	**0.11**	**131**



Stress vs Strain Plot

Sample 71

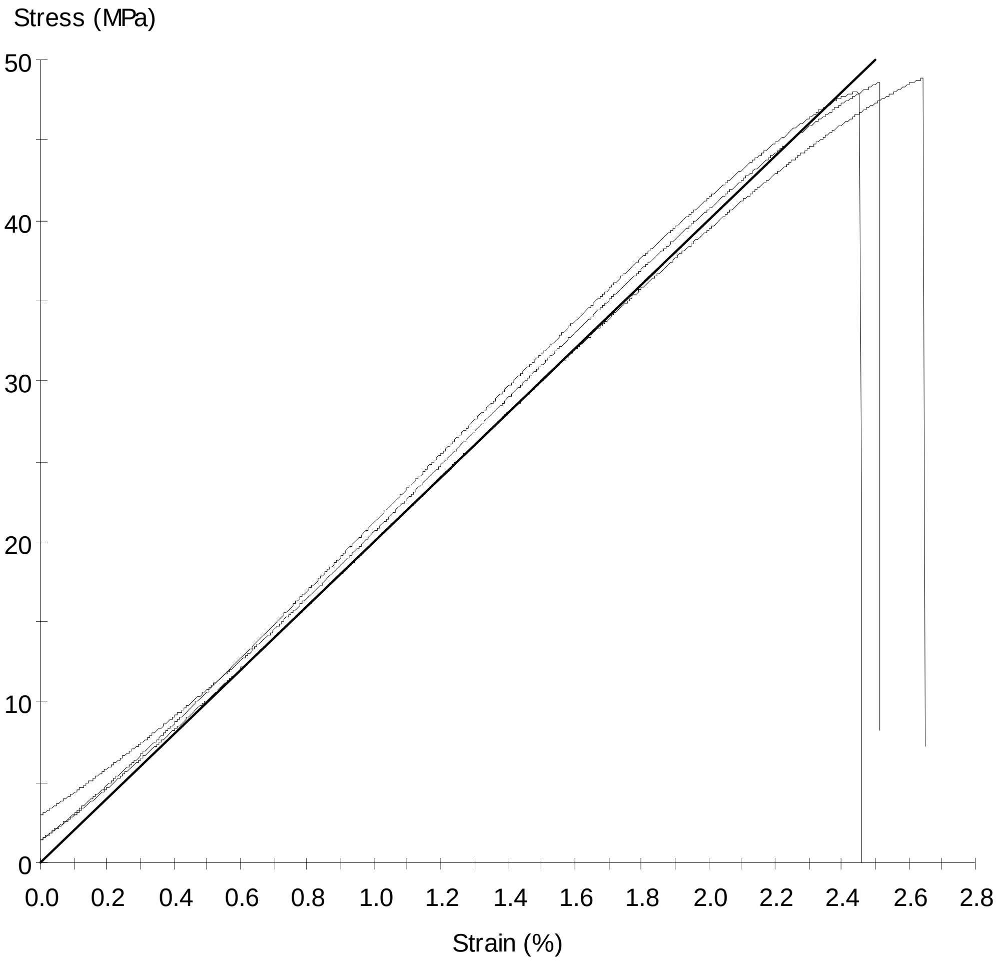
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.70	10.00	846	51.70	2.92	2.91	1.99	1.99	1956
2	15.00	10.00	806	51.56	2.68	2.68	1.83	1.83	2102
3	14.80	10.00	811	52.59	2.85	2.85	1.95	1.95	2048
Mean	**15.17**	**10.00**	**821**	**51.95**	**2.82**	**2.81**	**1.92**	**1.92**	**2036**
Std Dev	**0.47**	**0.00**	**22**	**0.56**	**0.13**	**0.12**	**0.08**	**0.08**	**74**



Stress vs Strain Plot

Sample 72

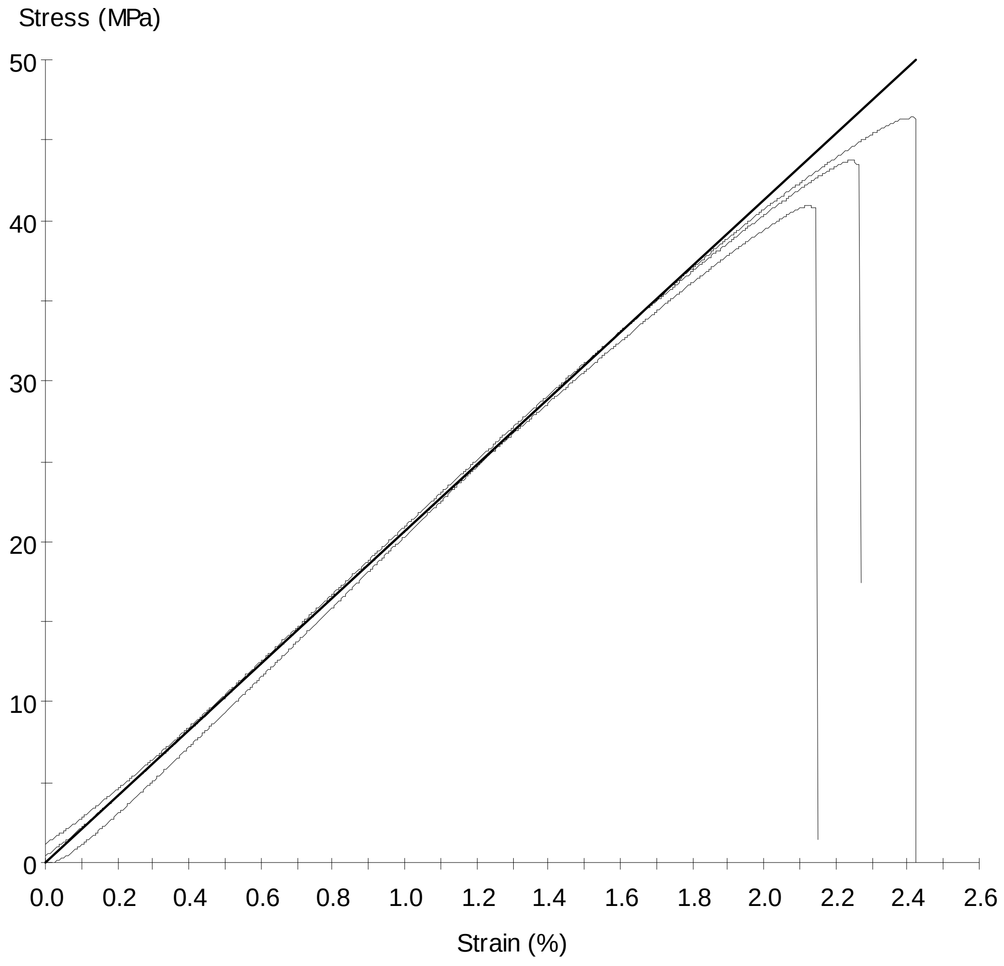
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.50	10.00	886	48.59	2.51	2.51	1.72	1.72	2065
2	17.00	10.00	850	47.99	2.46	2.44	1.67	1.67	2120
3	17.70	10.00	901	48.85	2.65	2.64	1.81	1.81	2001
Mean	**17.40**	**10.00**	**879**	**48.48**	**2.54**	**2.53**	**1.73**	**1.73**	**2062**
Std Dev	**0.36**	**0.00**	**26**	**0.44**	**0.10**	**0.10**	**0.07**	**0.07**	**60**



Stress vs Strain Plot

Sample 73

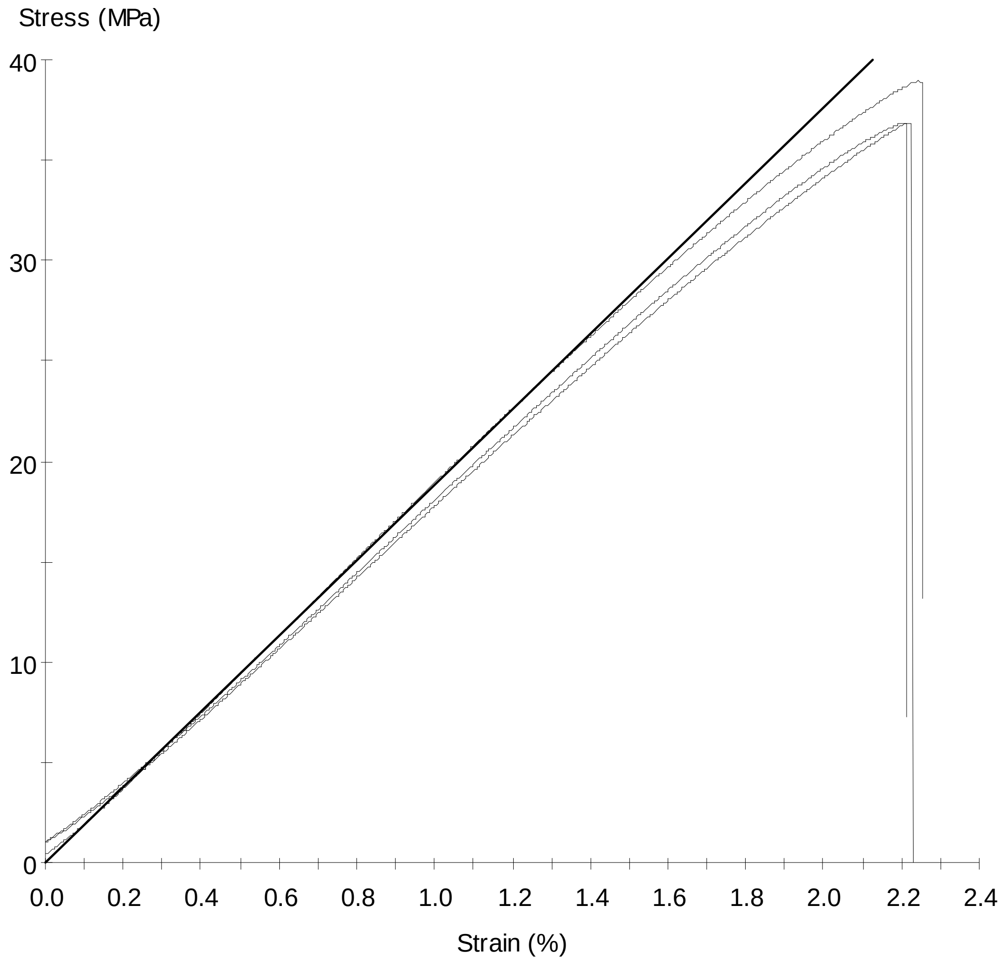
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.00	10.00	775	43.78	2.27	2.25	1.53	1.53	2092
2	16.20	10.00	783	46.41	2.42	2.41	1.65	1.65	2062
3	16.40	10.00	699	40.91	2.15	2.12	1.45	1.45	2066
Mean	**16.53**	**10.00**	**752**	**43.70**	**2.28**	**2.26**	**1.54**	**1.54**	**2073**
Std Dev	**0.42**	**0.00**	**47**	**2.75**	**0.14**	**0.15**	**0.10**	**0.10**	**16**



Stress vs Strain Plot

Sample 74

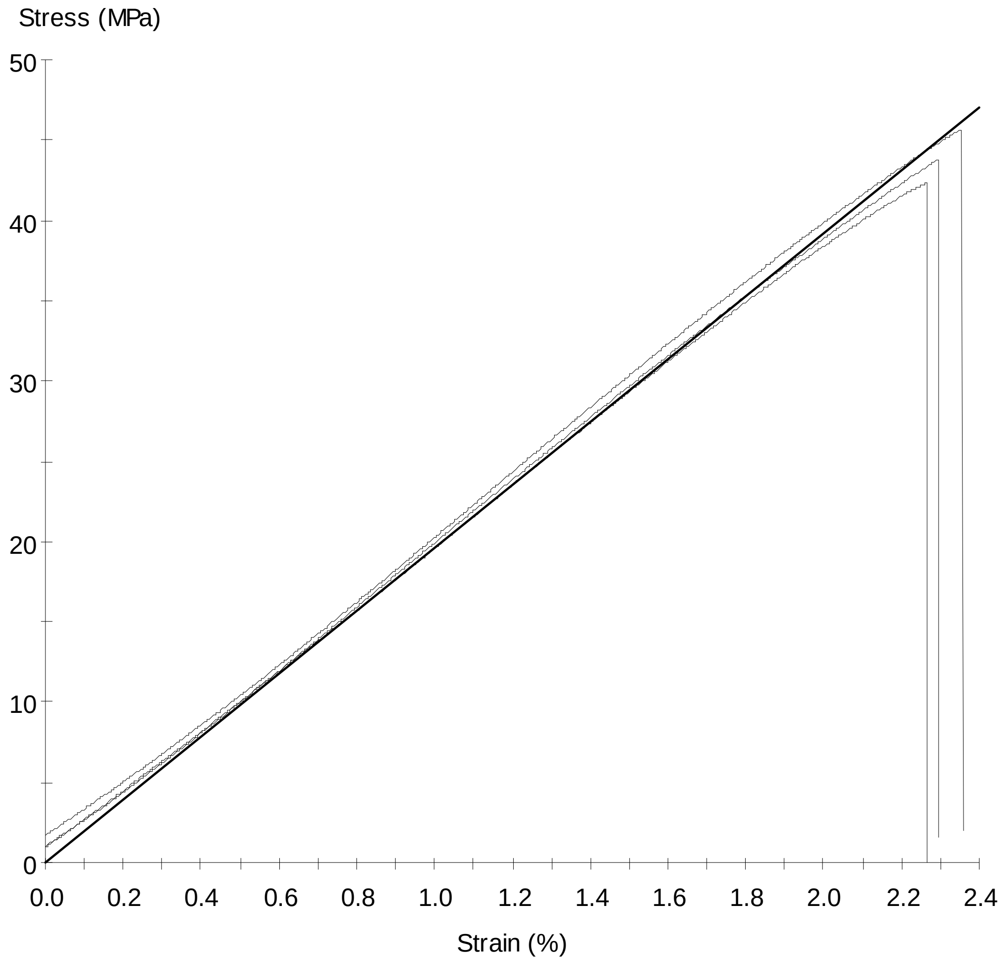
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.60	10.00	637	36.85	2.21	2.21	1.51	1.51	1803
2	17.05	10.00	655	36.87	2.23	2.22	1.52	1.52	1774
3	16.85	10.00	684	38.96	2.26	2.24	1.53	1.53	1889
Mean	**16.83**	**10.00**	**659**	**37.56**	**2.23**	**2.22**	**1.52**	**1.52**	**1822**
Std Dev	**0.23**	**0.00**	**24**	**1.21**	**0.02**	**0.02**	**0.01**	**0.01**	**60**



Stress vs Strain Plot

Sample 75

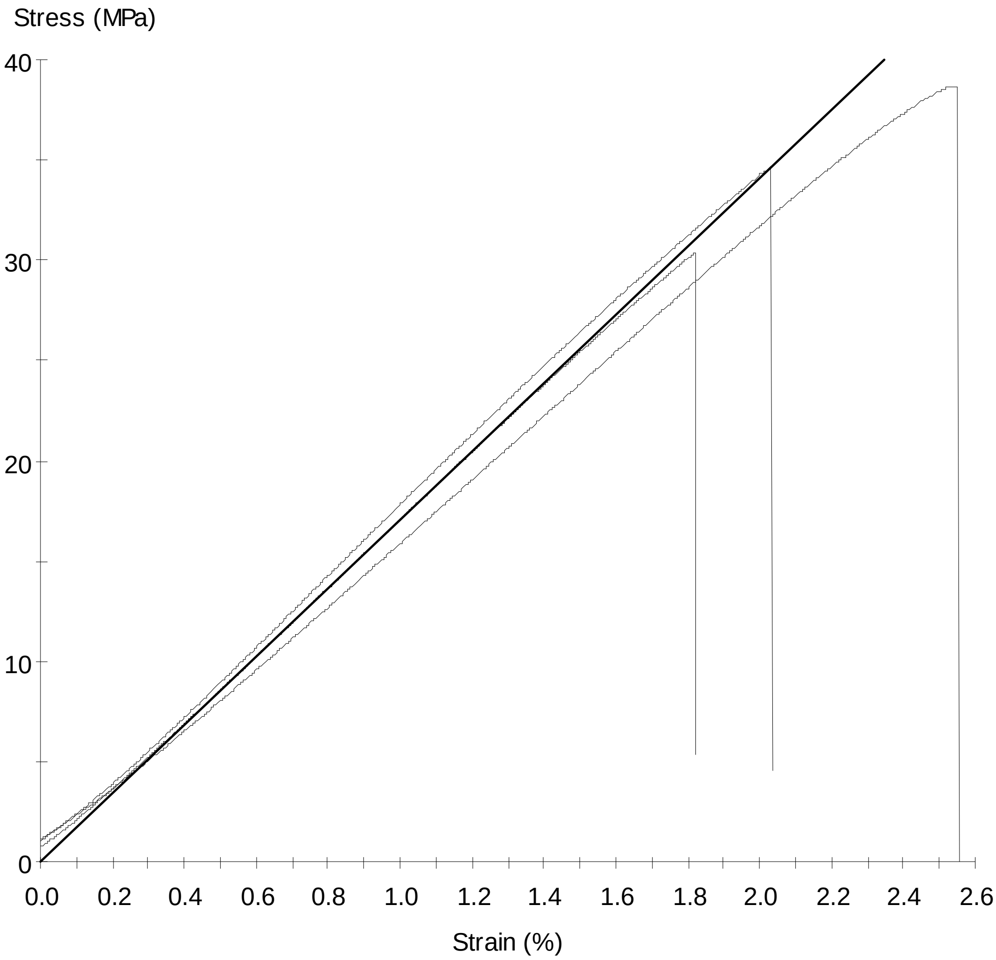
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.25	10.00	773	45.64	2.36	2.35	1.61	1.61	2026
2	14.80	10.00	676	43.83	2.30	2.30	1.57	1.57	1990
3	15.15	10.00	668	42.34	2.27	2.27	1.55	1.55	1959
Mean	**15.40**	**10.00**	**705**	**43.94**	**2.31**	**2.30**	**1.57**	**1.57**	**1992**
Std Dev	**0.76**	**0.00**	**58**	**1.65**	**0.05**	**0.04**	**0.03**	**0.03**	**34**



Stress vs Strain Plot

Sample 76

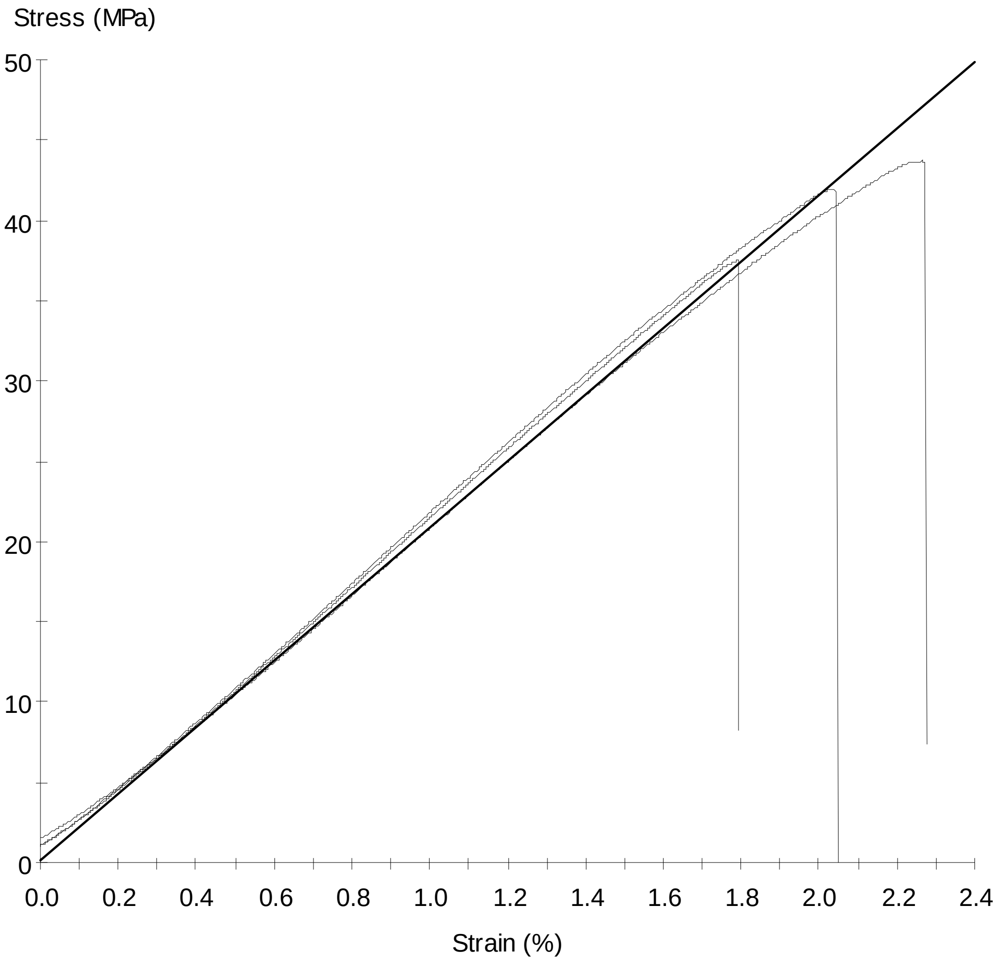
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.85	10.00	639	38.68	2.55	2.55	1.74	1.74	1586
2	16.80	10.00	607	34.68	2.03	2.03	1.39	1.39	1783
3	16.90	10.00	535	30.37	1.82	1.82	1.24	1.24	1706
Mean	**16.52**	**10.00**	**593**	**34.58**	**2.14**	**2.13**	**1.46**	**1.46**	**1692**
Std Dev	**0.58**	**0.00**	**53**	**4.15**	**0.38**	**0.37**	**0.25**	**0.25**	**99**



Stress vs Strain Plot

Sample 77

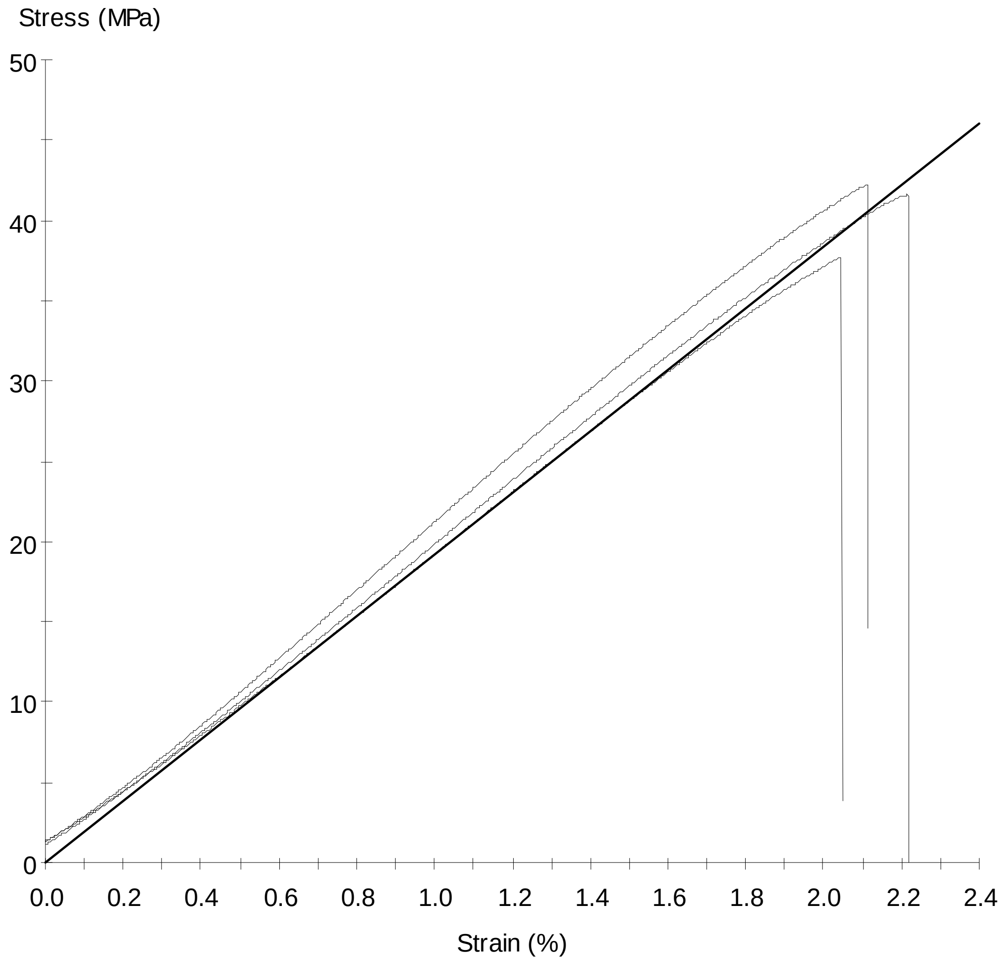
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	16.20	10.00	633	37.54	1.79	1.79	1.22	1.22	2140
2	17.24	10.00	753	41.94	2.05	2.03	1.39	1.39	2173
3	17.00	10.00	774	43.70	2.27	2.26	1.54	1.54	2080
Mean	**16.81**	**10.00**	**720**	**41.06**	**2.04**	**2.03**	**1.38**	**1.38**	**2131**
Std Dev	**0.54**	**0.00**	**76**	**3.18**	**0.24**	**0.24**	**0.16**	**0.16**	**47**



Stress vs Strain Plot

Sample 78

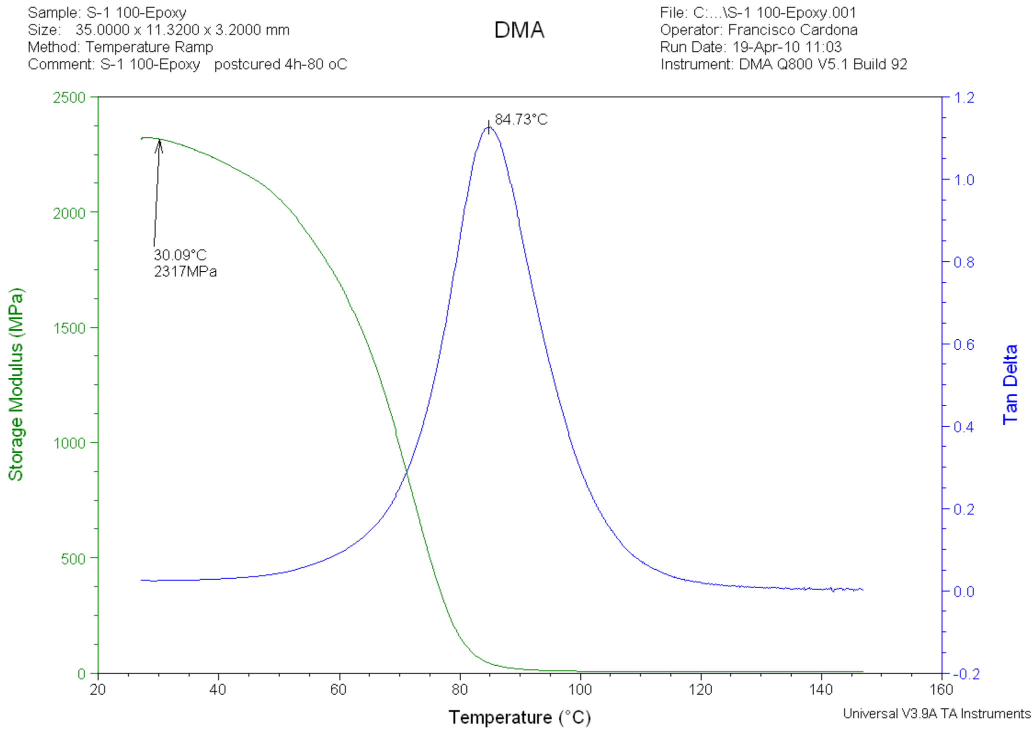
Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.56	10.00	771	42.15	2.11	2.11	1.44	1.44	2120
2	16.70	10.00	723	41.58	2.22	2.22	1.51	1.51	1984
3	17.50	10.00	687	37.67	2.05	2.05	1.40	1.40	1921
Mean	**17.25**	**10.00**	**727**	**40.47**	**2.13**	**2.12**	**1.45**	**1.45**	**2008**
Std Dev	**0.48**	**0.00**	**42**	**2.44**	**0.09**	**0.09**	**0.06**	**0.06**	**102**



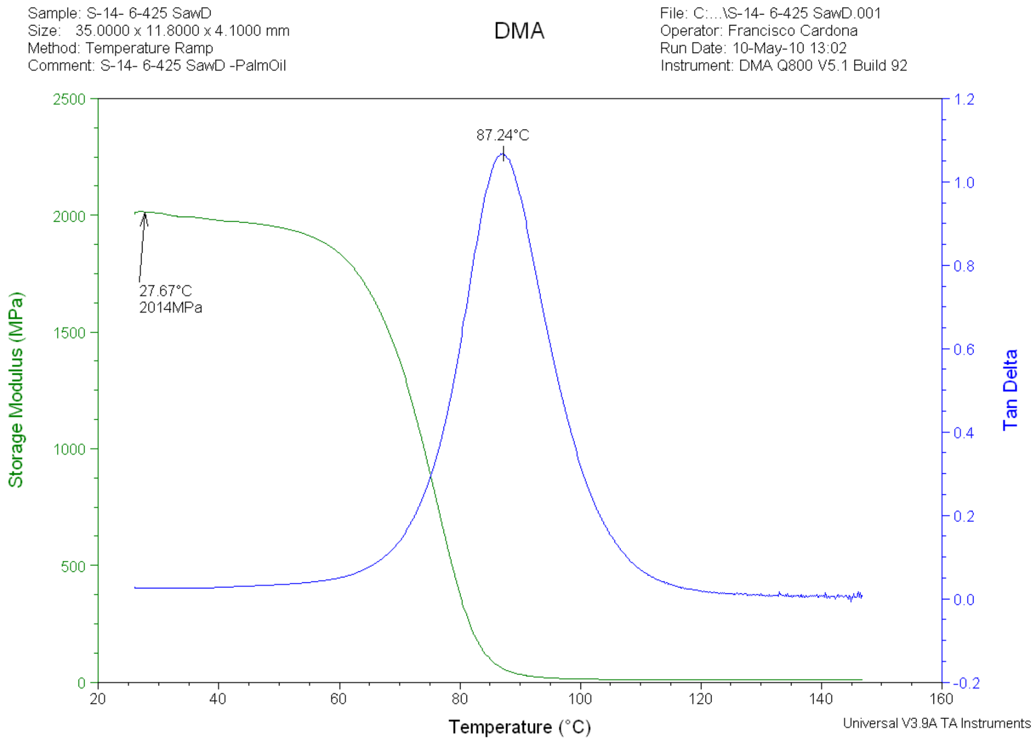
Stress vs Strain Plot

Appendix D – DMA Results

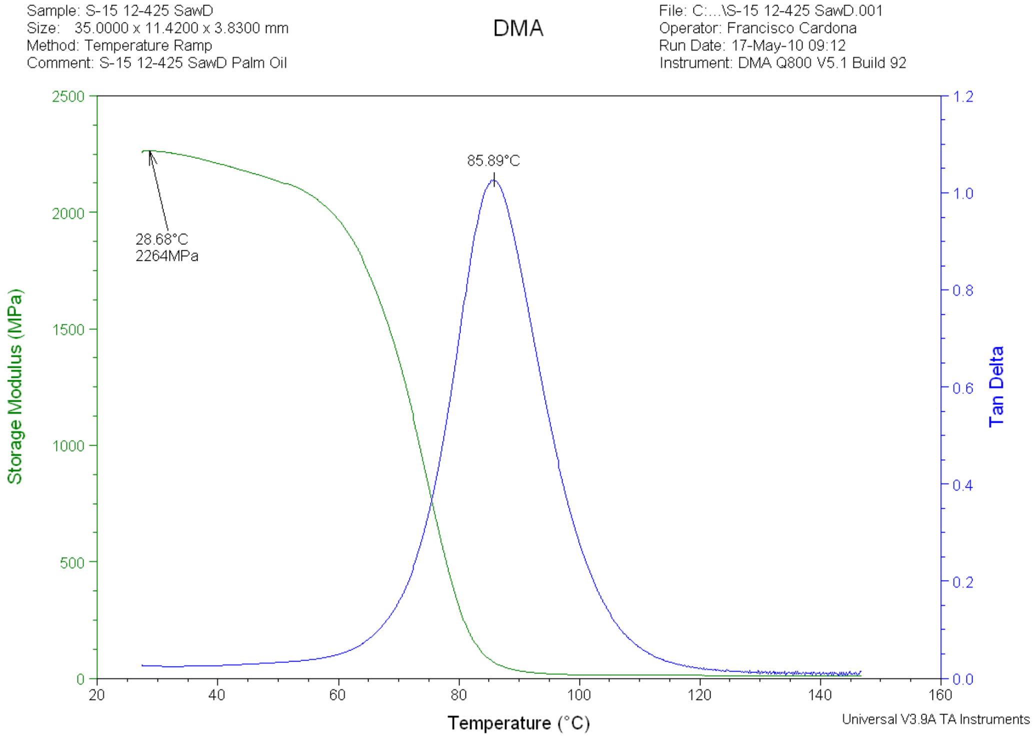
Sample 1



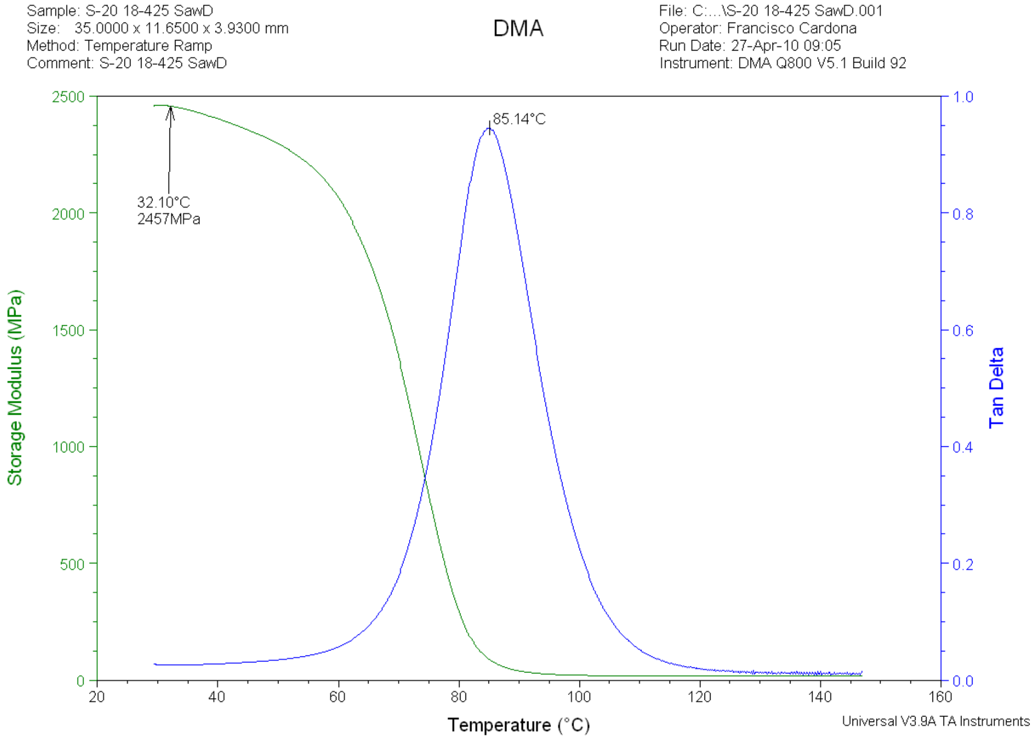
Sample 2



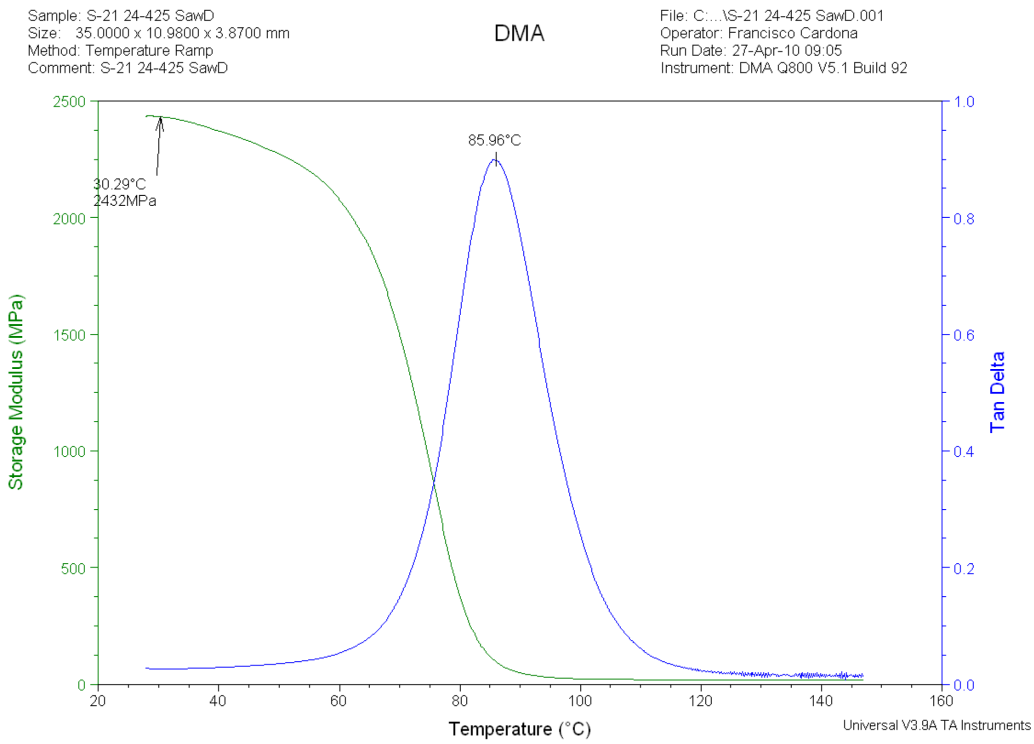
Sample 3



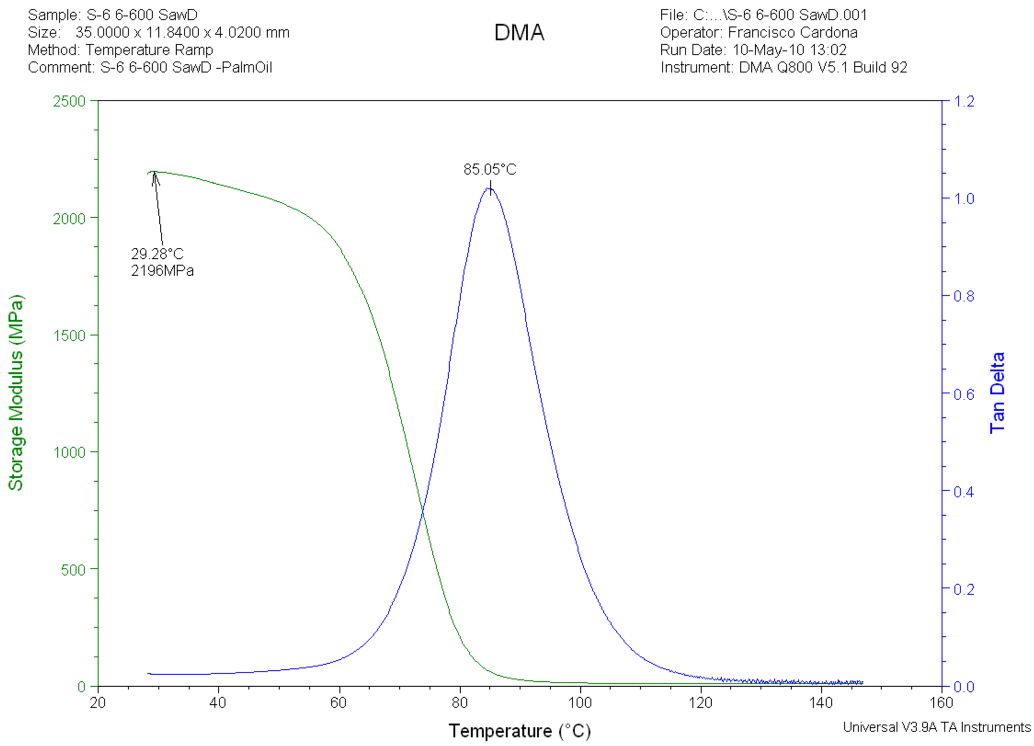
Sample 4



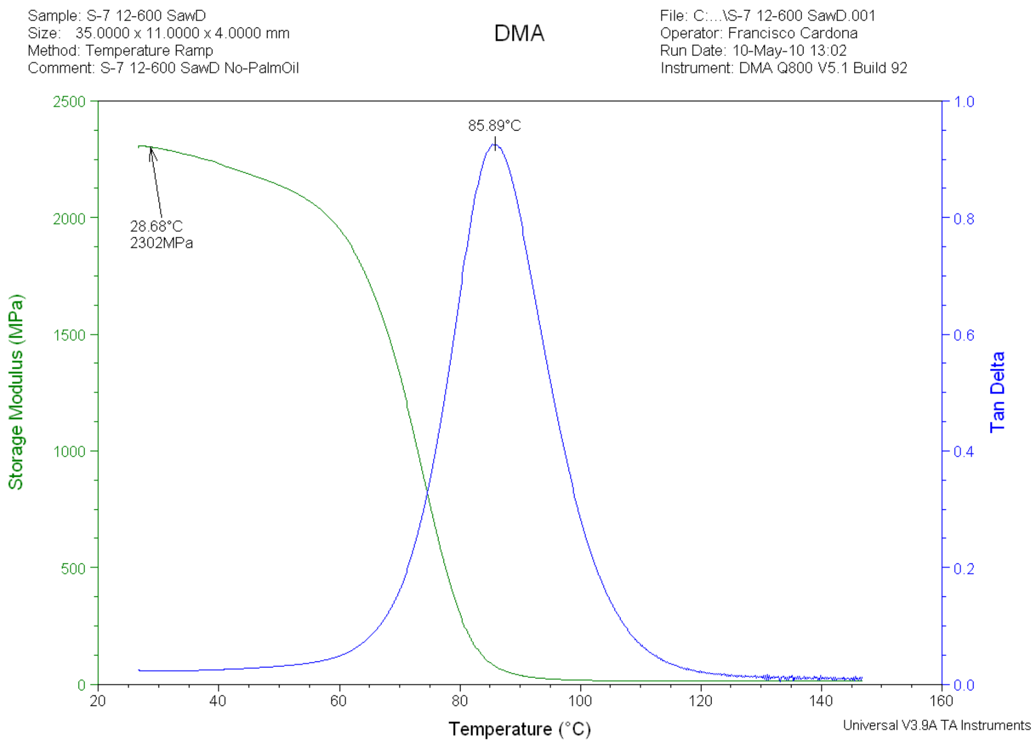
Sample 5



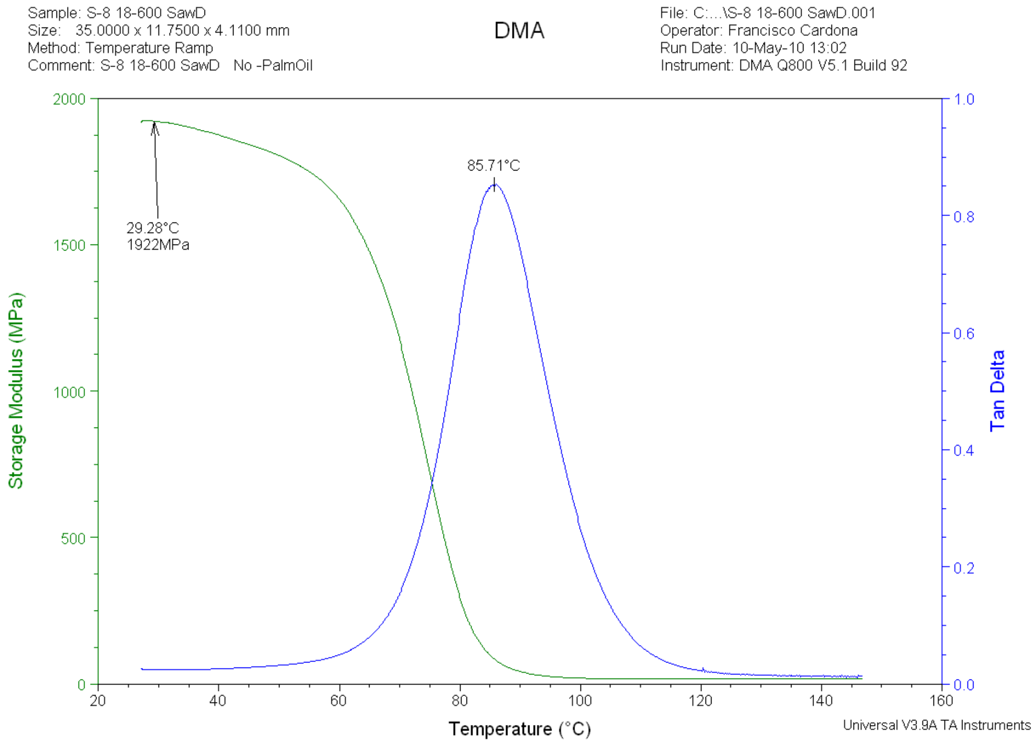
Sample 6



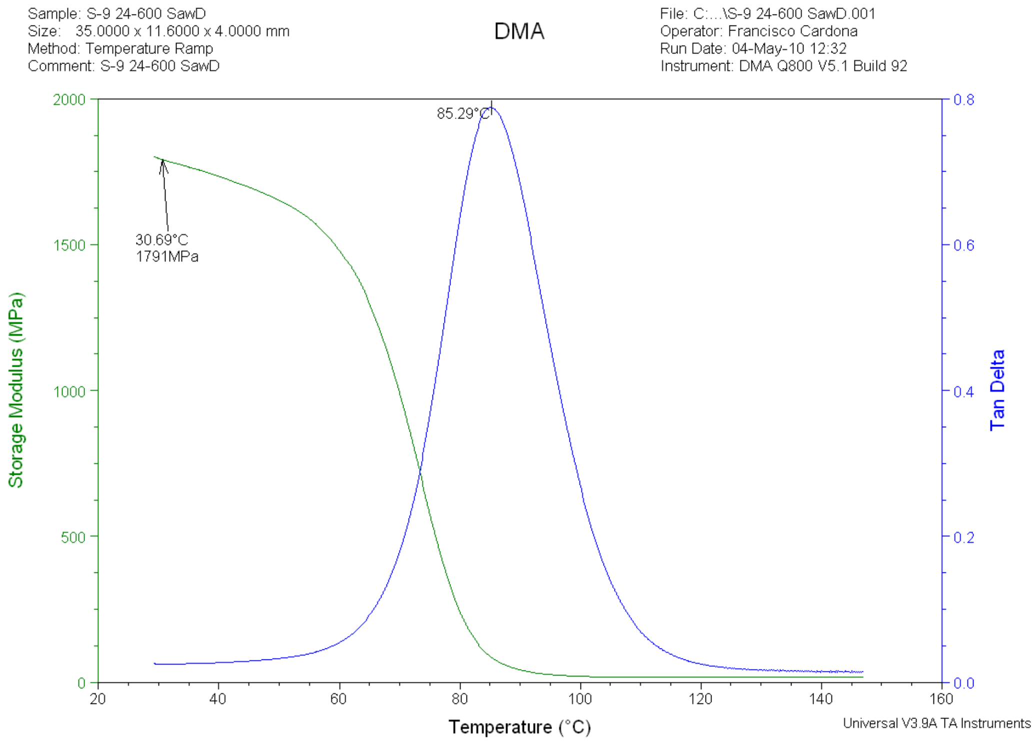
Sample 7



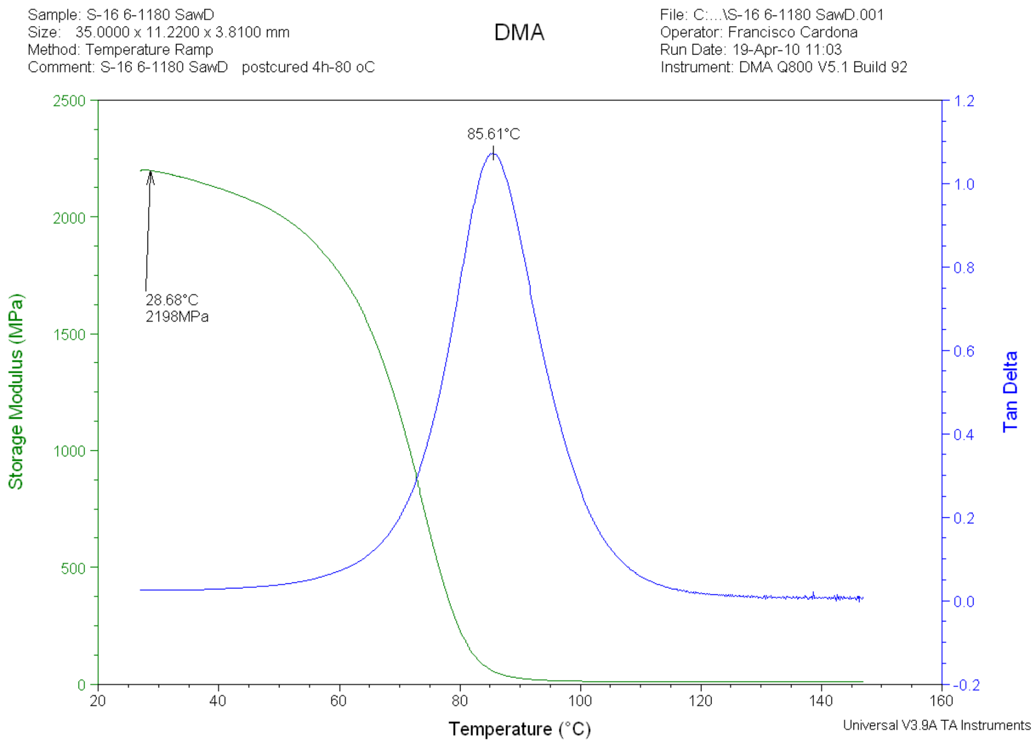
Sample 8



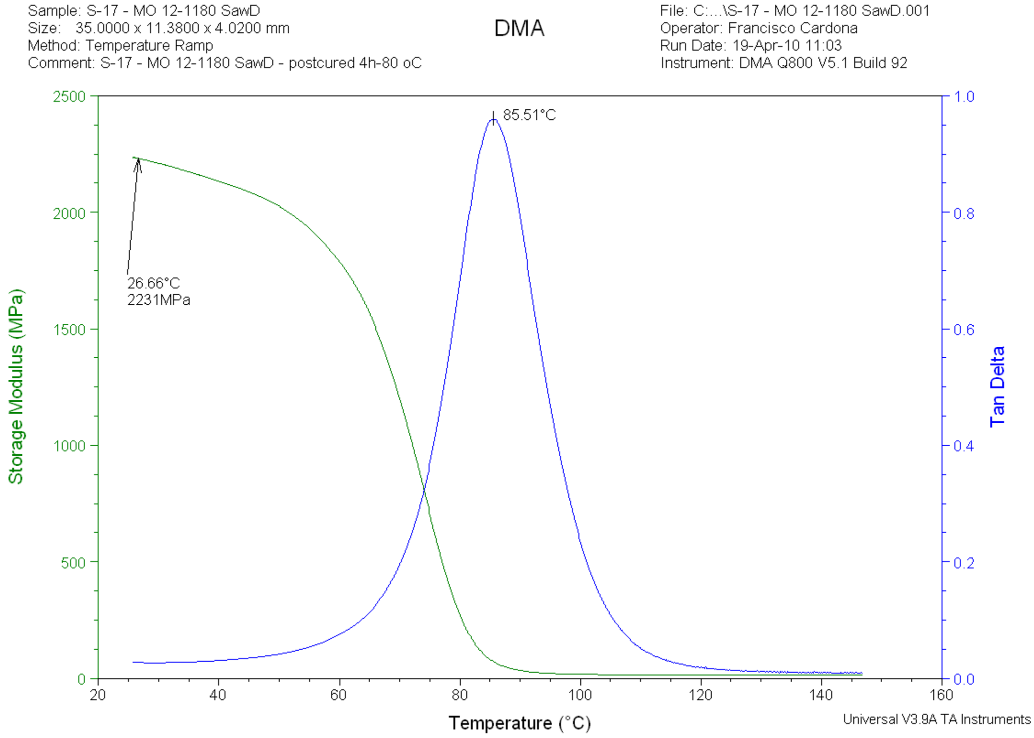
Sample 9



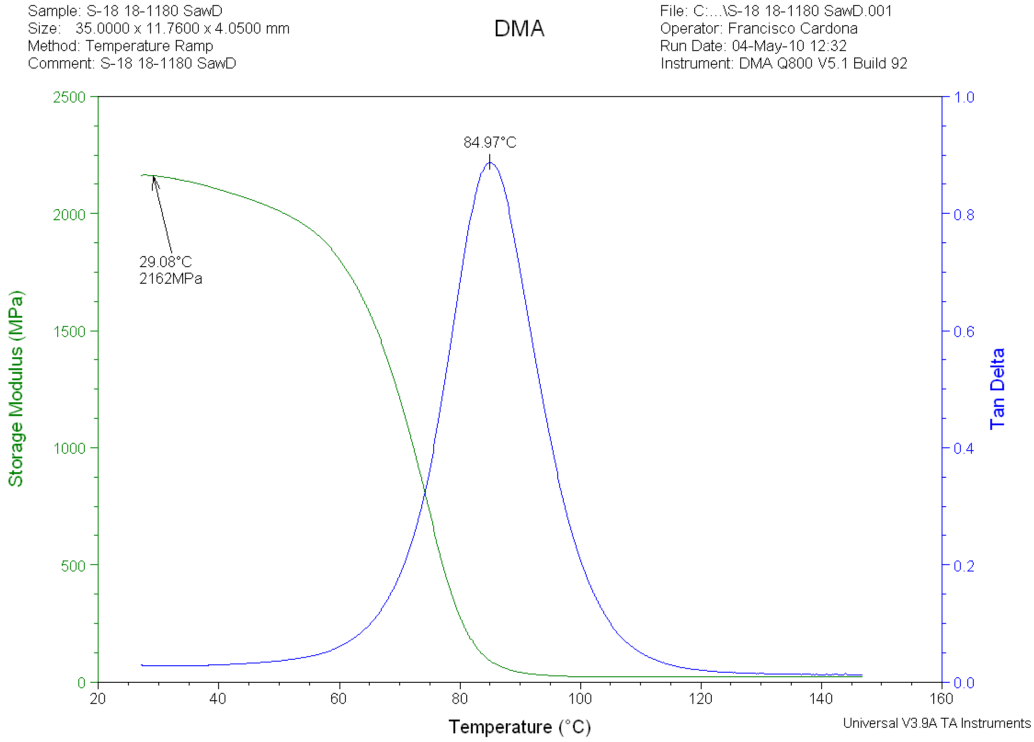
Sample 10



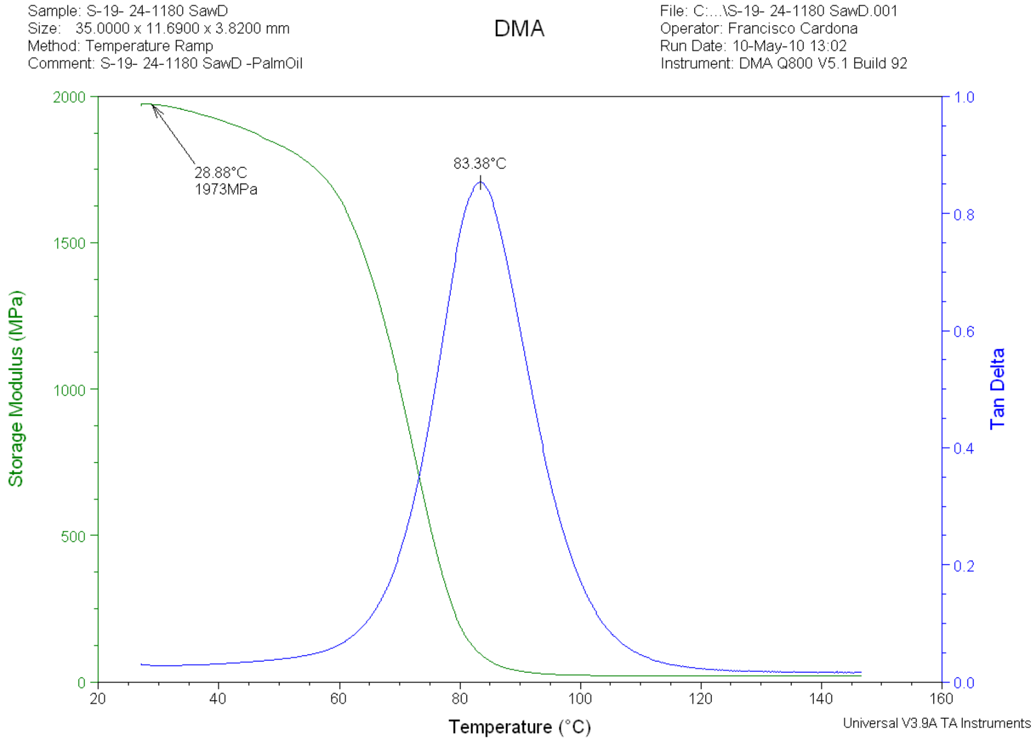
Sample 11



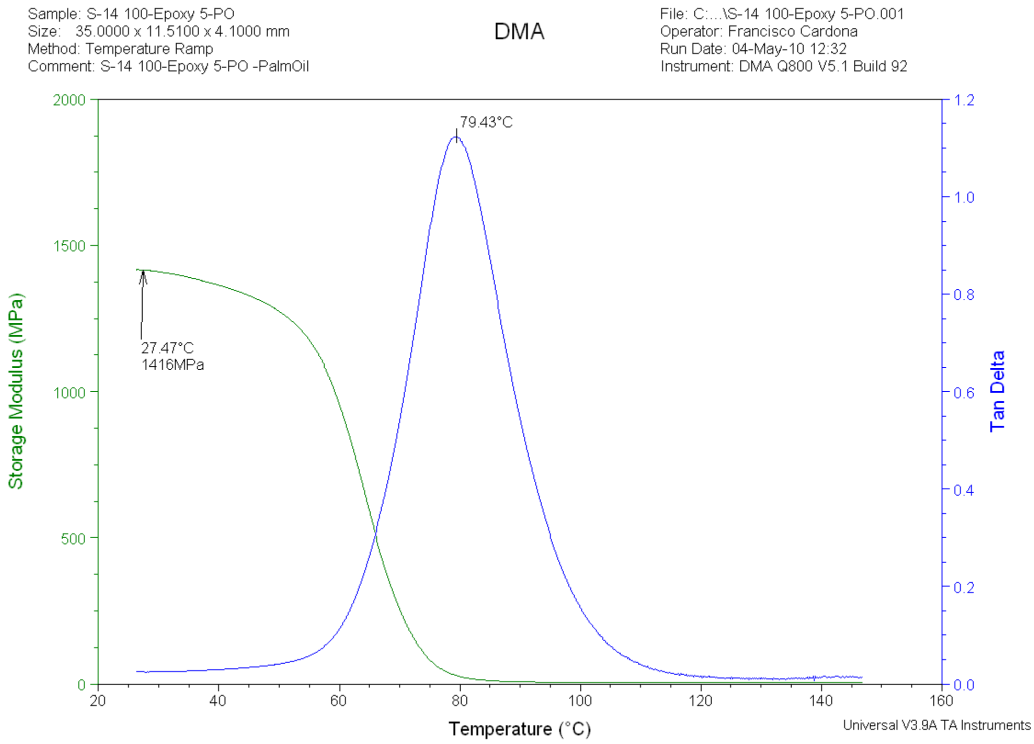
Sample 12



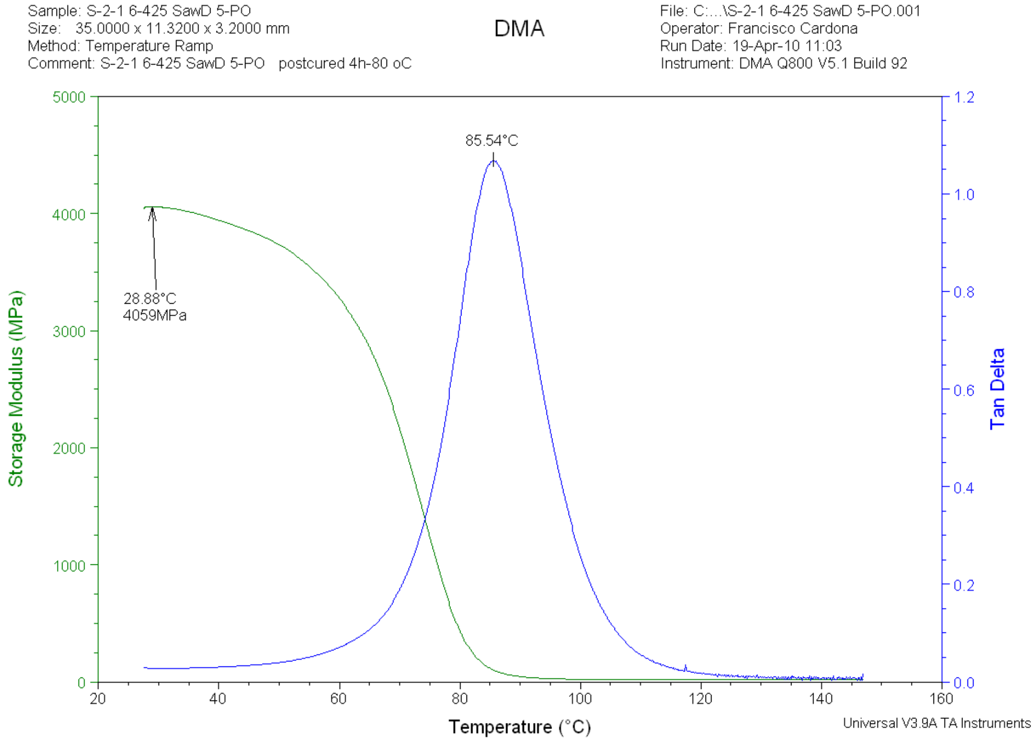
Sample 13



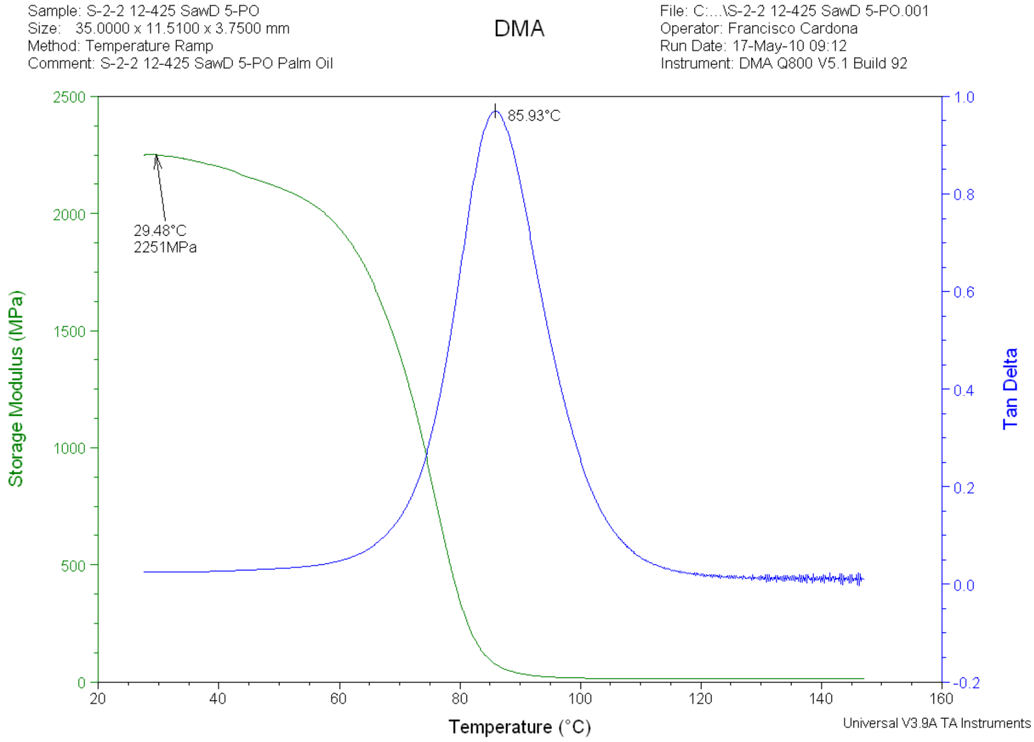
Sample 14



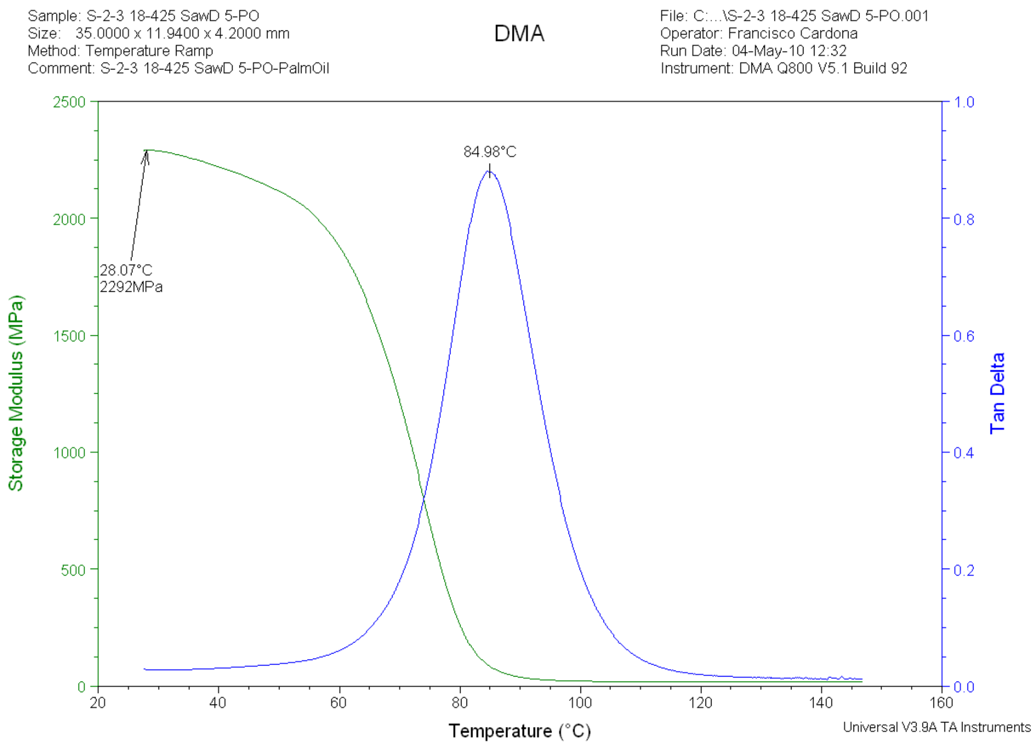
Sample 15



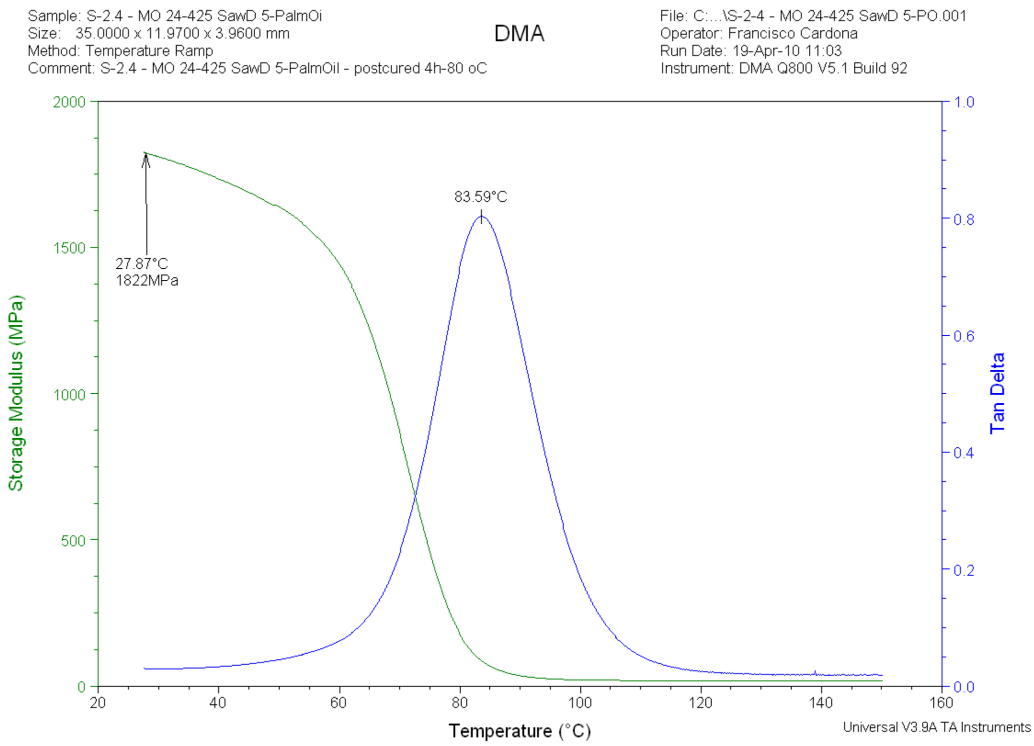
Sample 16



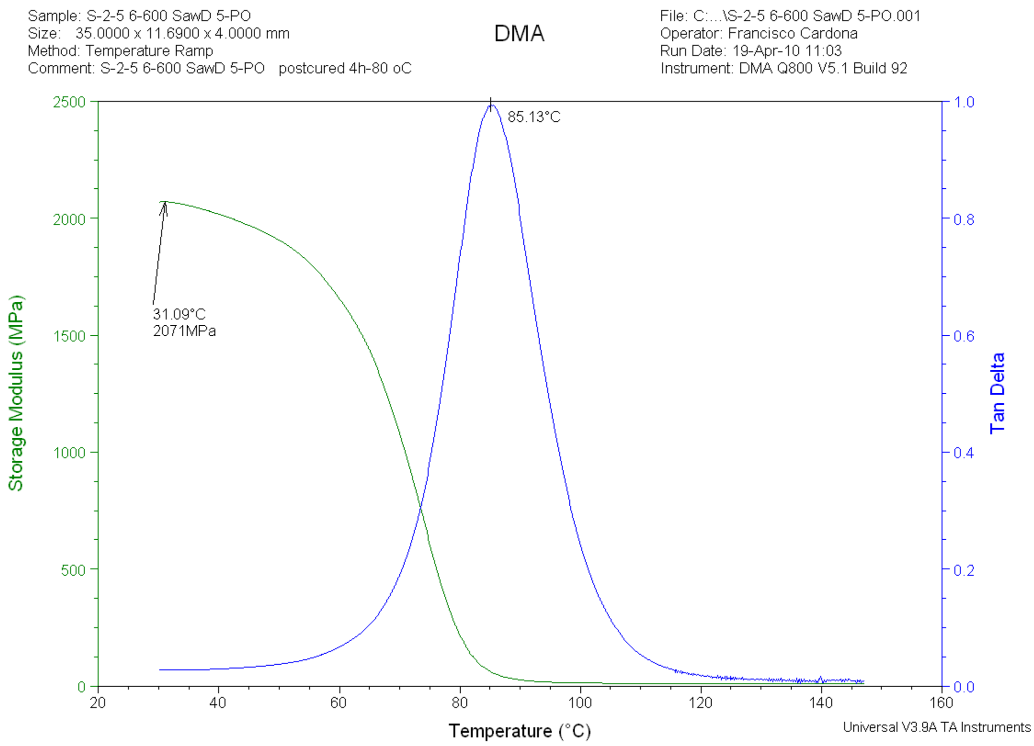
Sample 17



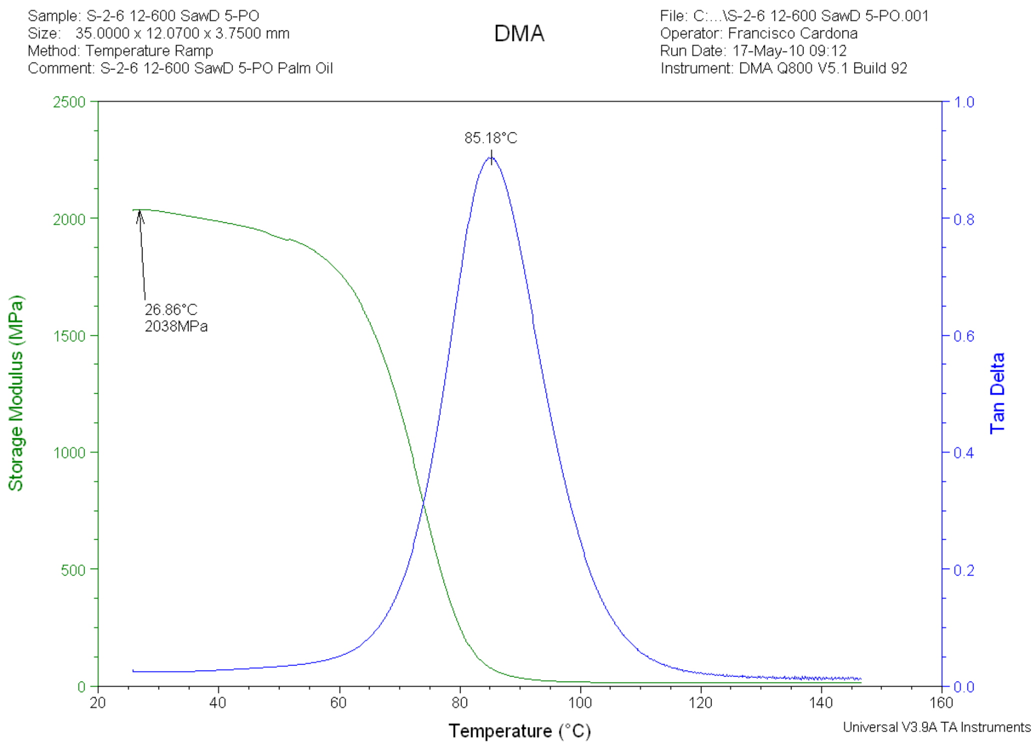
Sample 18



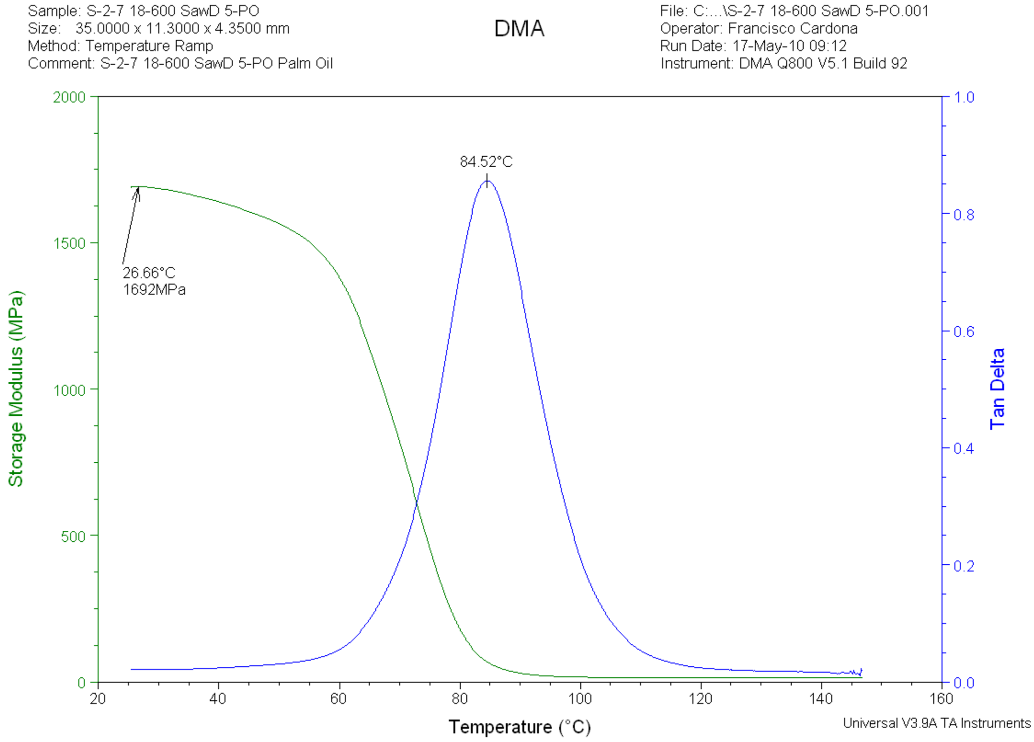
Sample 19



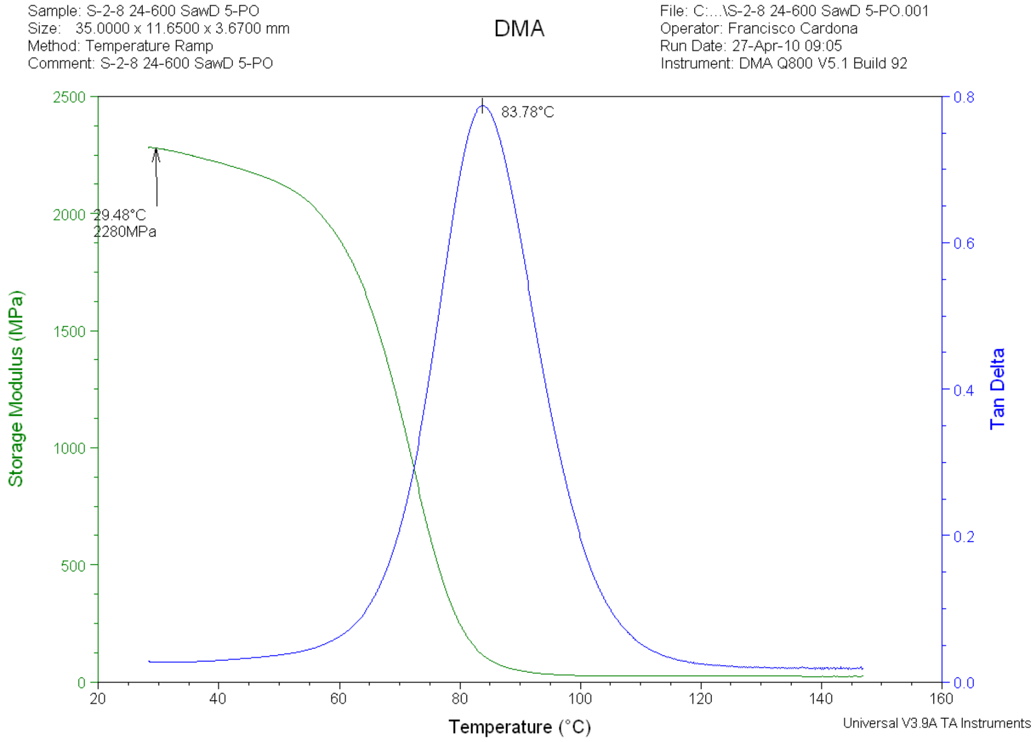
Sample 20



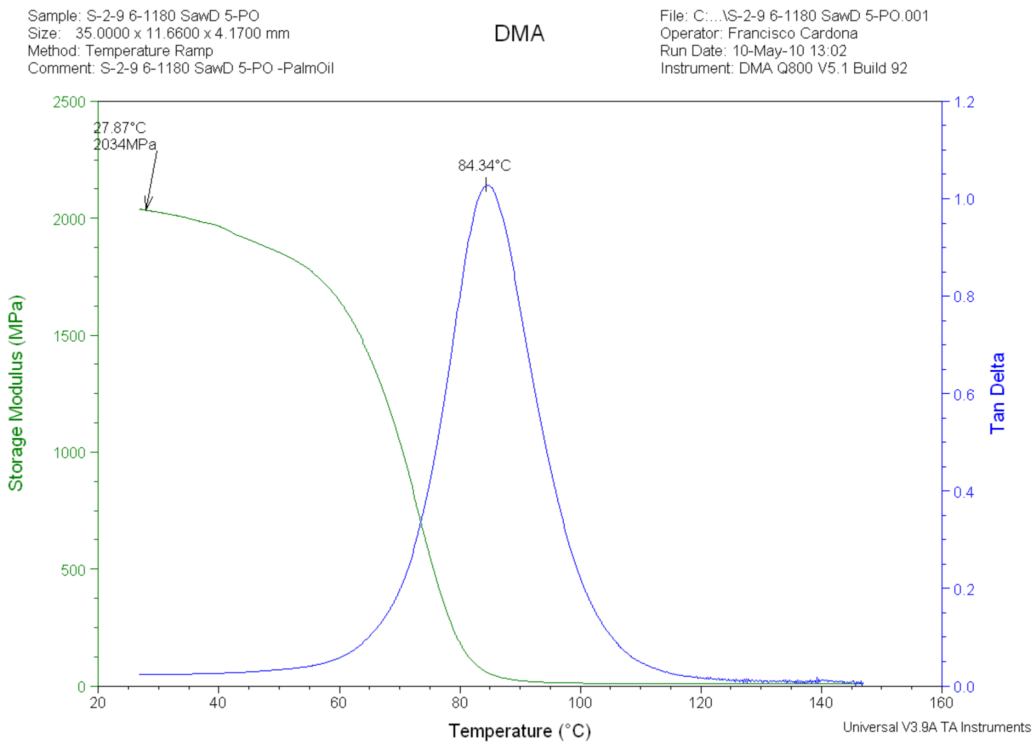
Sample 21



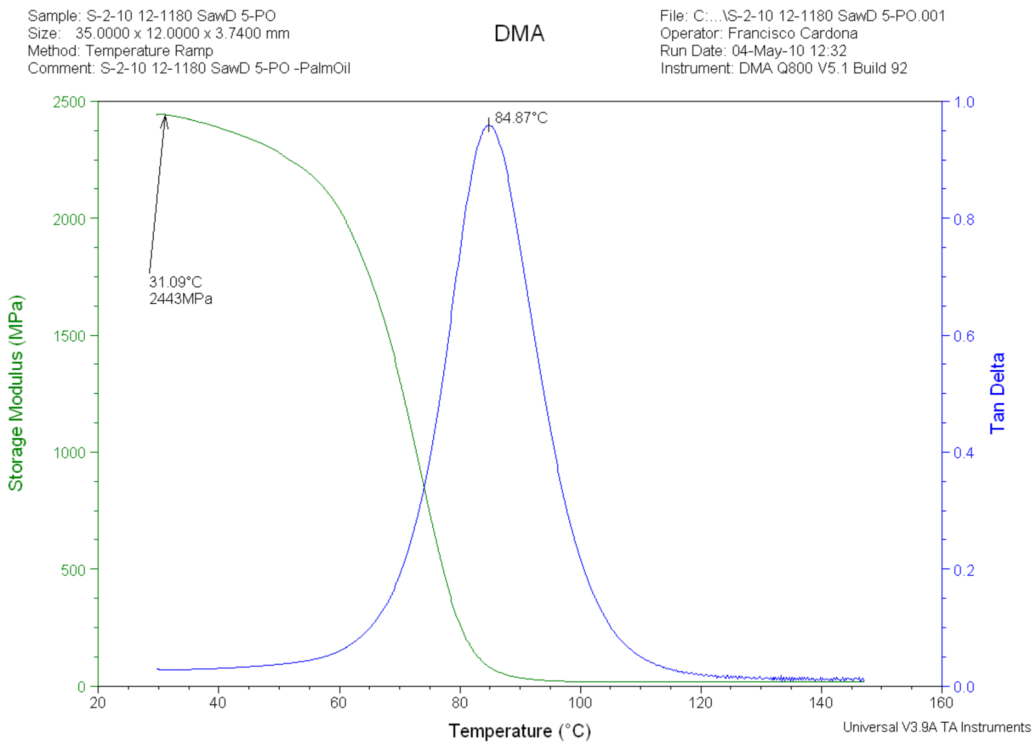
Sample 22



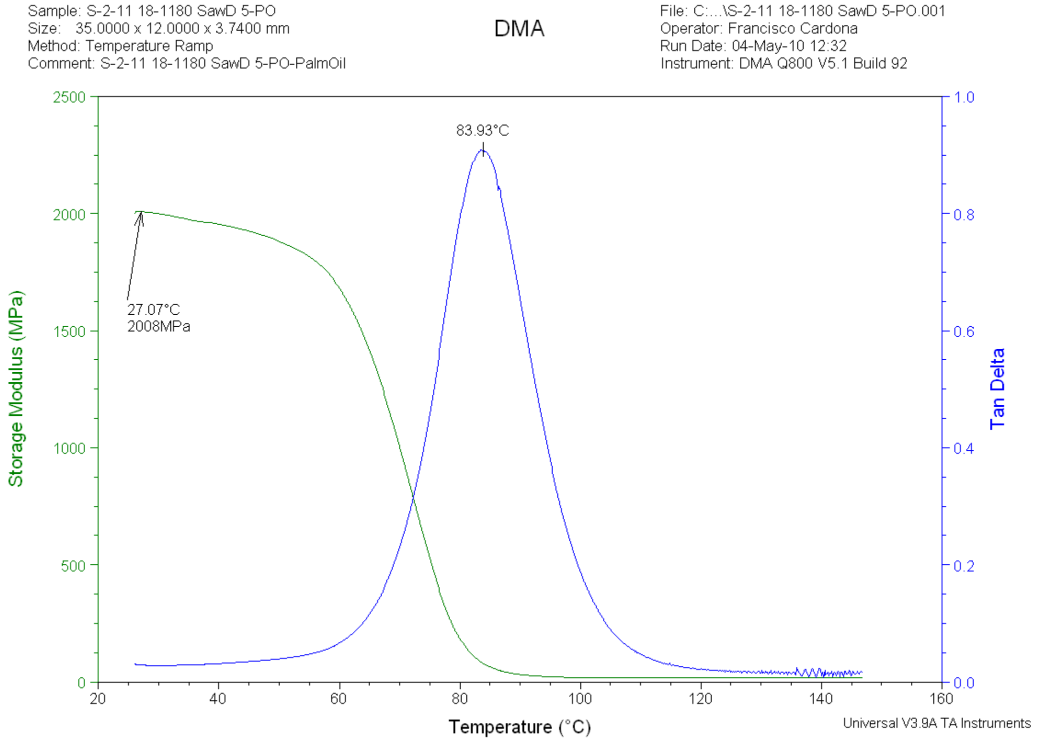
Sample 23



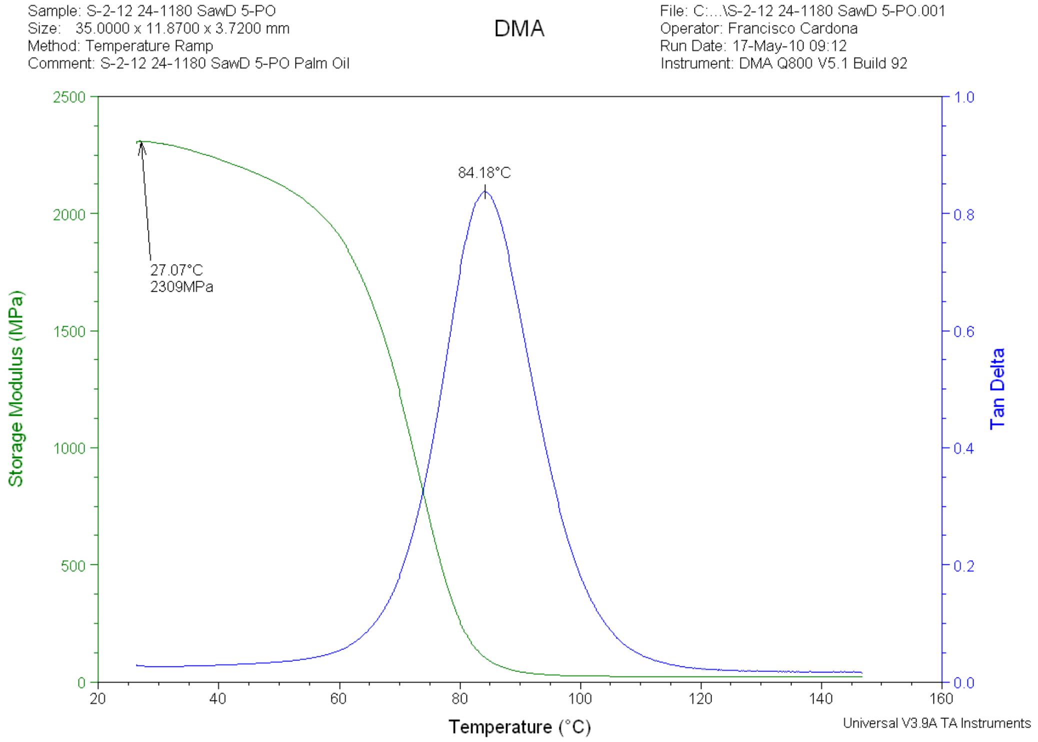
Sample 24



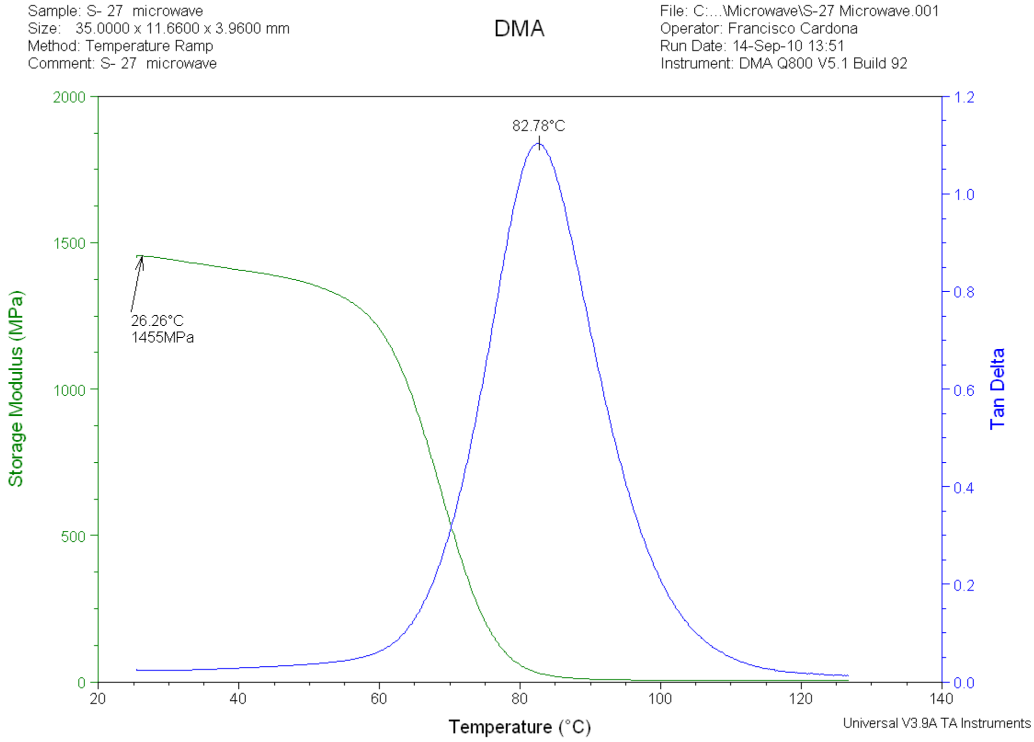
Sample 25



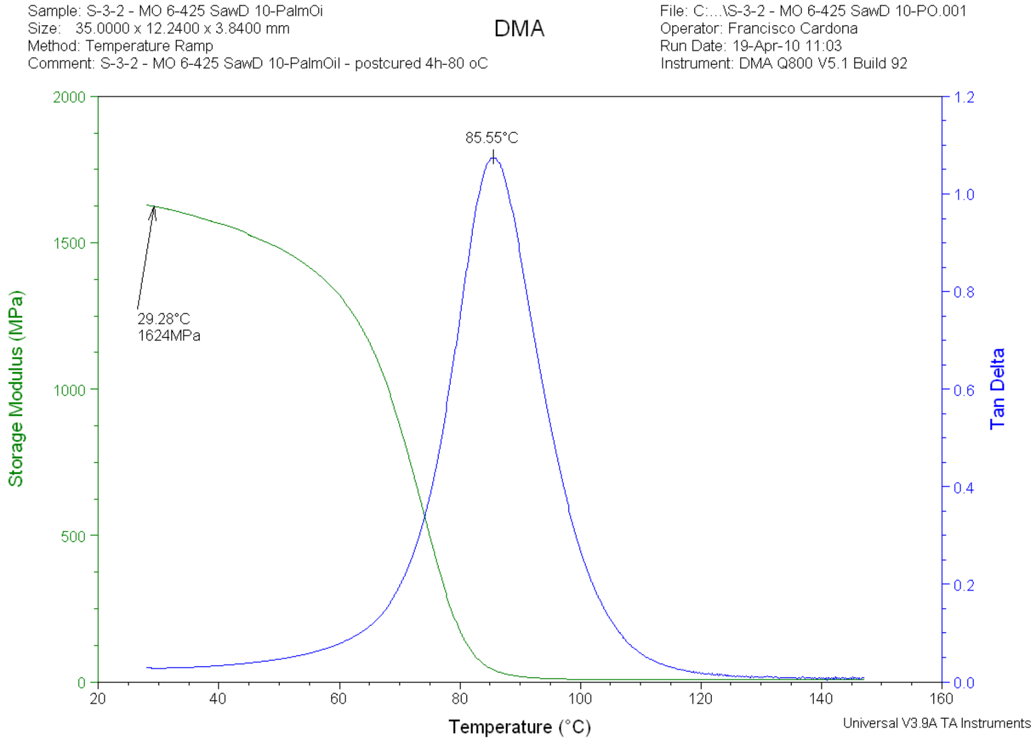
Sample 26



Sample 27



Sample 28



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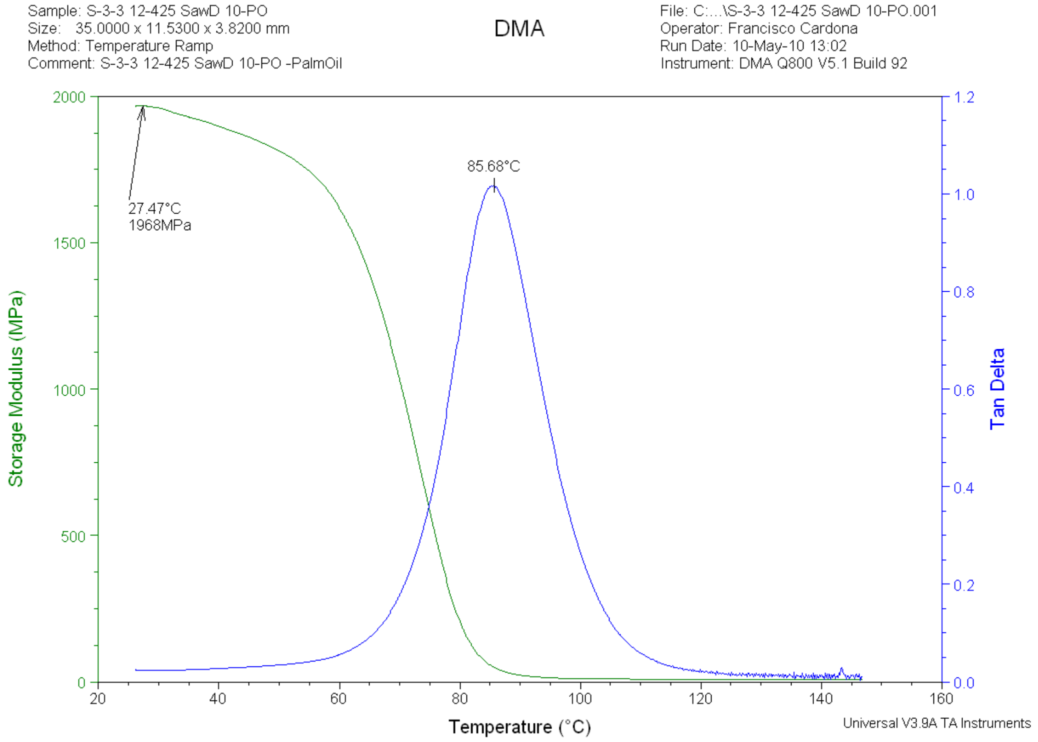
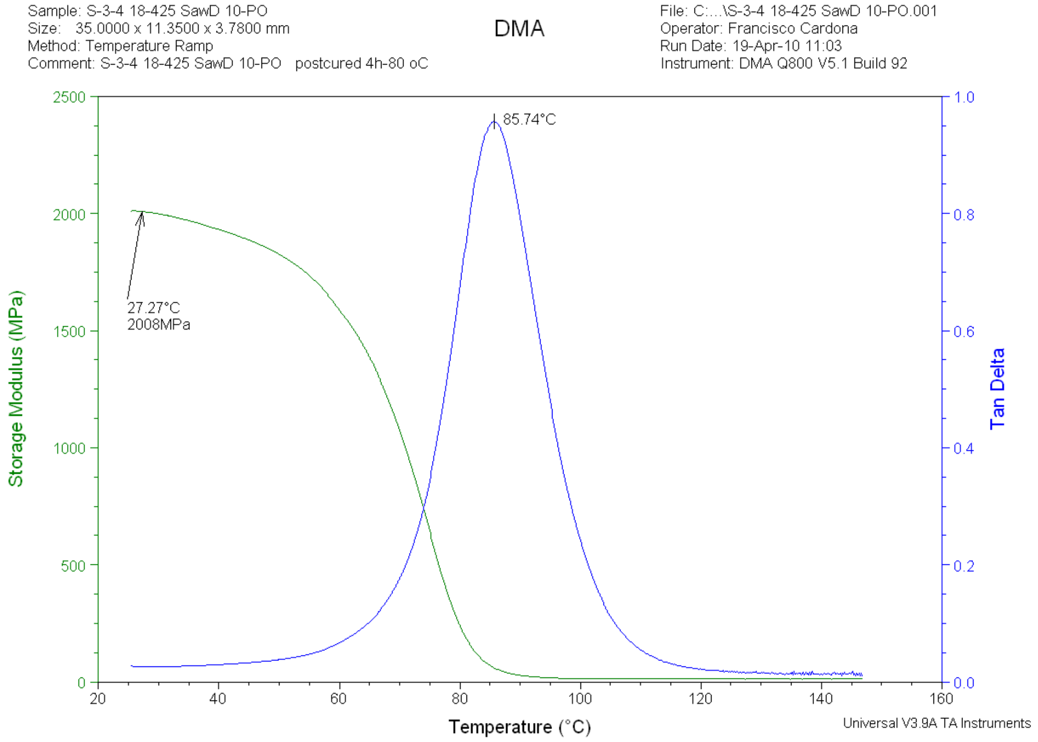


Sample 30



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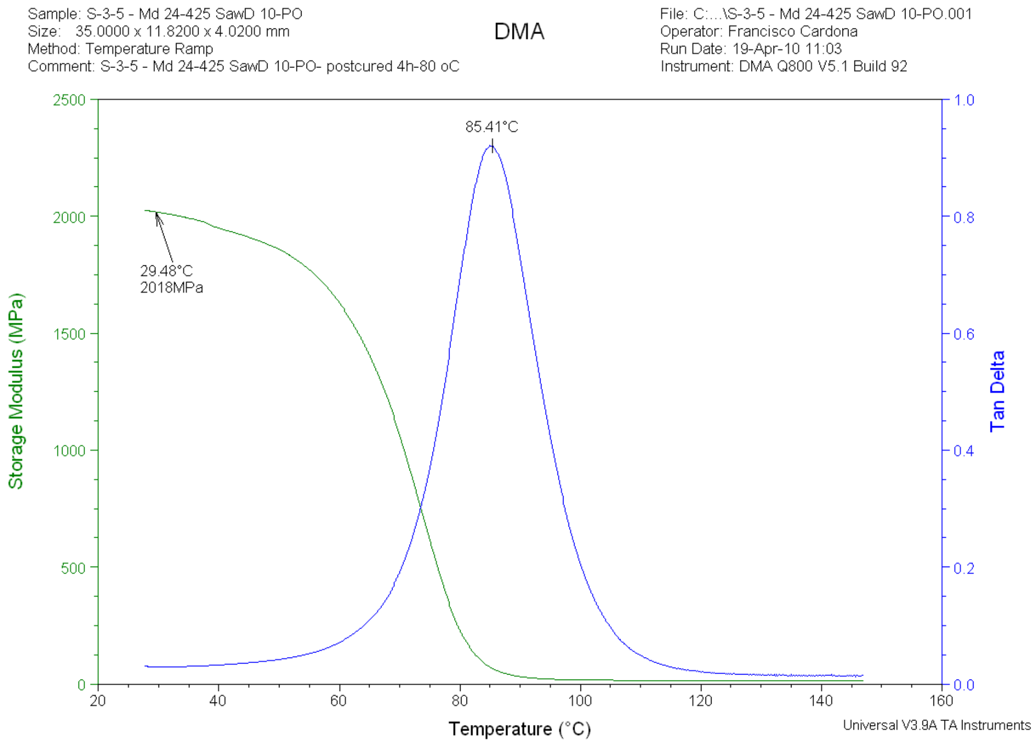

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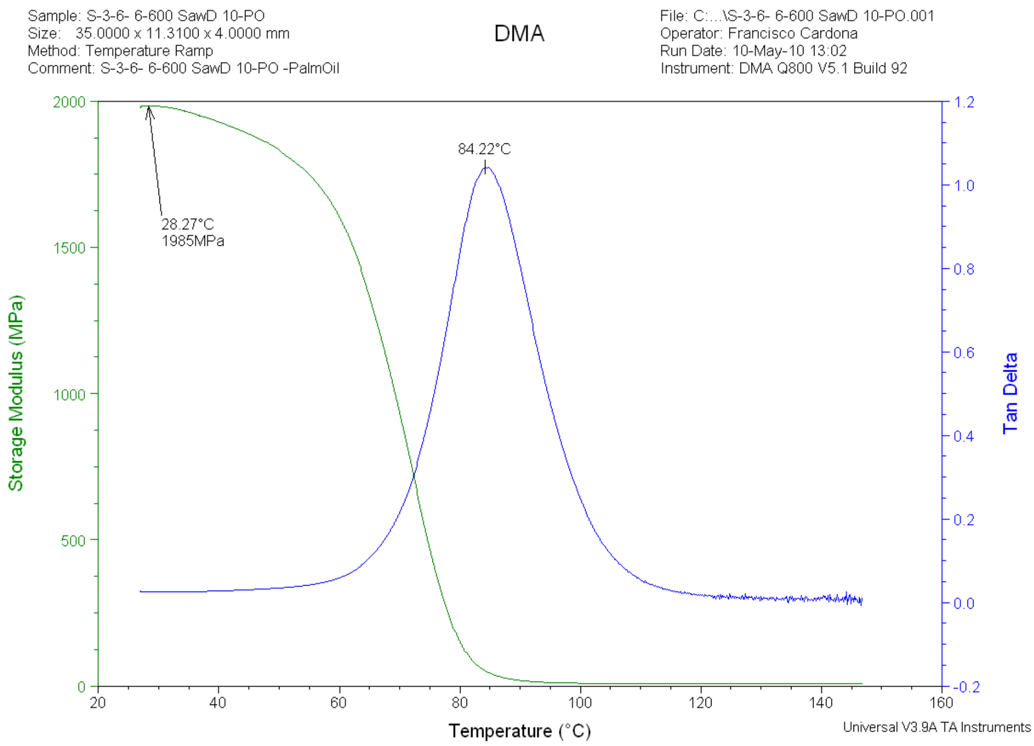

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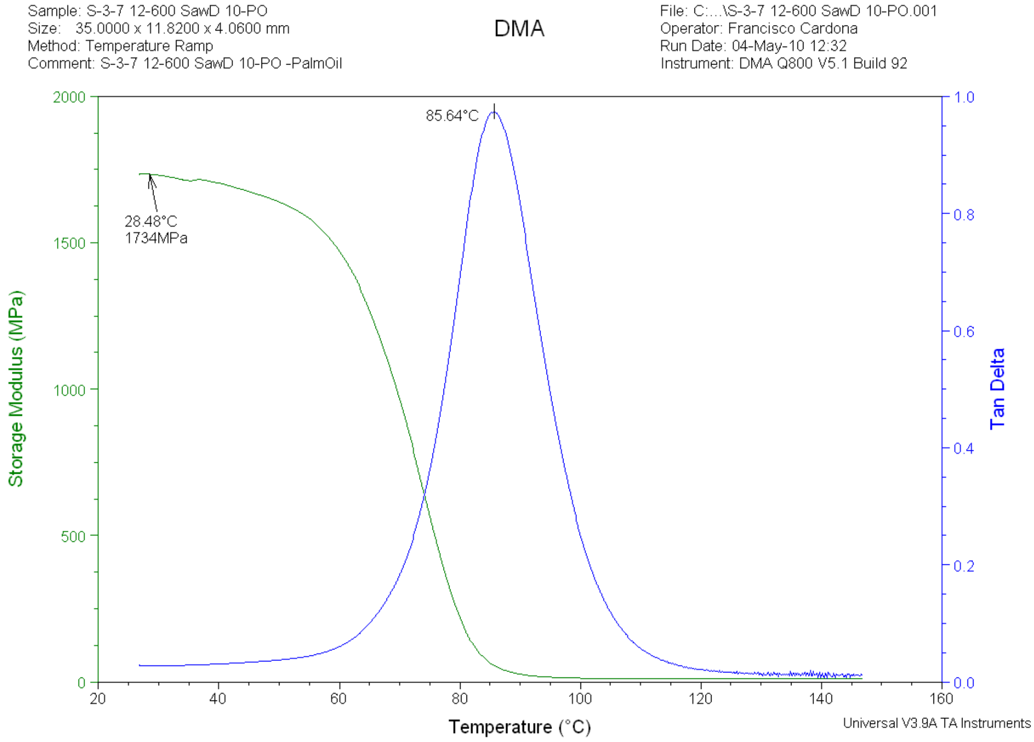

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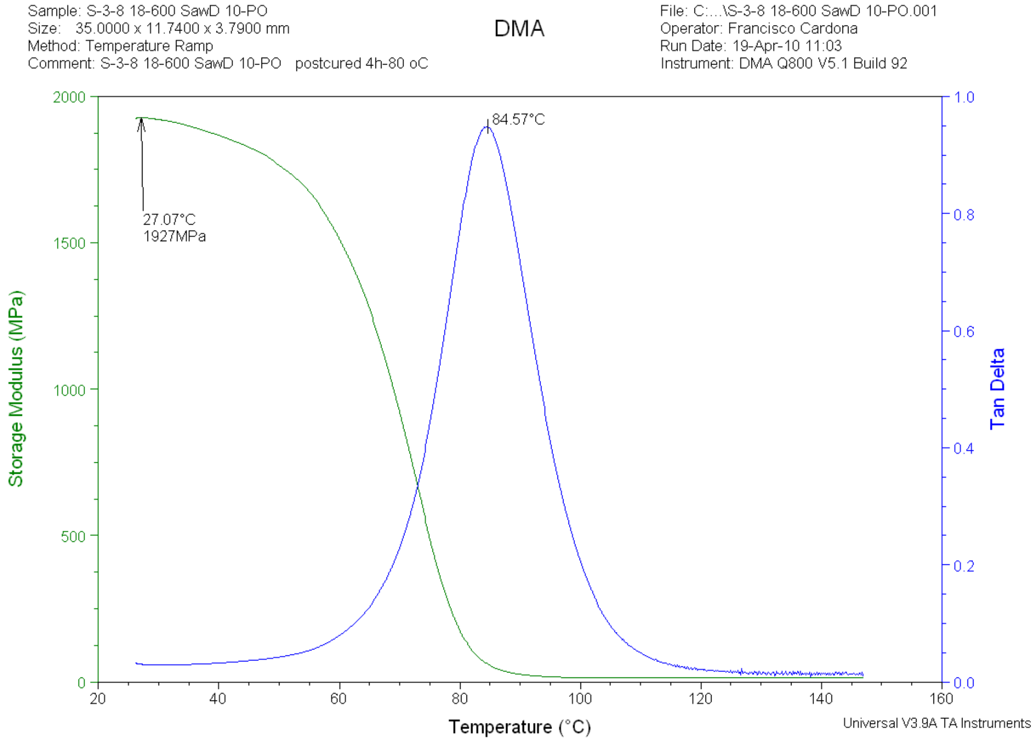

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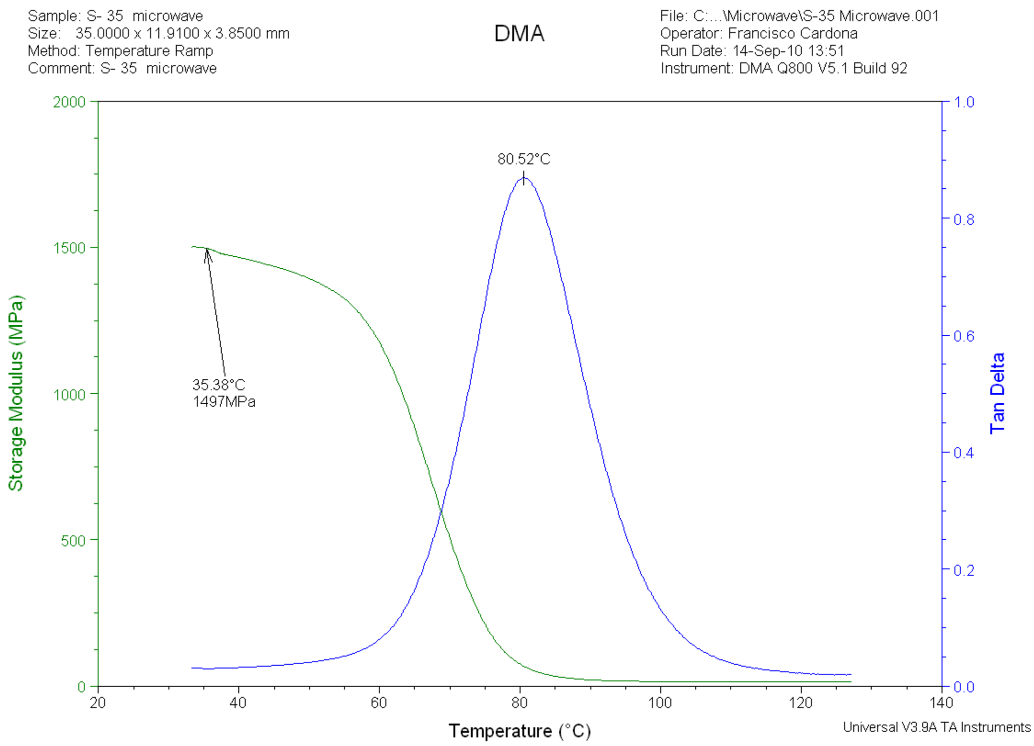

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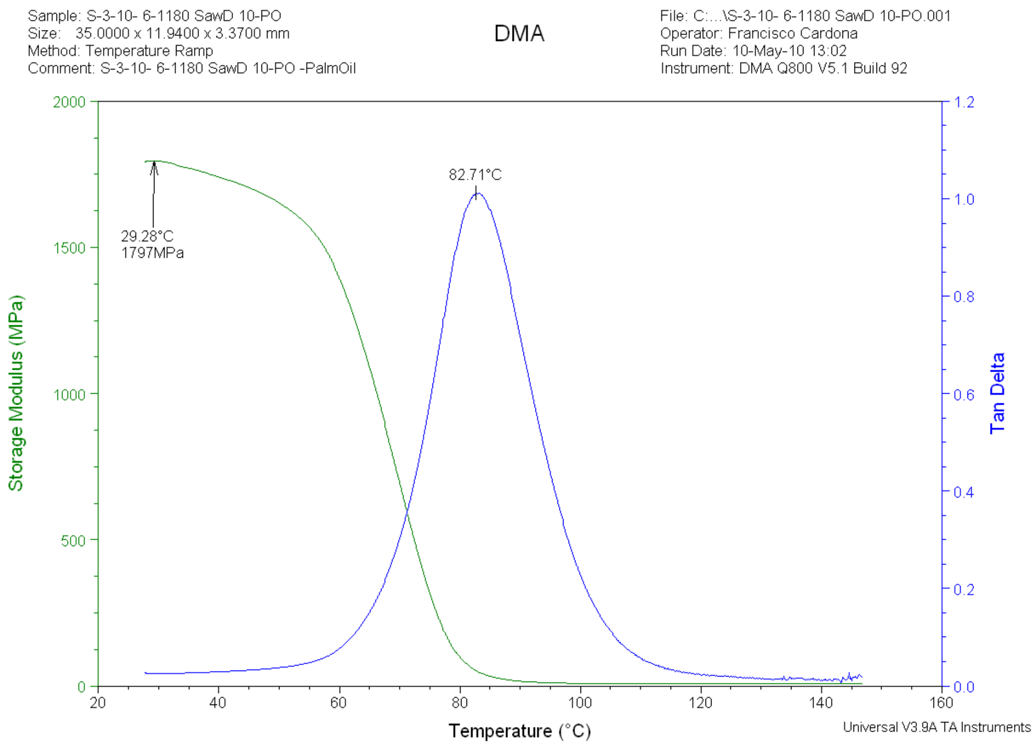

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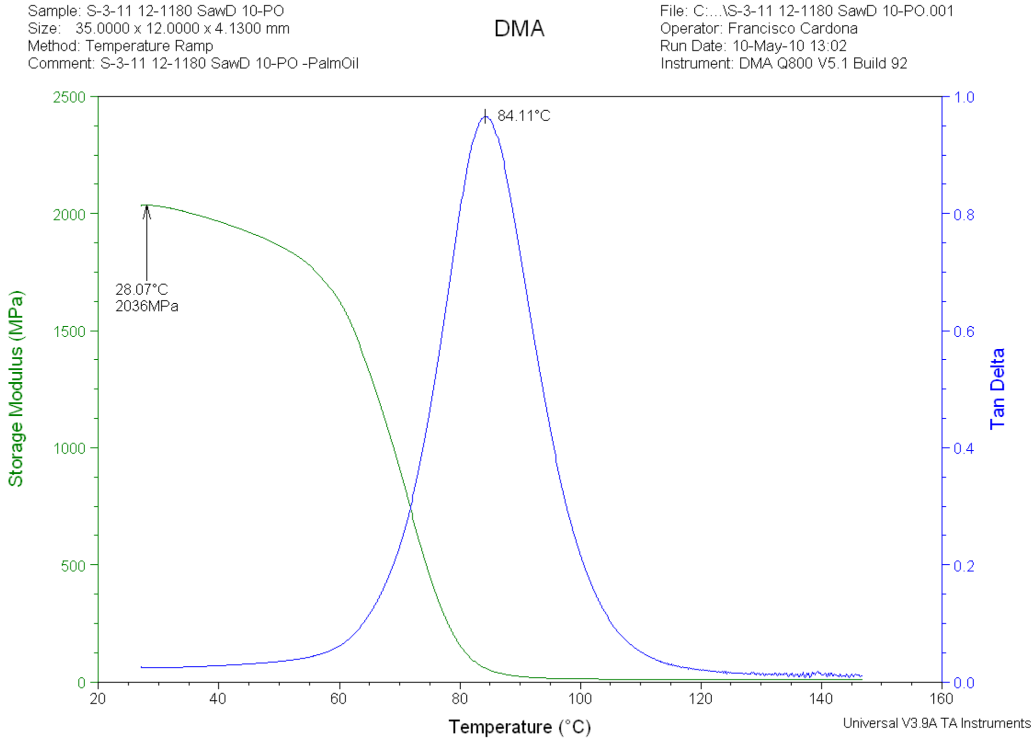

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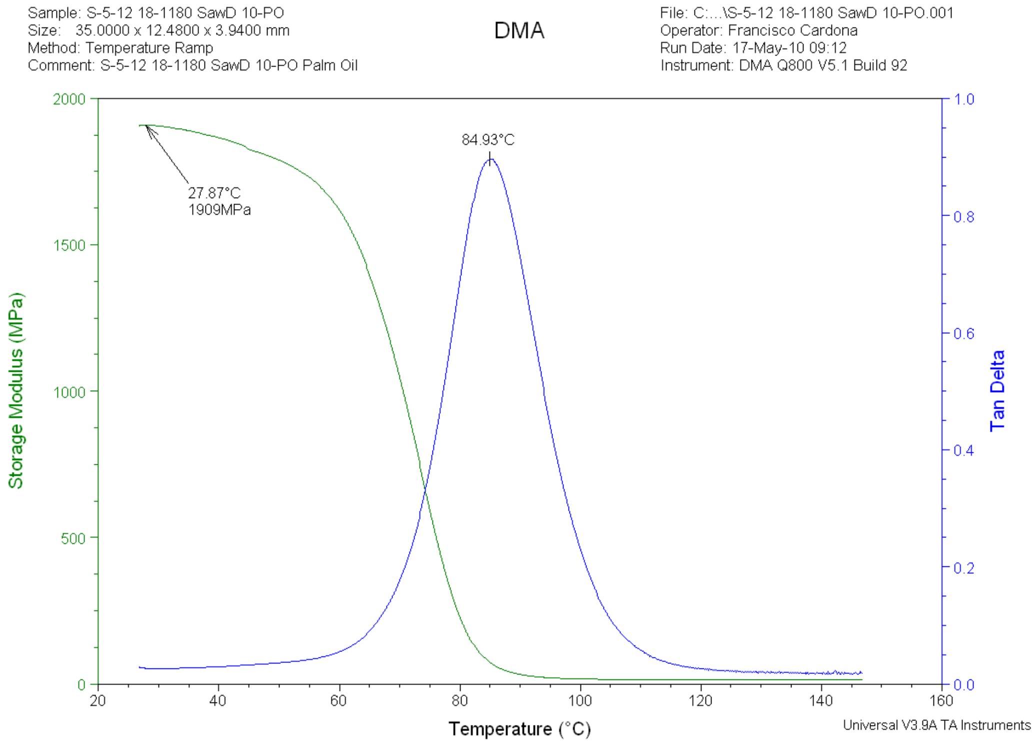
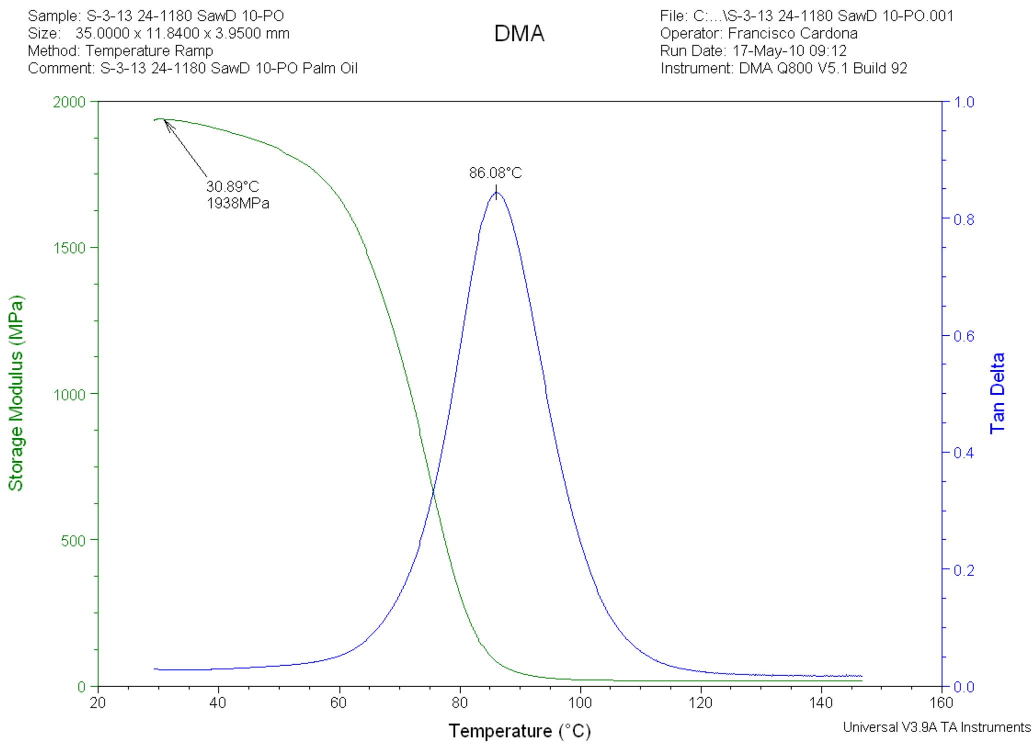


Sample 39



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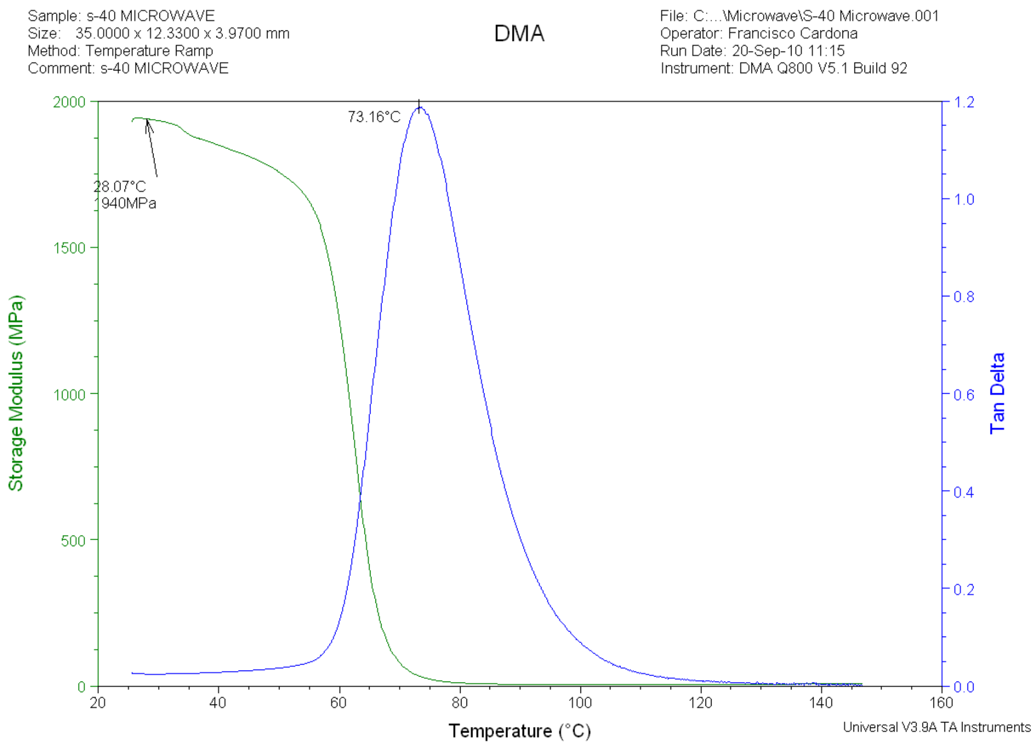
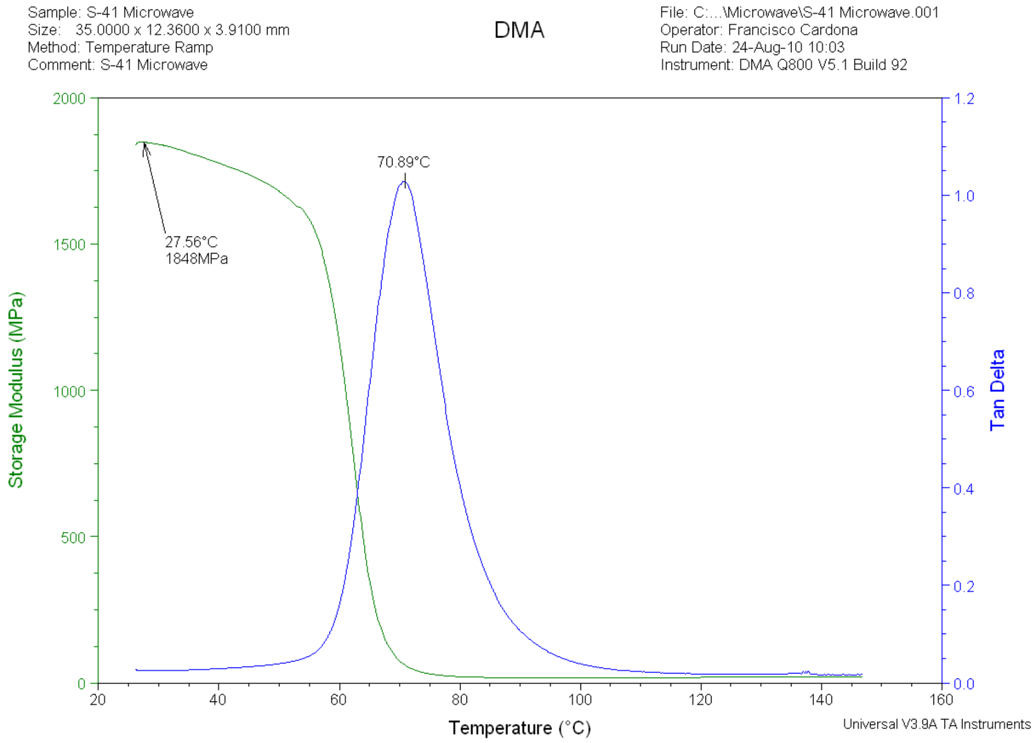


Sample 41



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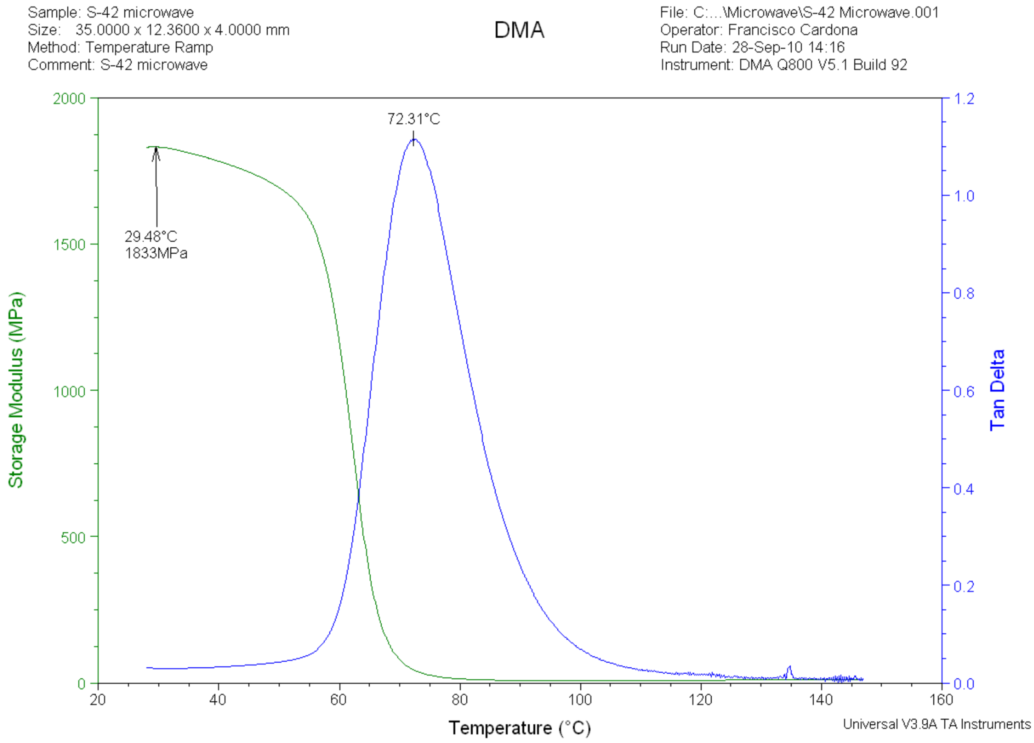

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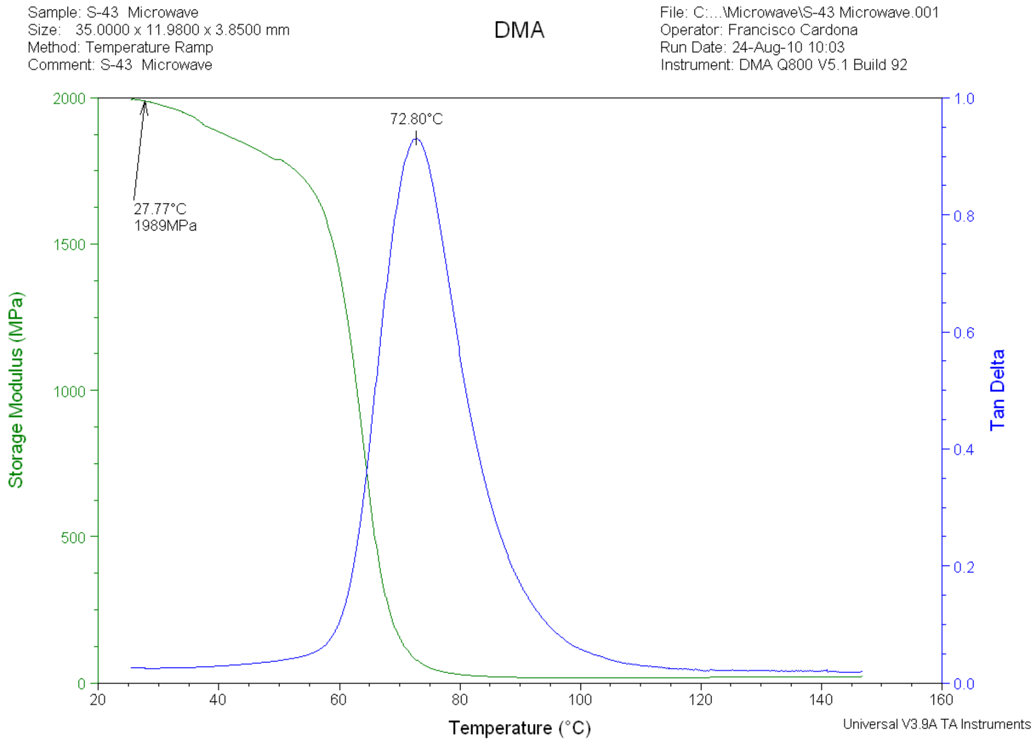

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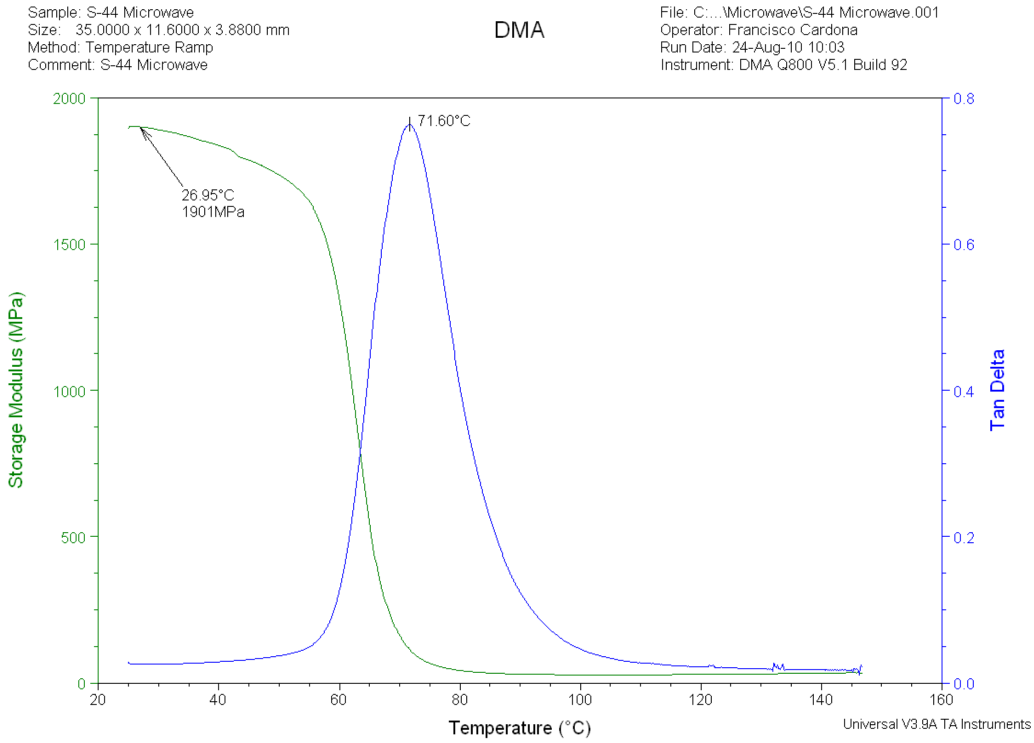

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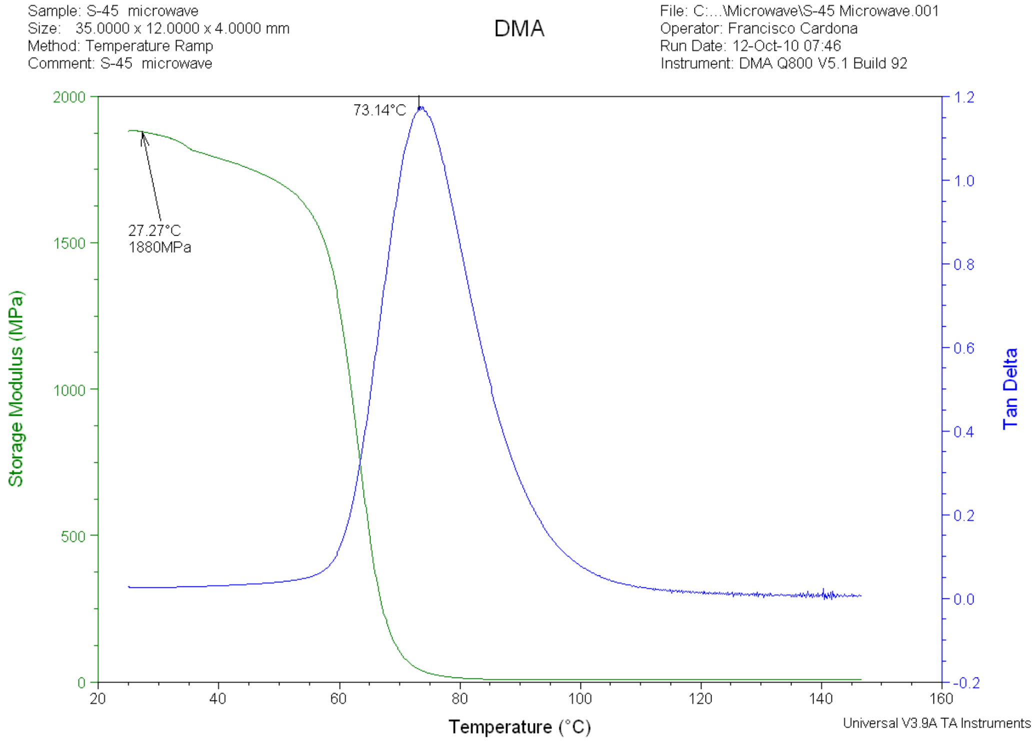

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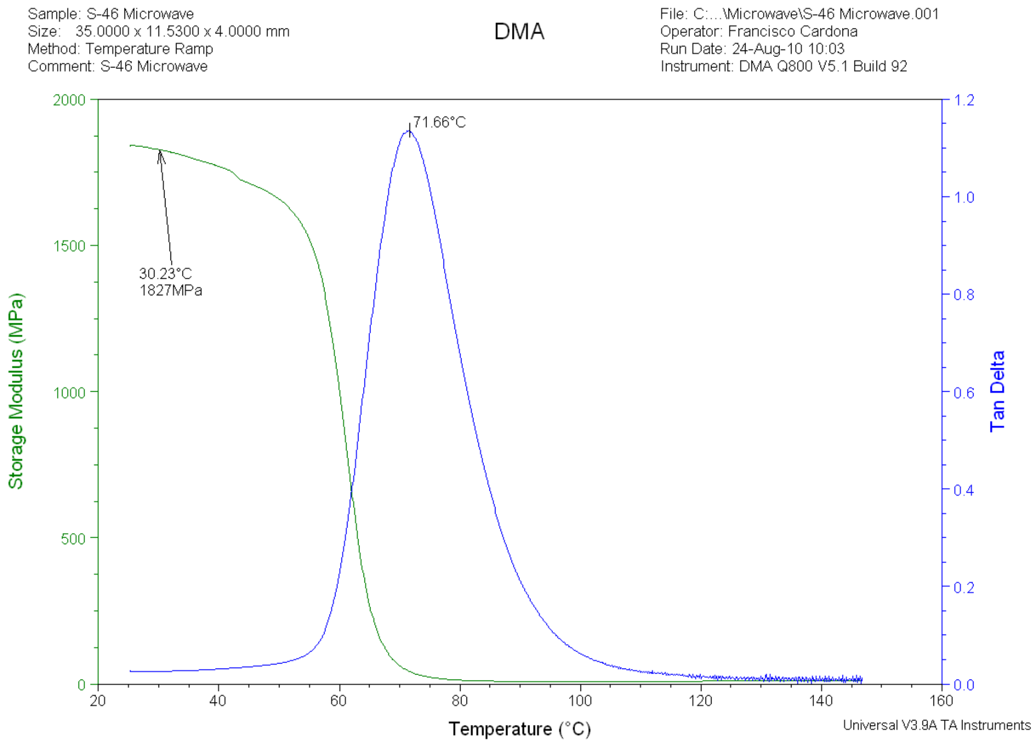

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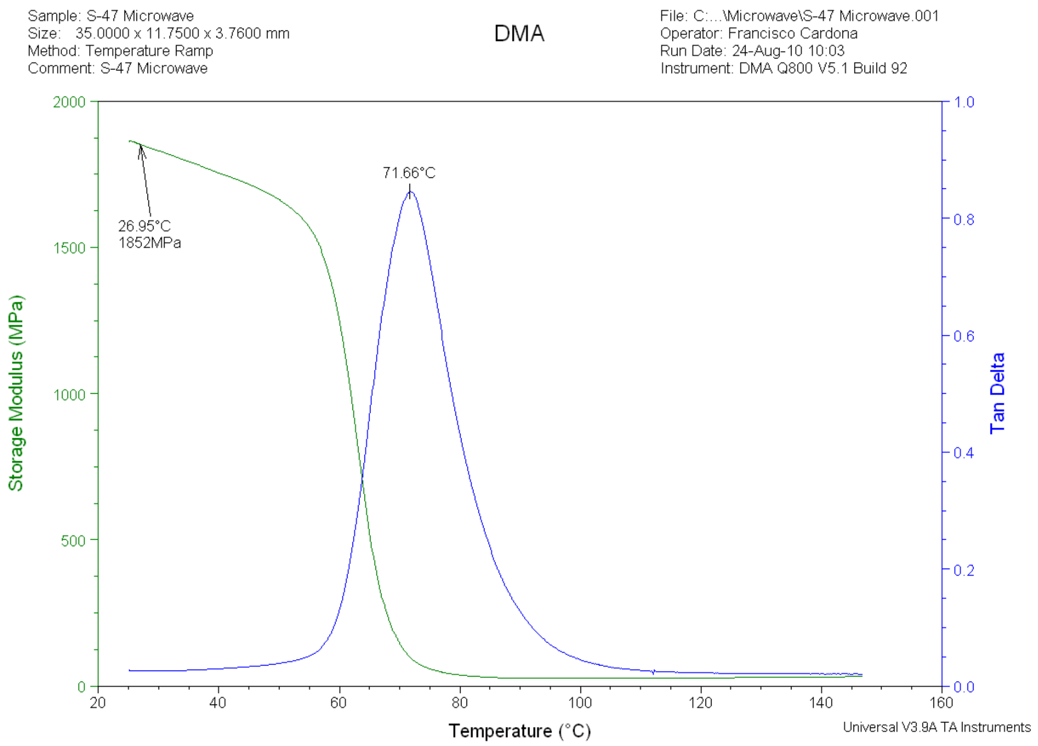
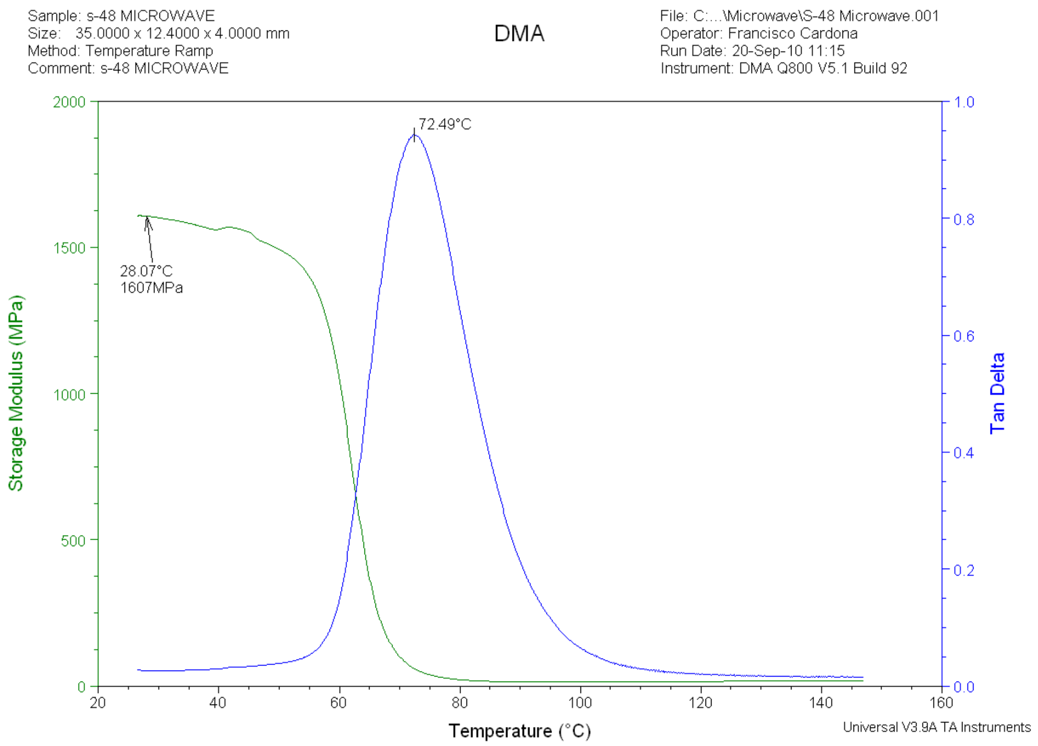
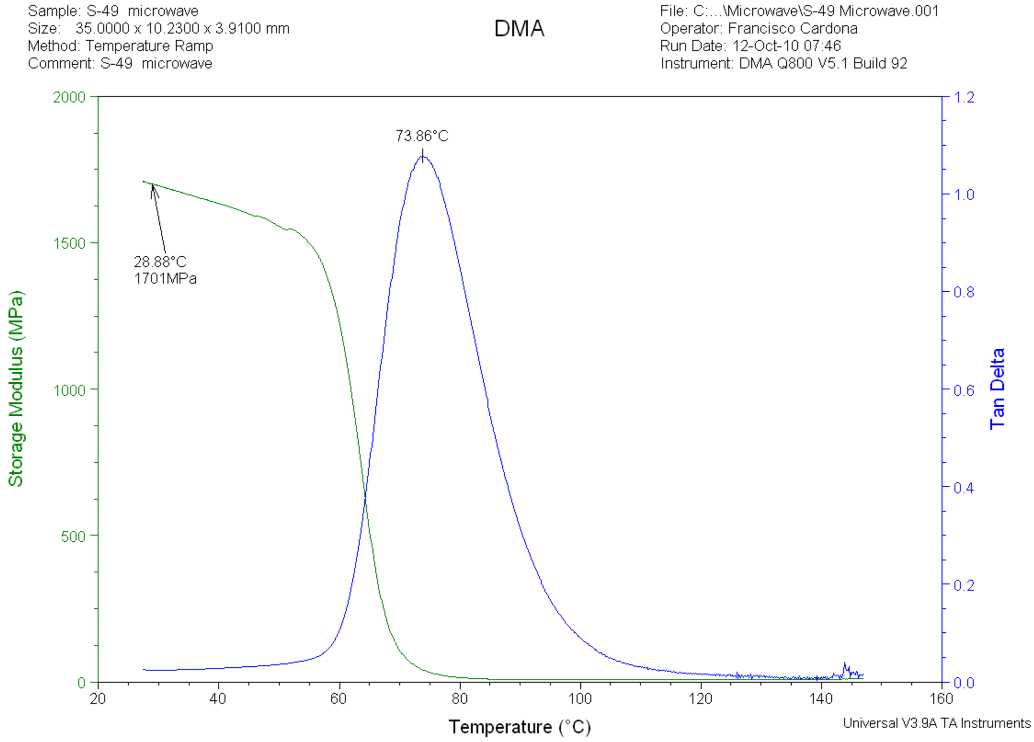


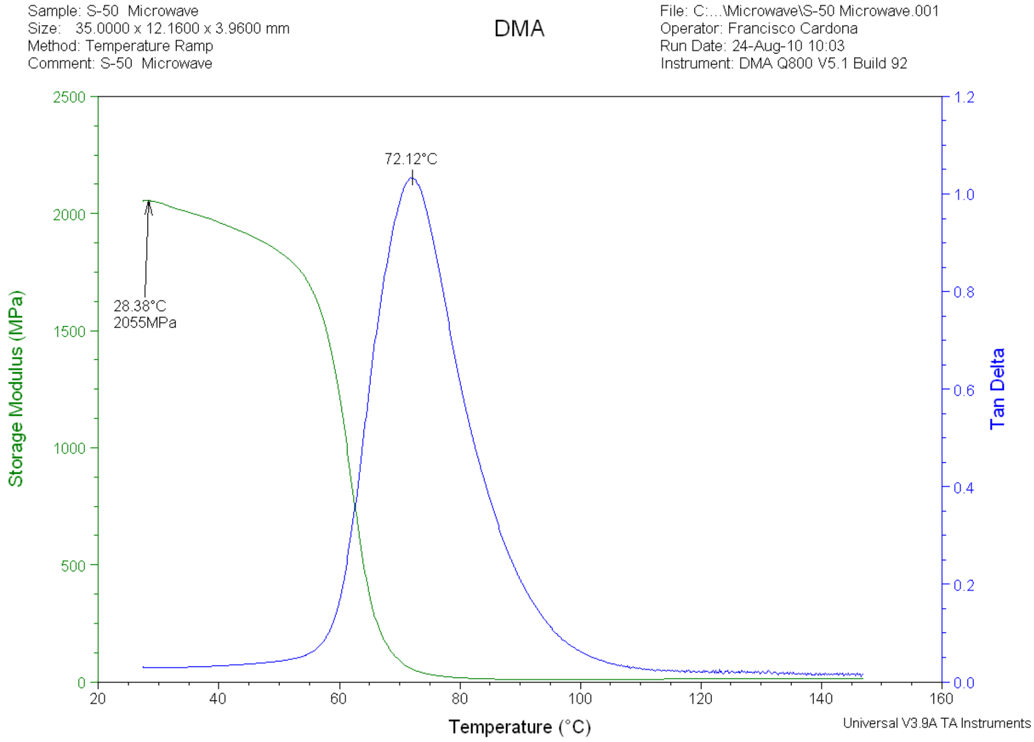
Sample 48



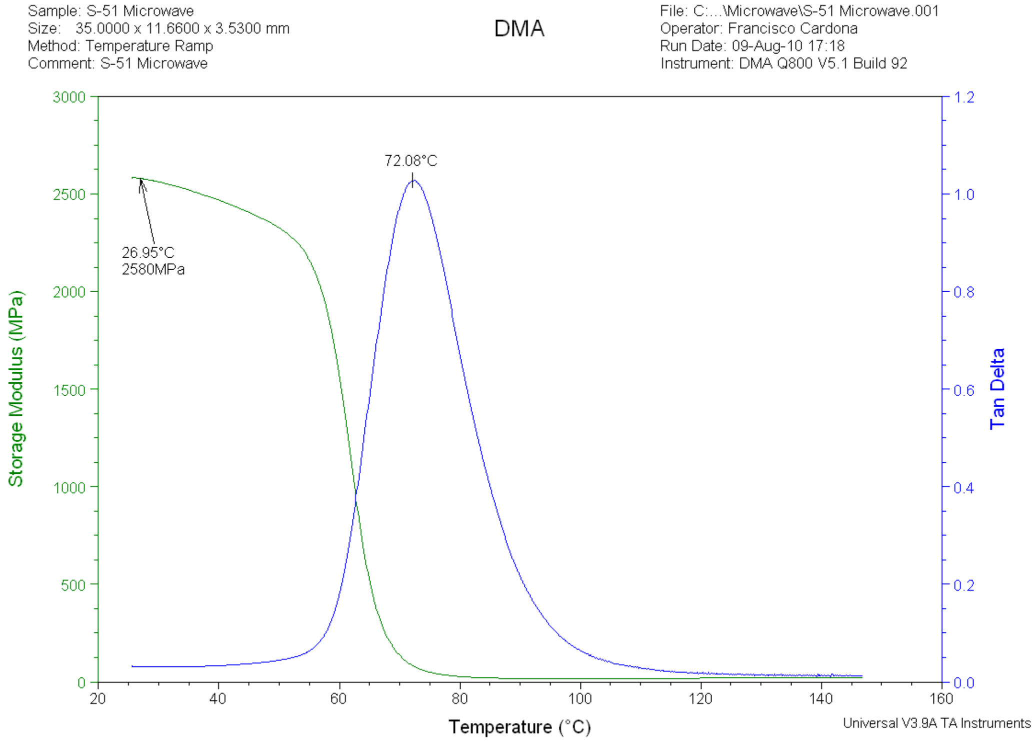
Sample 49



Sample 50



Sample 51



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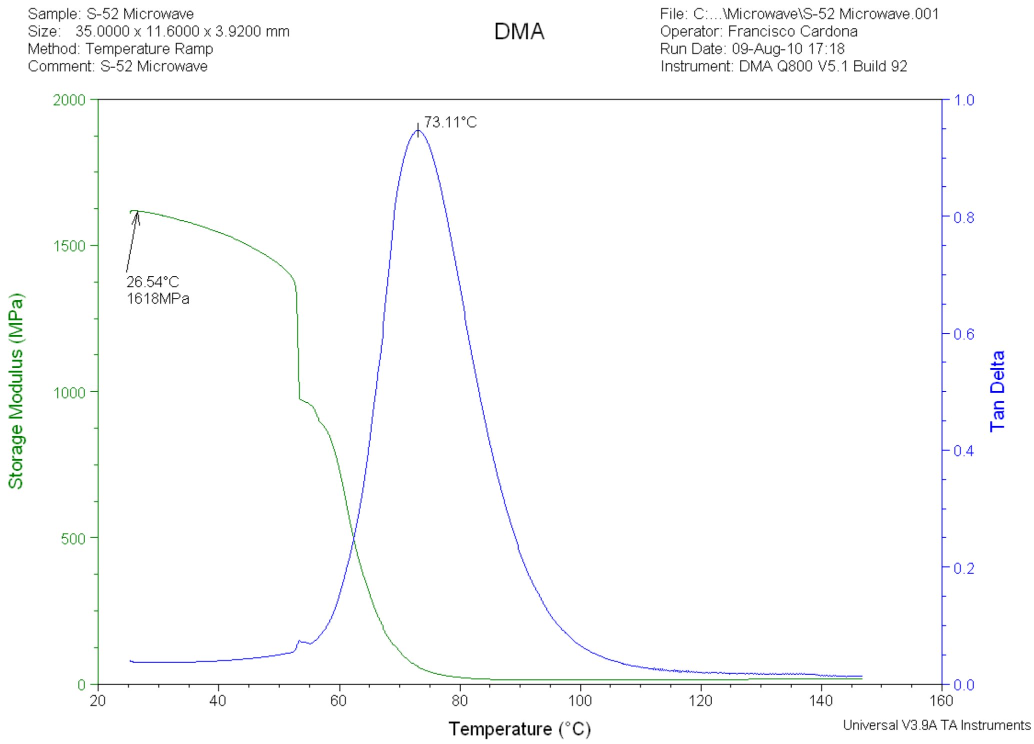

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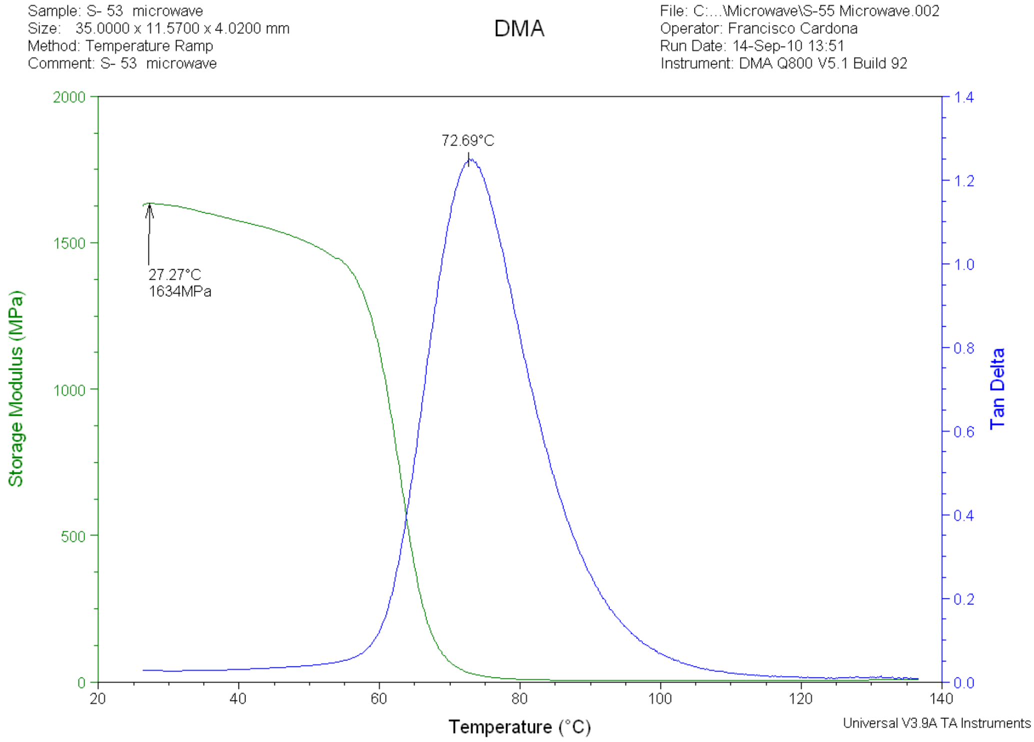
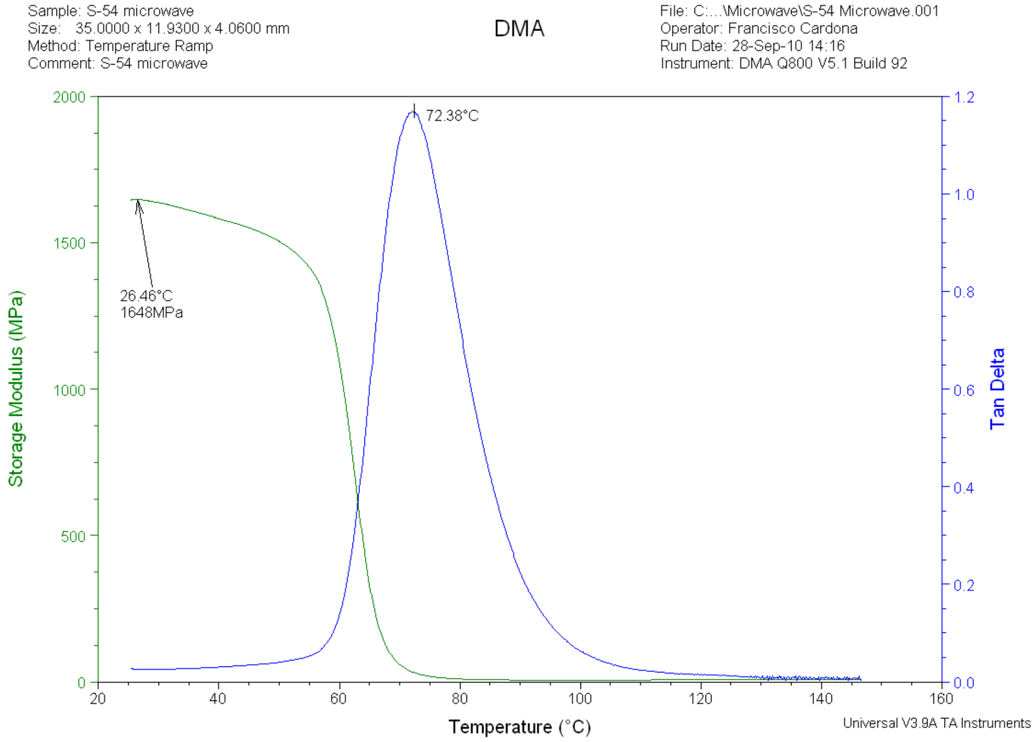


Sample 54



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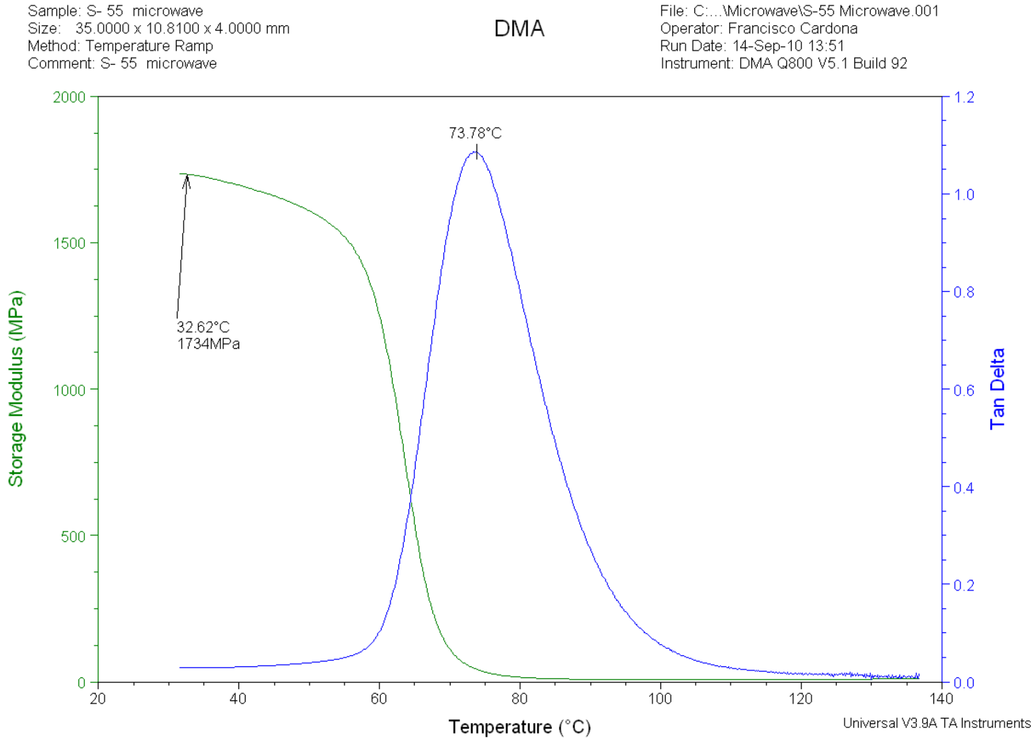

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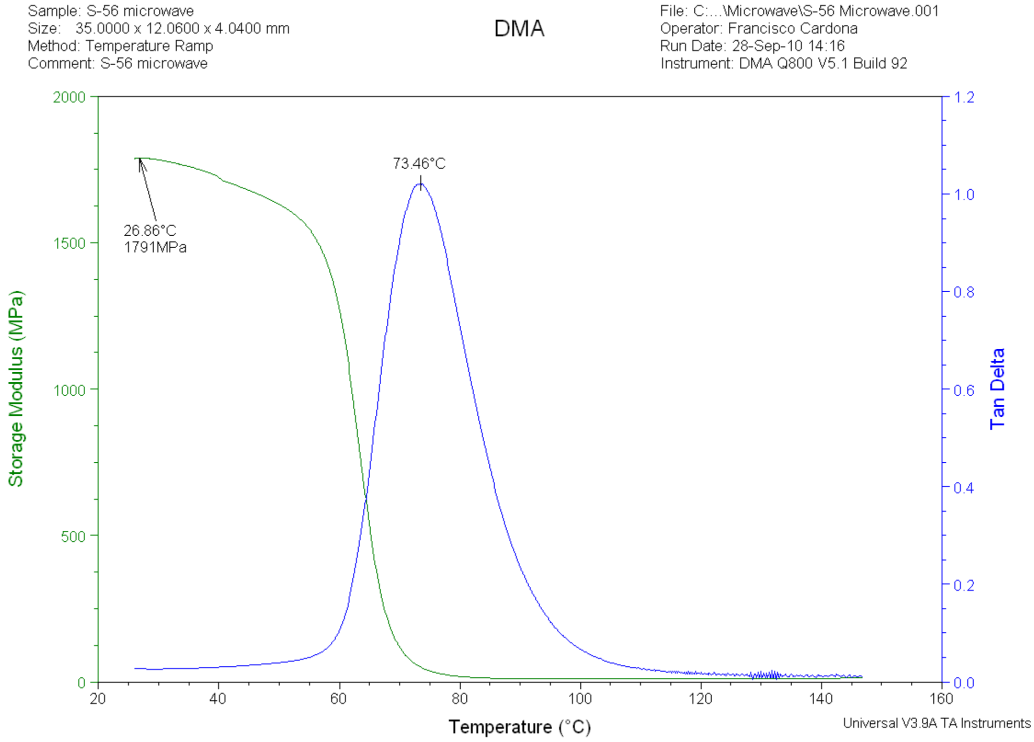

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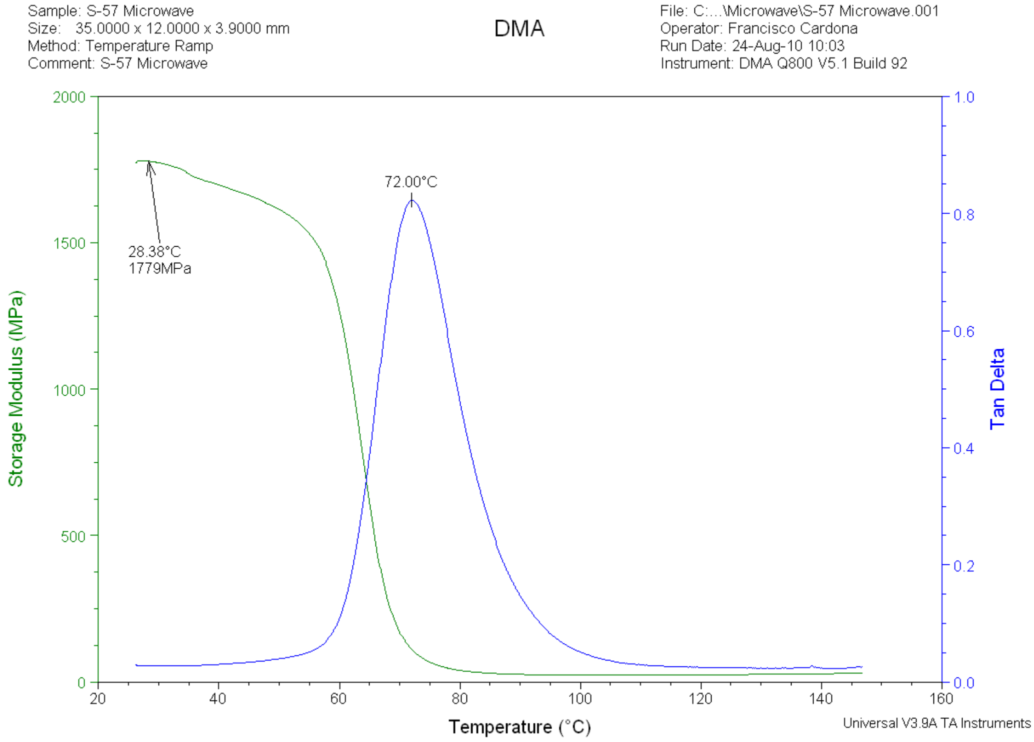

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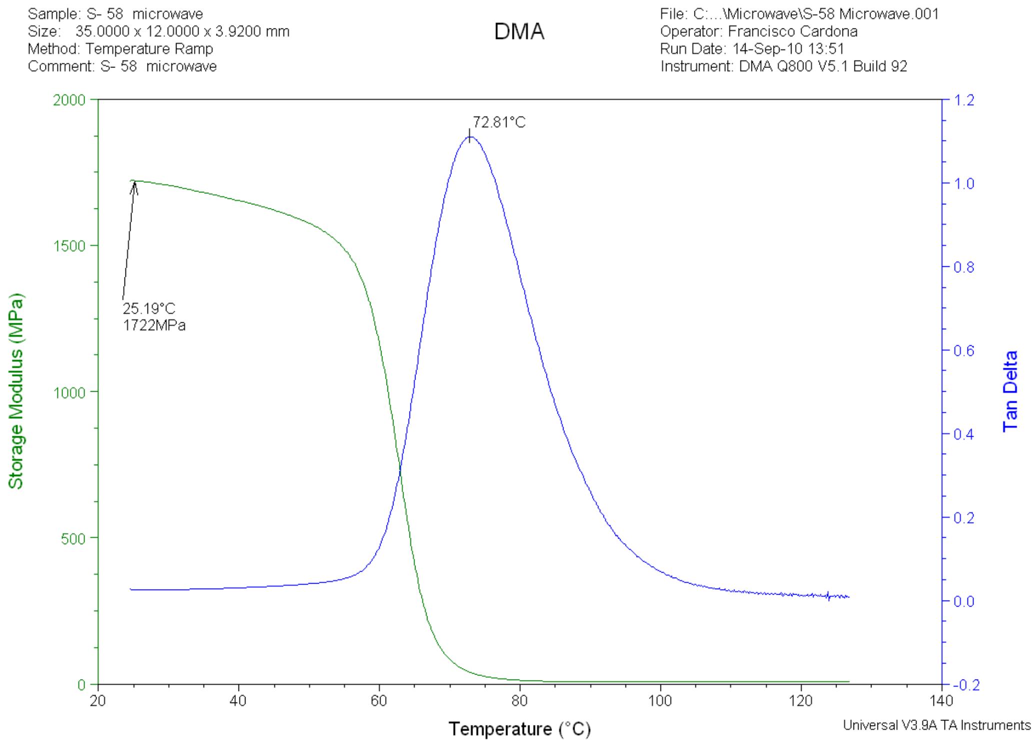

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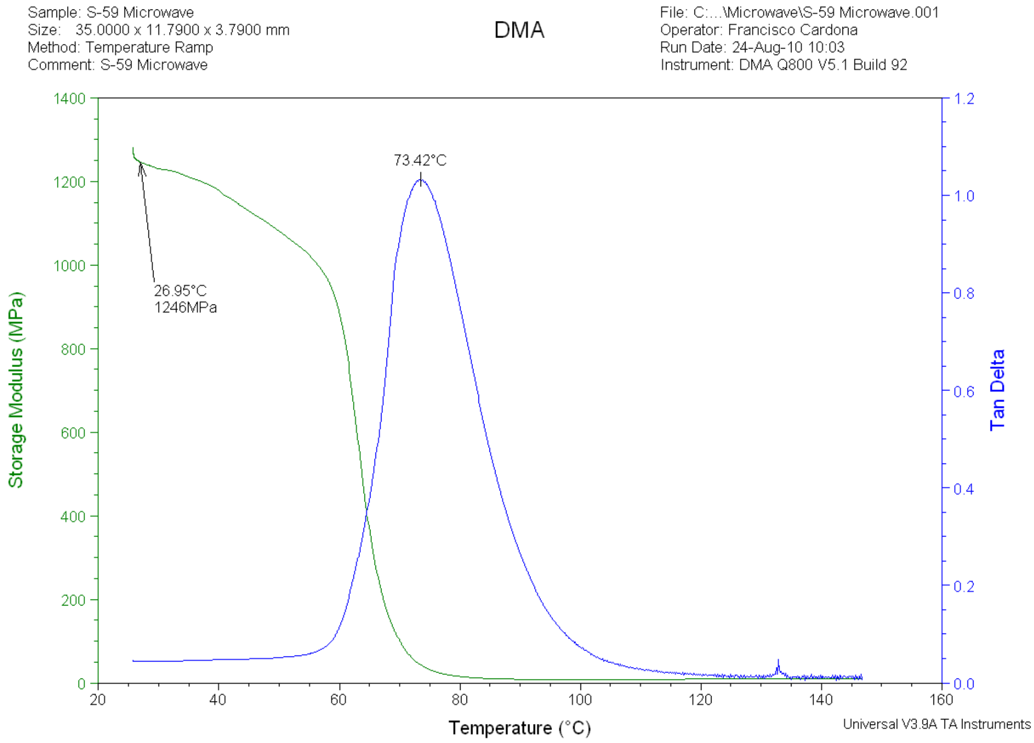

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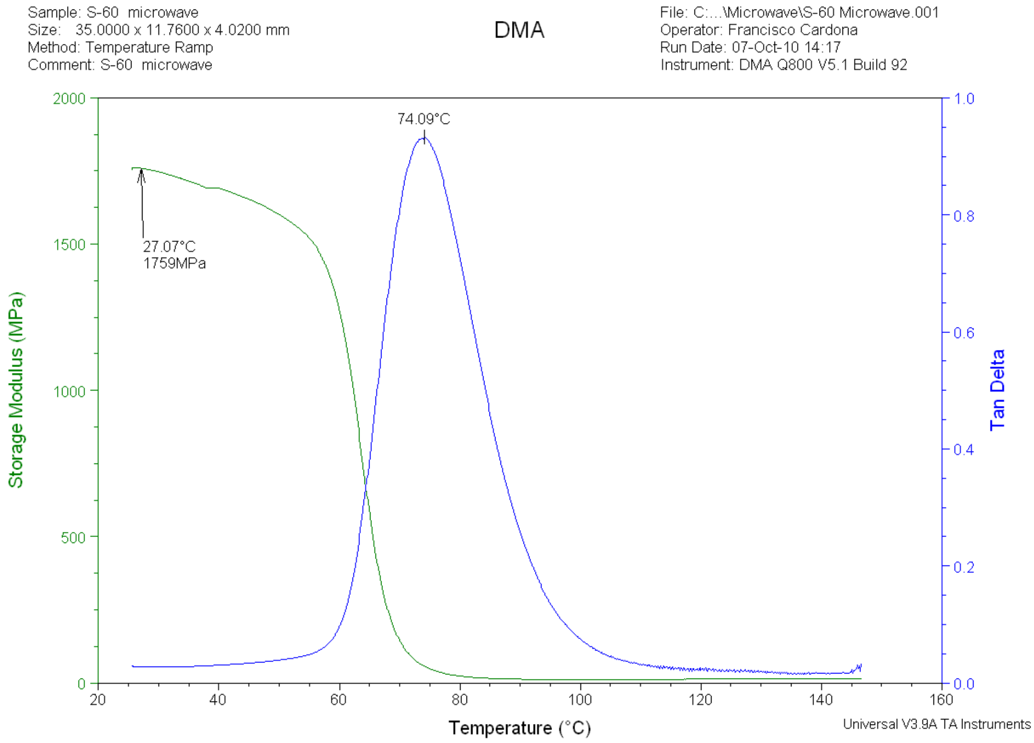
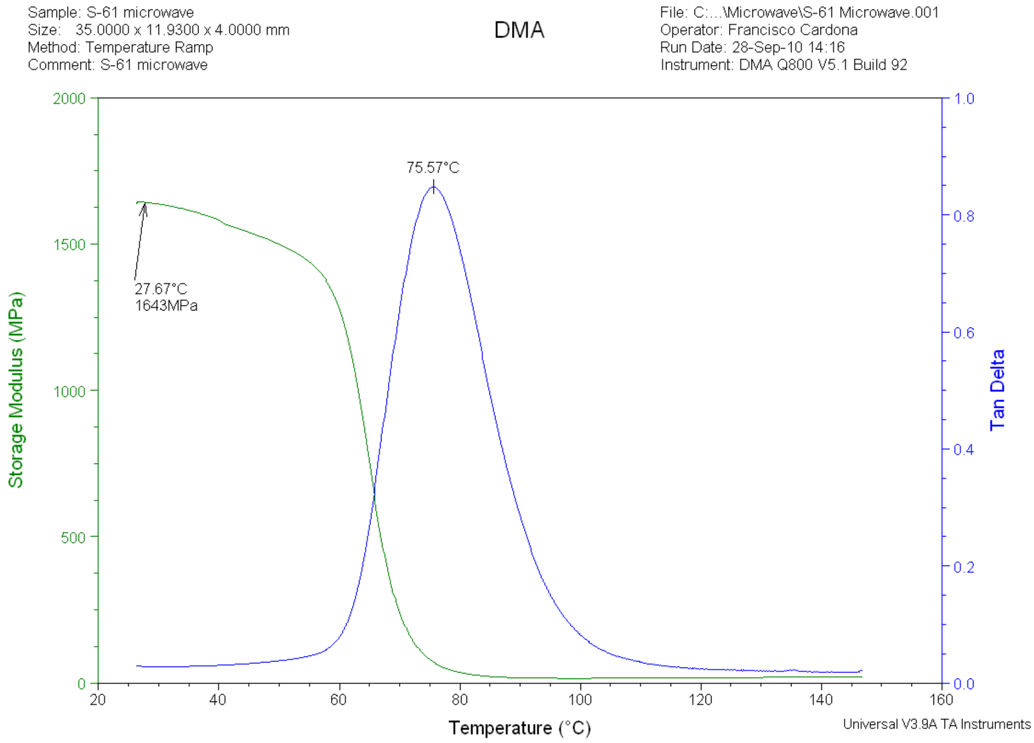
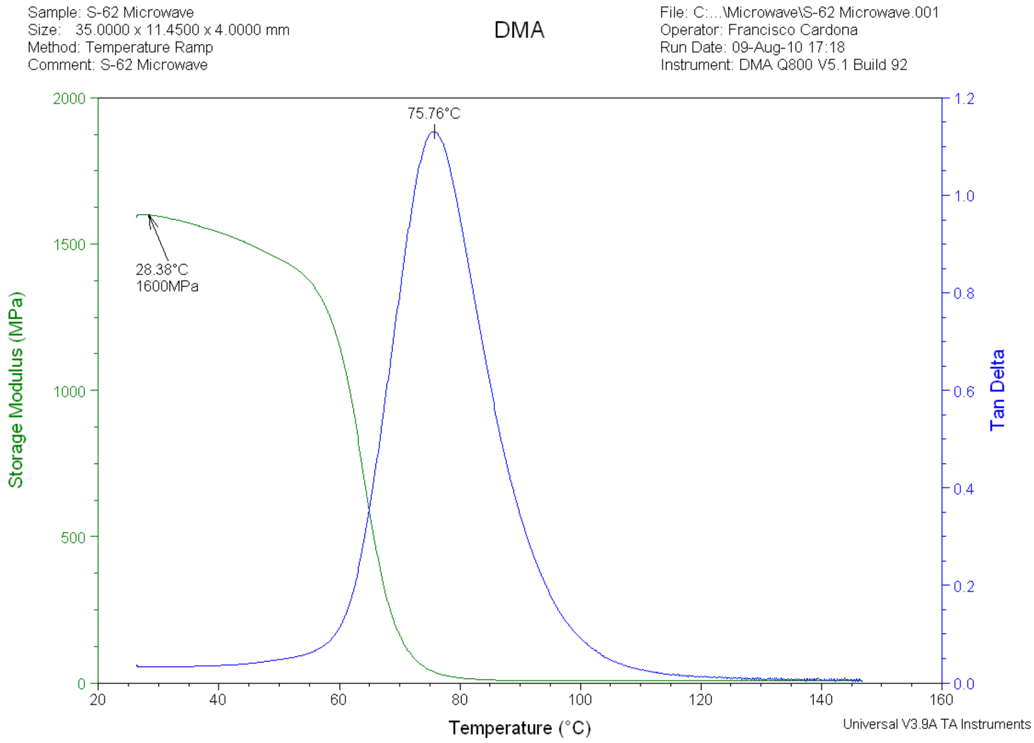


Sample 61



Sample 62



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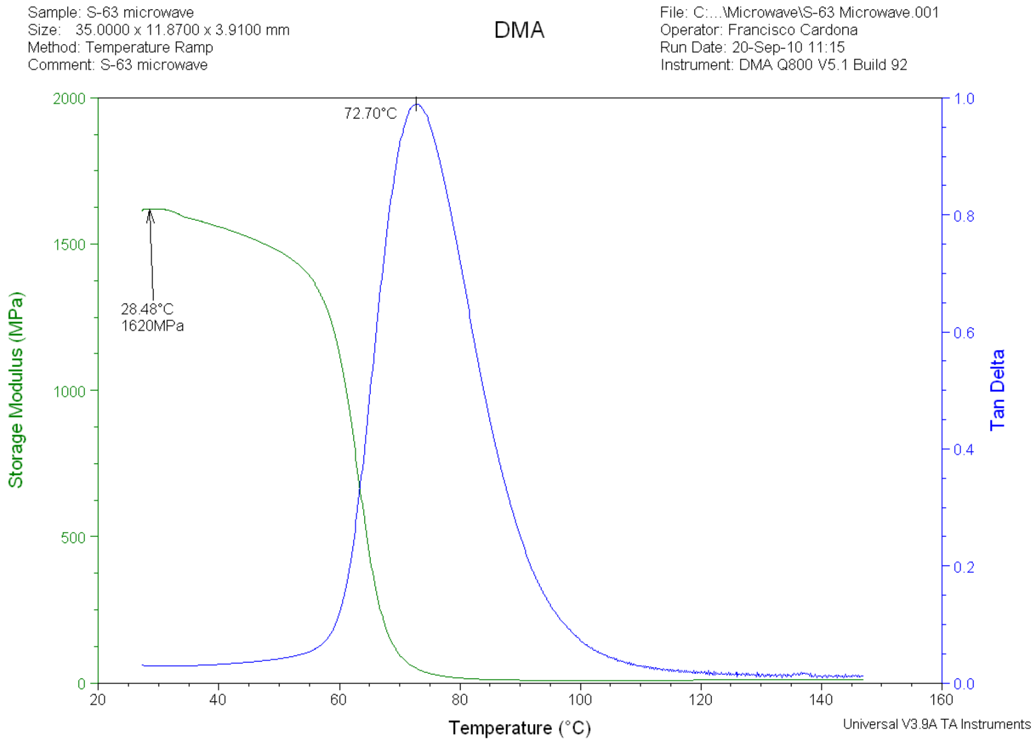

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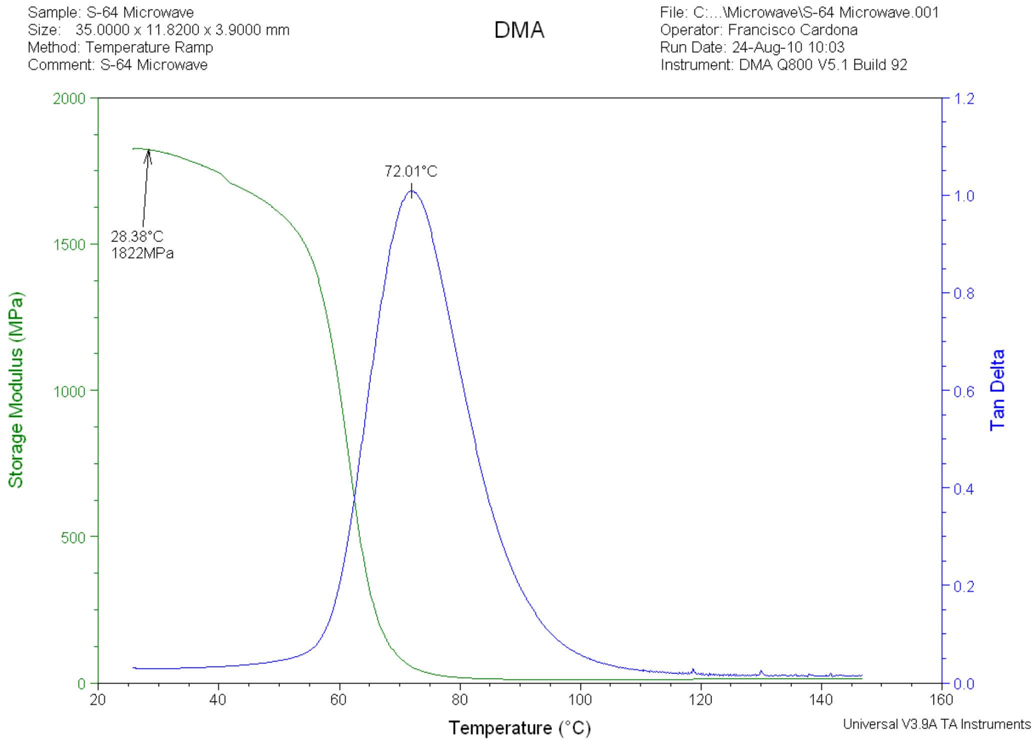
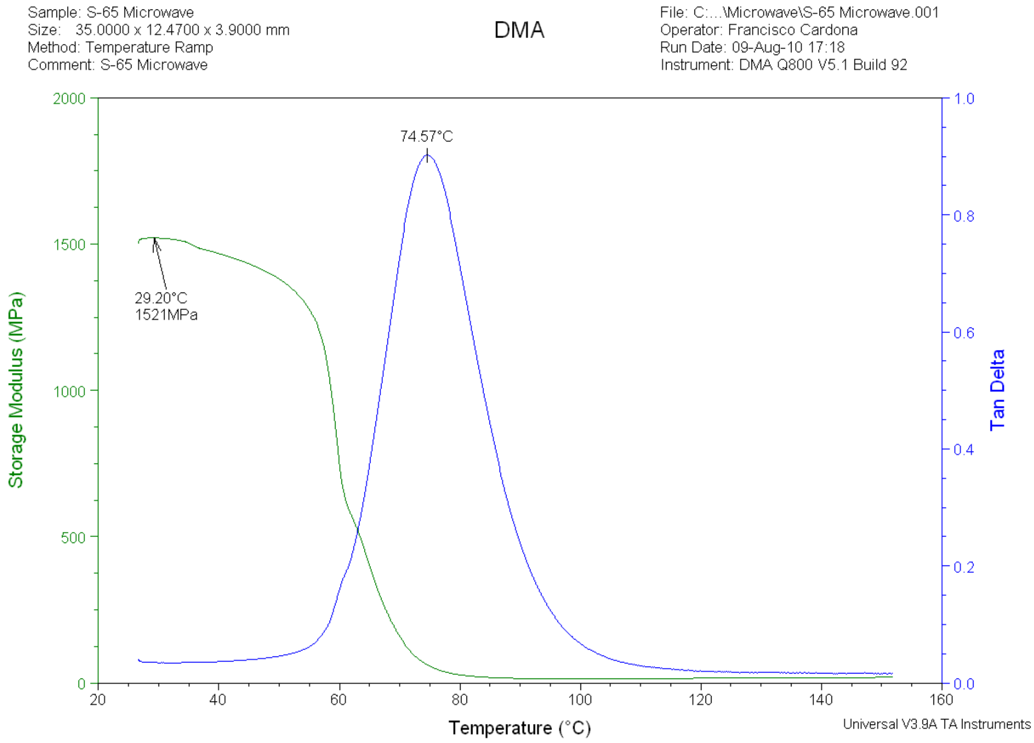


Sample 65



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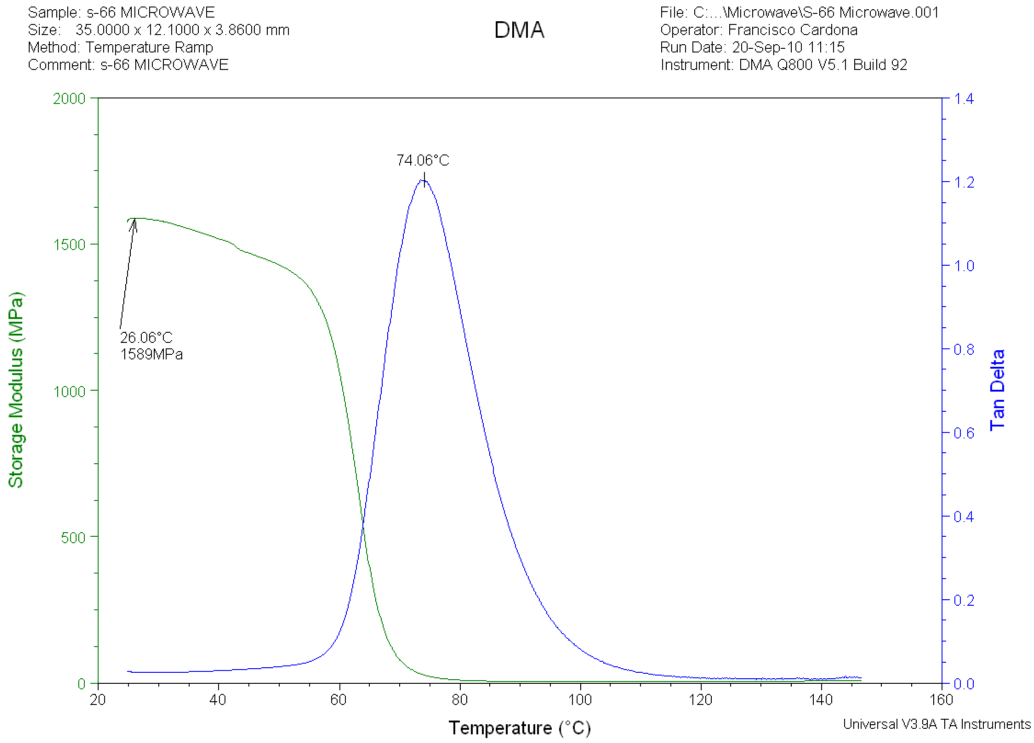

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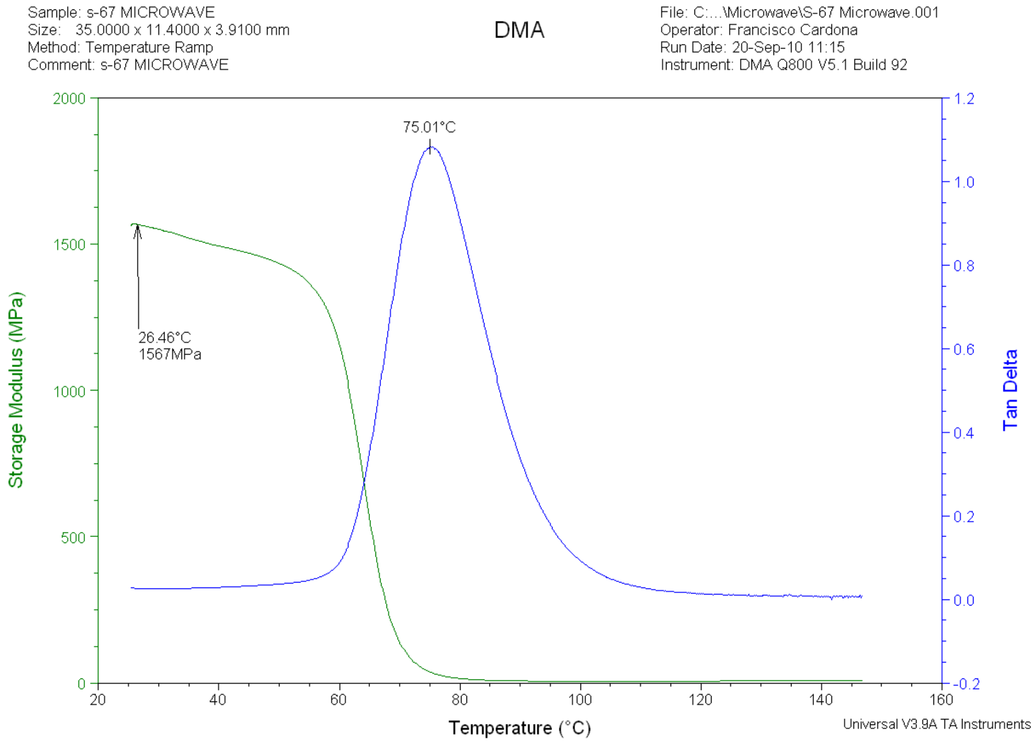

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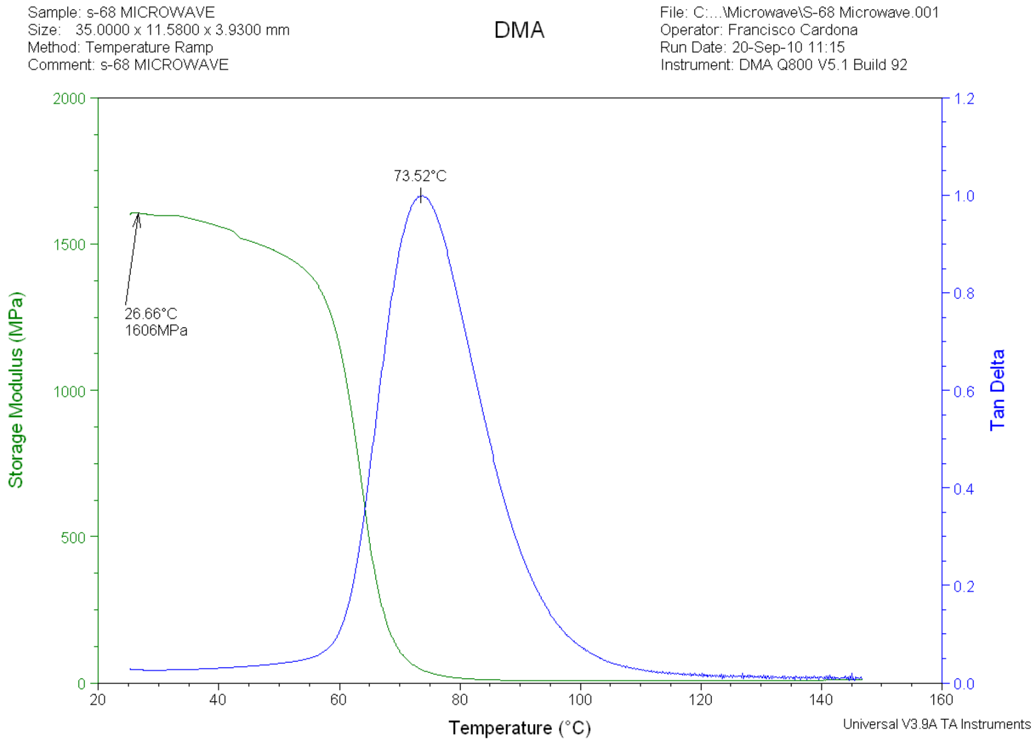
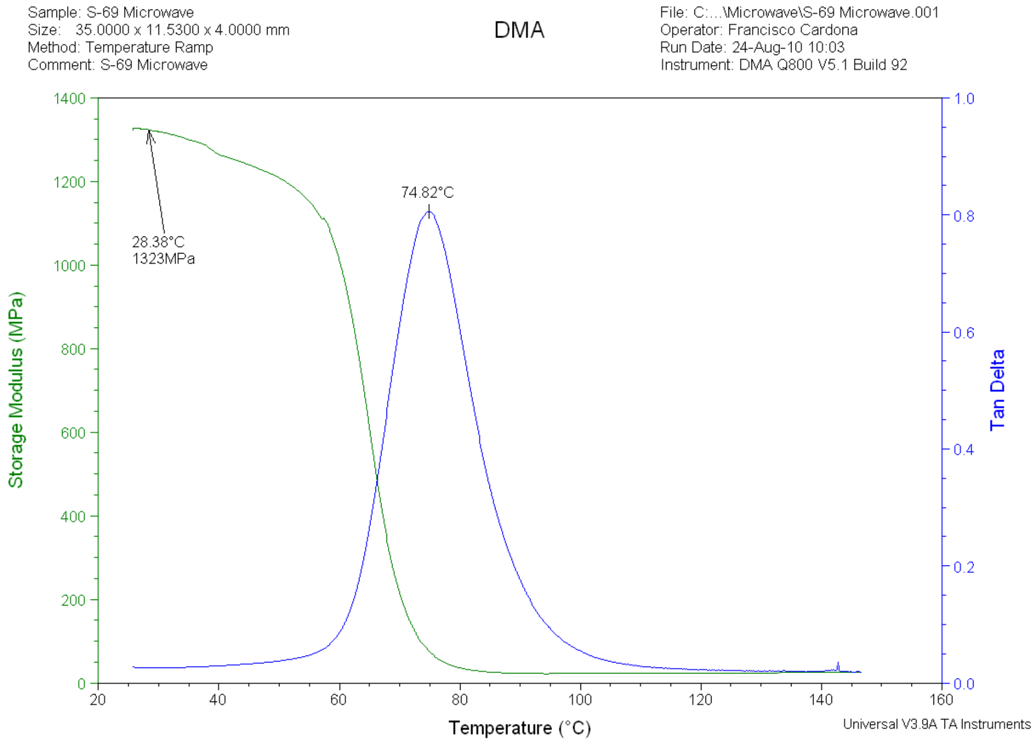
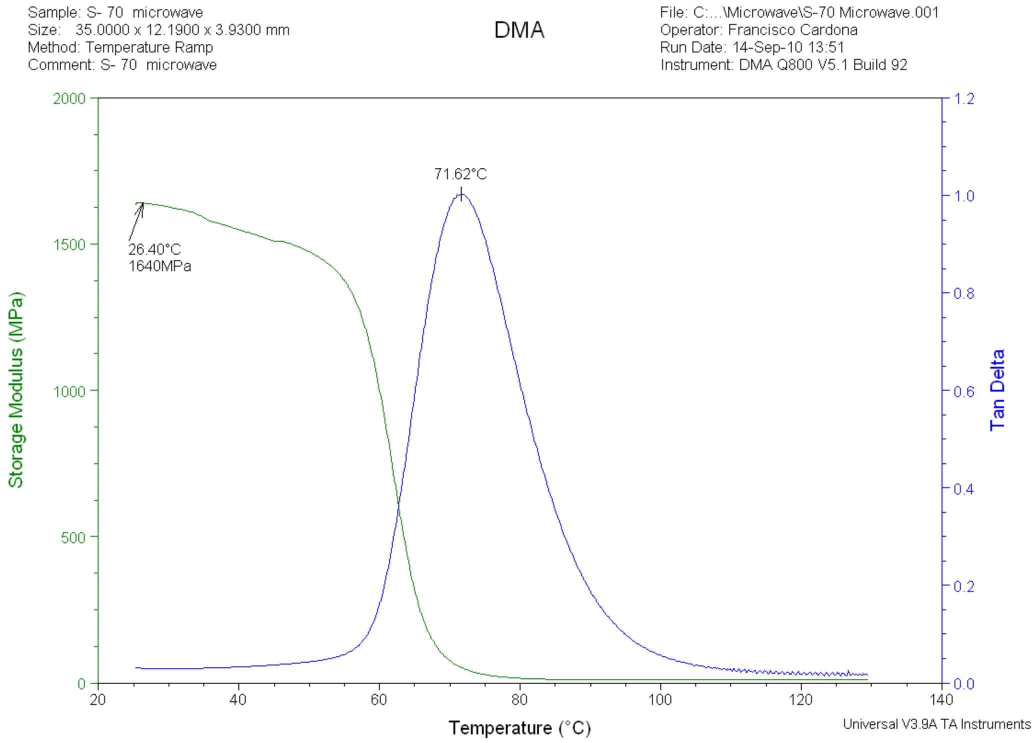


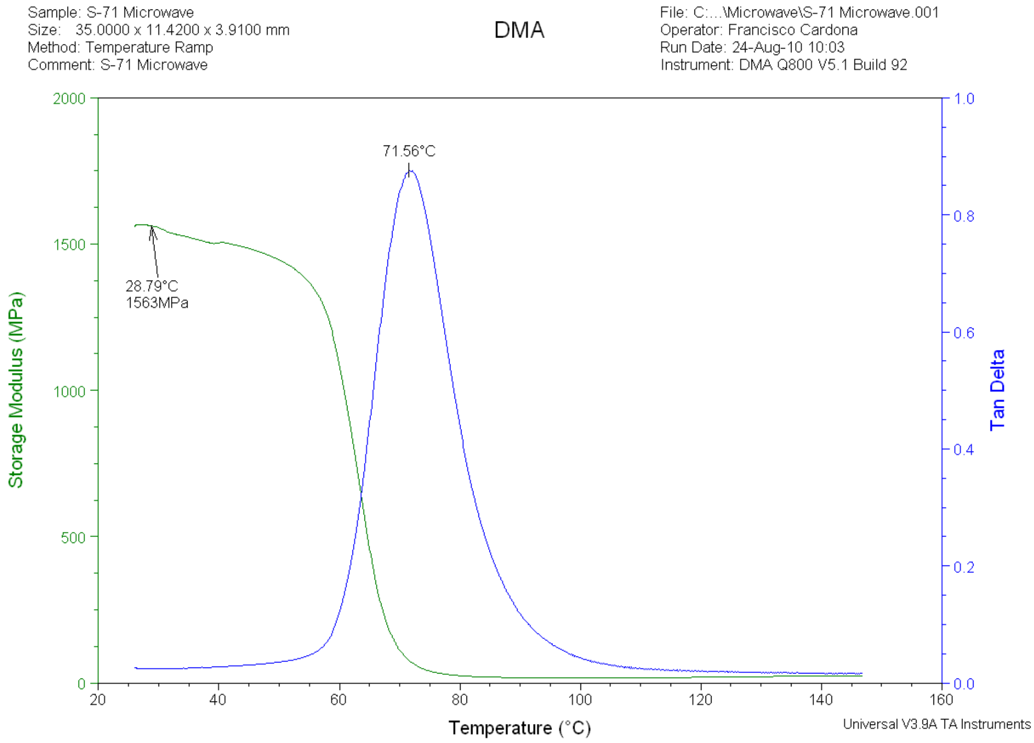
Sample 69



Sample 70



Sample 71



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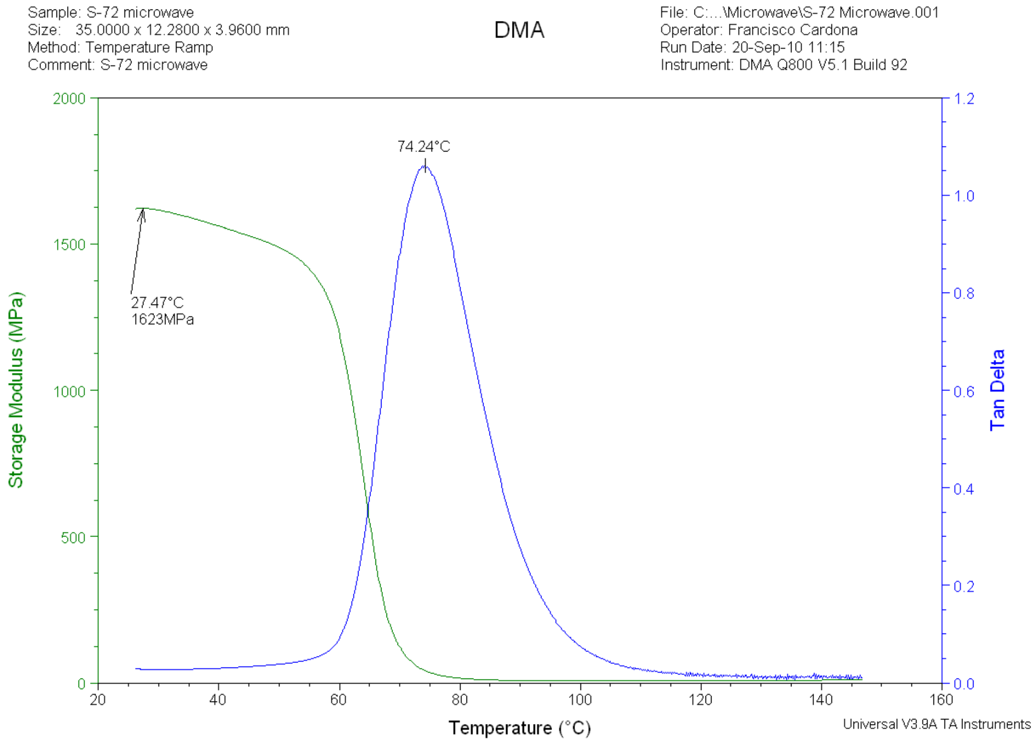
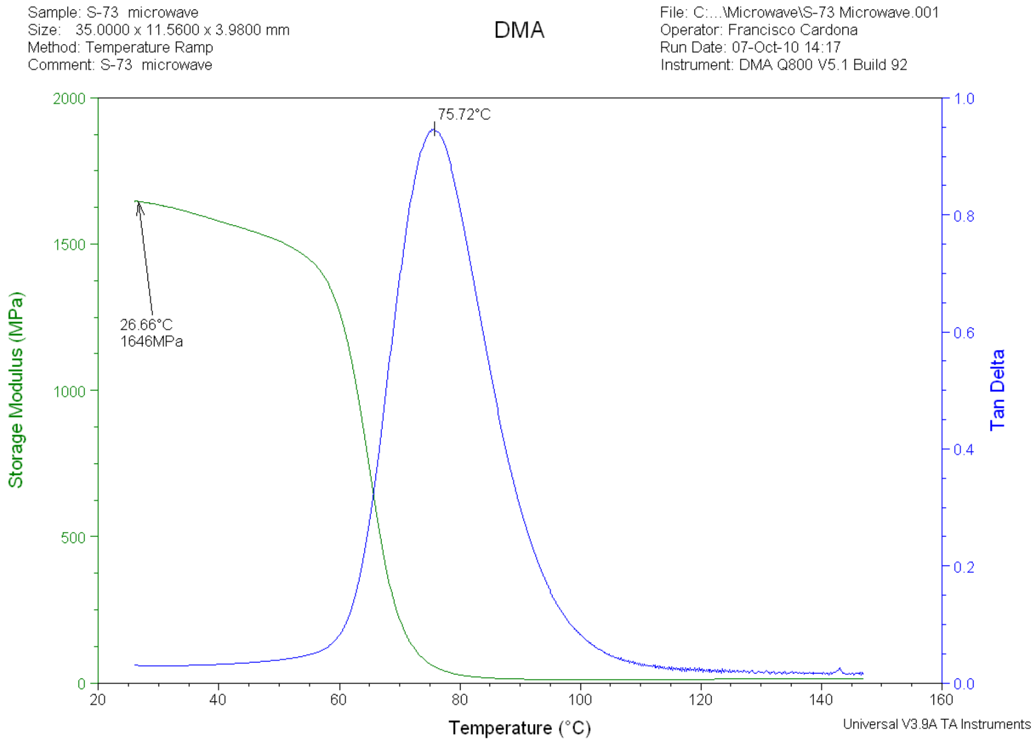


Sample 73



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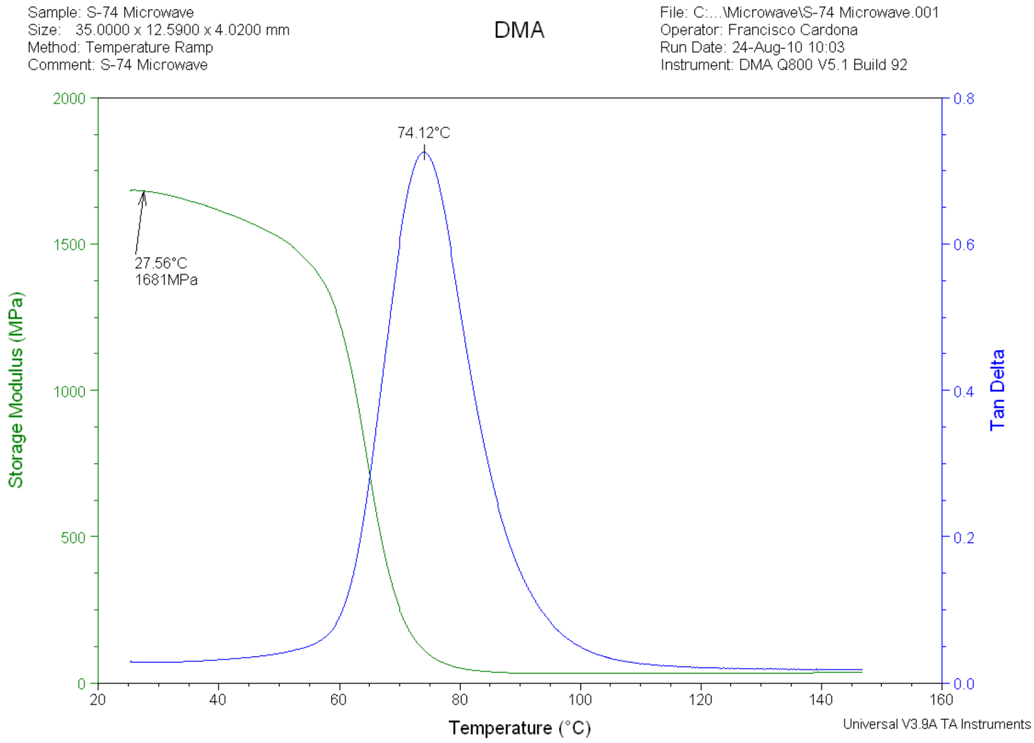

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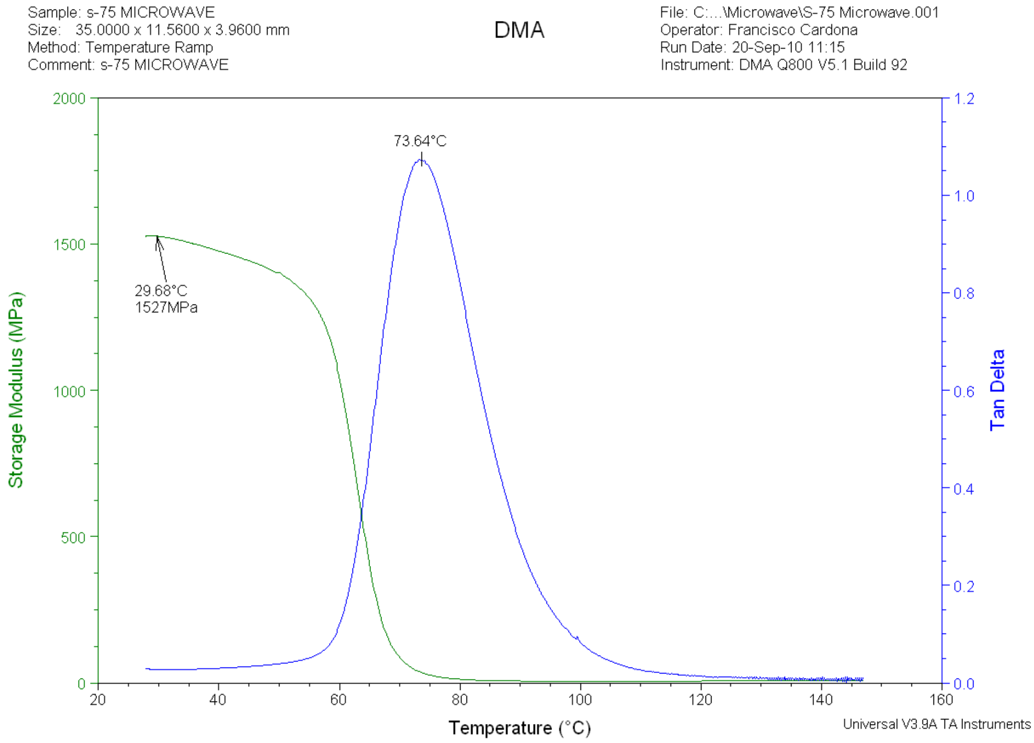

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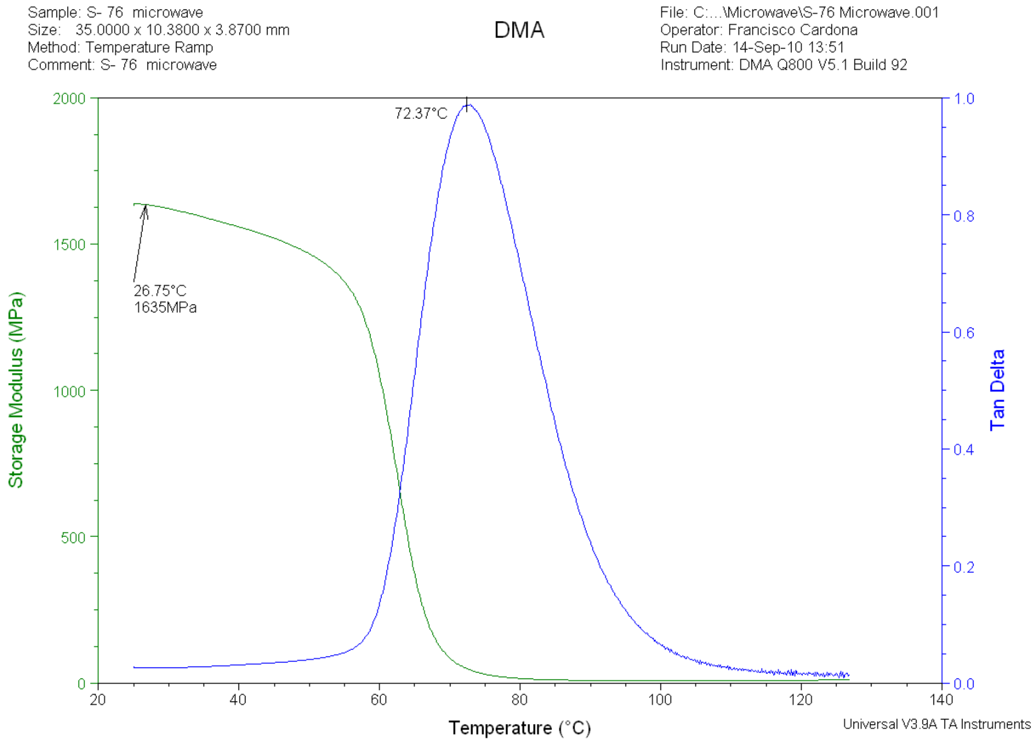
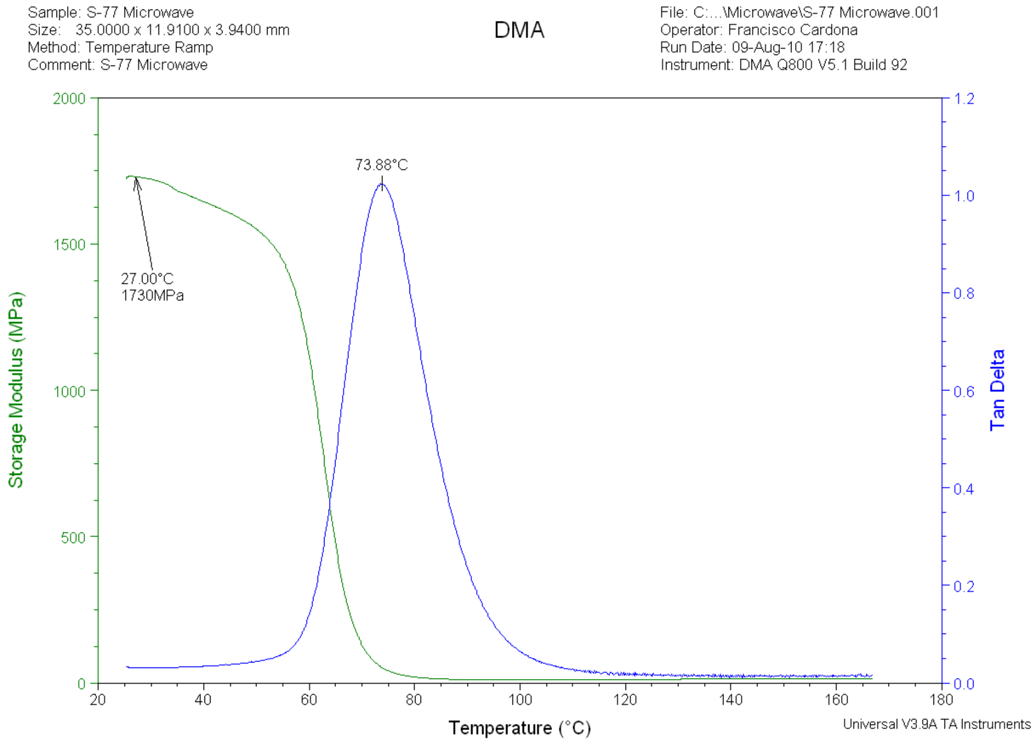


Sample 77



Sample 78