

MAJOR PROJECT 2nd REPORT

ON

“Modification in Mechanical & Thermal Properties Of Epoxy through Blending with Poly(Vinyl Acetate)”

**Under the guidance of
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2K12/PTE/08

CERTIFICATE

This is to certify that the M. Tech. project, **“Modification in Mechanical & Thermal Properties Of Epoxy through Blending with Poly(Vinyl Acetate)”** has been developed under the supervision of Dr. RichaShrivastava Assistant Professor, Department of Applied Chemistry and Polymer Technology during the Fourth semester in the academic session 2014. It has been submitted by Nitesh Kumar of M. Tech.Polymer Technology, Delhi Technological University.

It is further stated that above student submitted the present volume as a project report to the Department of Applied Chemistry and Polymer Technology for partial fulfillment for the award of the degree of M. Tech., Polymer Technology, Delhi Technological University, Delhi. This is an indigenous work and the matter embodied in this report has not been submitted to any other university or institution for the award of any degree or diploma.

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ACKNOWLEDGEMENT

The success and final outcome of this project required a lot of guidance and assistance from many people and we are extremely fortunate to have got this all along the completion of my project work.

I am not forget to remember **Prof. D. Kumar**, HOD, Department of Applied Science and Polymer Technology for his unlisted encouragement and more over for their timely support and guidance till the completion of my project work.

I respect and thank **Dr. RichaShrivastava** for giving me an opportunity to do the project work on **“Modification in Mechanical & Thermal Properties Of Epoxy through Blending with Poly(Vinyl Acetate)”** and providing me all support and guidance which made me complete the project on time.

I am thankful to and fortunate enough to get constant encouragement, support and guidance from all teaching as well as non-teaching staffs of Department of Applied Science and Chemical Technology, which helped me in successfully completing my project work. Also, I would like to extend my sincere regards to all the non-teaching staff of department of polymer science for their timely support.

Mr. Nitesh Kumar (2K12/PTE/08)

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CHAPTER 1

INTRODUCTION

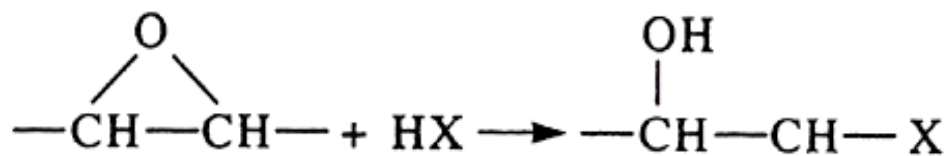
INTRODUCTION

1.1. EPOXY RESIN

Epoxy resins are a class of thermoset materials used extensively in structural and specialty composite applications because they offer a unique combination of properties that are unattainable with other thermoset resins. Available in a wide variety of physical forms from low-viscosity liquid to high-melting solids, they are amenable to a wide range of processes and applications.

Epoxies offer high strength, low shrinkage, excellent adhesion to various substrates, effective electrical insulation, chemical and solvent resistance, low cost, and low toxicity. They are easily cured without evolution of volatiles or by-products by a broad range of chemical specie. Epoxy resins are also chemically compatible with most substrates and tend to wet surfaces easily, making them especially well-suited to composites applications.

Epoxy resin are characterized by more than one 1, 2- epoxy group per molecule. Three-membered epoxy ring is highly reactive to many substances, particularly by with proton donor (eg: amine, anhydride)

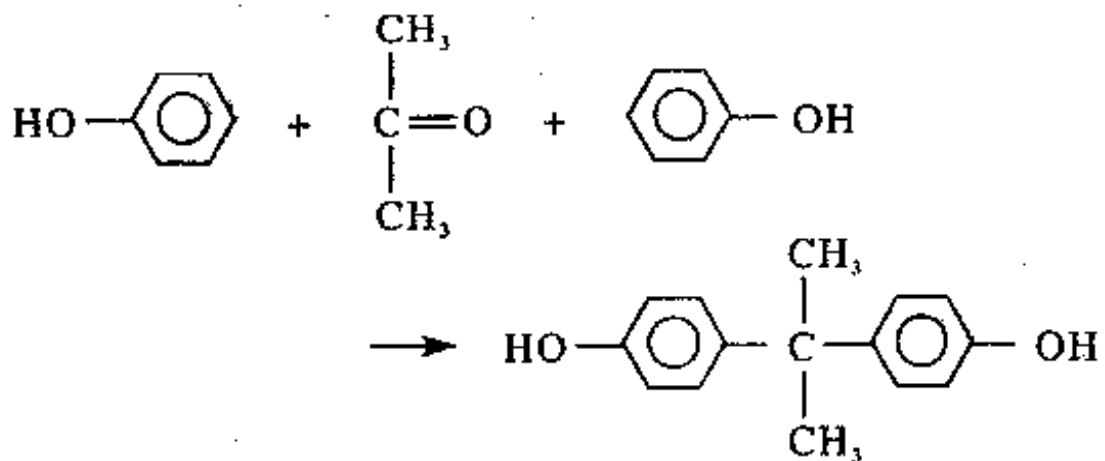


Such reactions allow chain extension and/or cross linking to occur without the elimination of small molecules such as water.

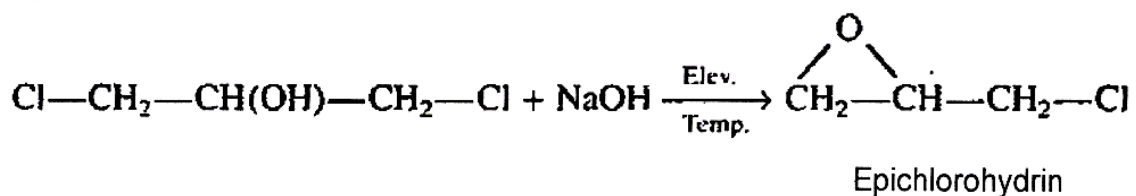
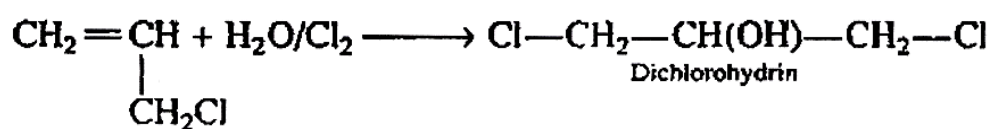
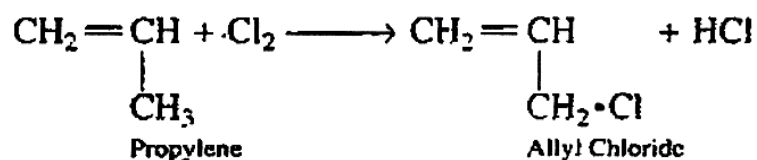
1.1.1 Monomers

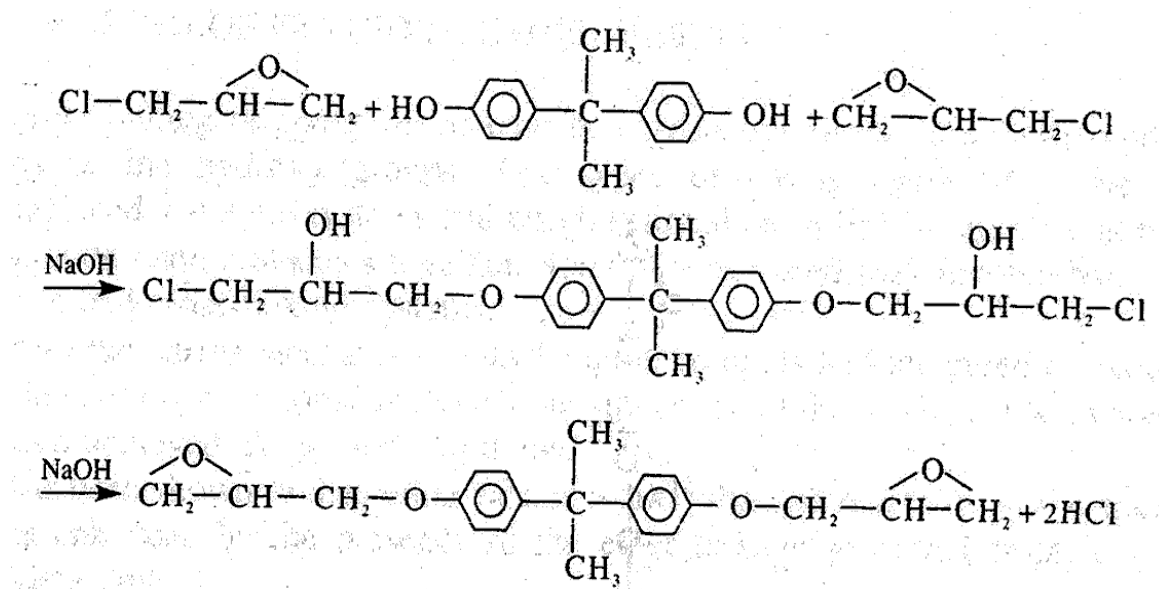
The monomers for general purpose epoxy resins are bis-phenol A and epichlorohydrin.

A. Bis- phenol A is prepared by reaction of acetone and phenol.

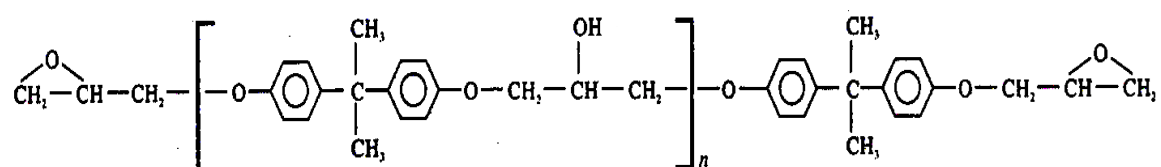


B. Epichlorohydrin: Starting material for the preparation of Epichlorohydrin is propylene and chlorine.





General formula for glycidyl ether epoxy resin is represented by the structure :

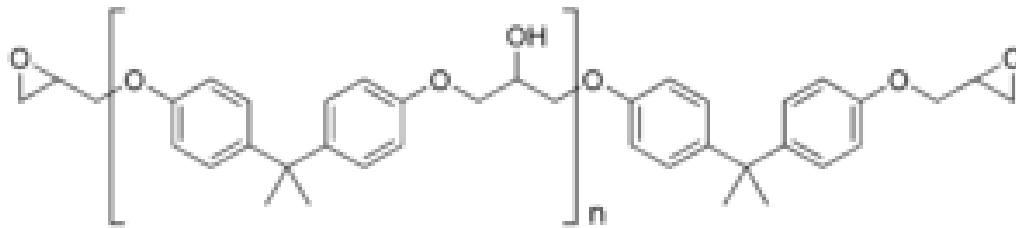


With $n = 0$, the product reduces to diglycide ether and the molecular weight is 340; with $n = 10$, the molecular weight is about 3000. Epoxy is a copolymer; that is, it is formed from two different chemicals. These are referred to as the "resin" and the "hardener". The resin consists of monomers or short chain polymers with an epoxide group at either end.

1.1.2 Hardener

The hardener consists of polyamine monomers, for example Triethylenetetramine (TETA). When these compounds are mixed together, the amine groups react with the epoxide groups to form a covalent bond. Each NH group can react with an epoxide group, so that the resulting polymer is heavily cross linked, and is thus rigid and strong. The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds; the process can take minutes to hours.

1.1.3 Chemistry



Structure of unmodified epoxy prepolymer

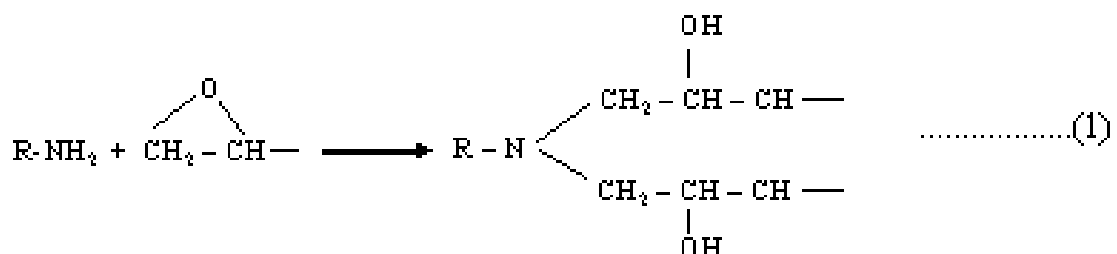
(n denotes the number of polymerized subunits and is in the range from 0 to about 25)

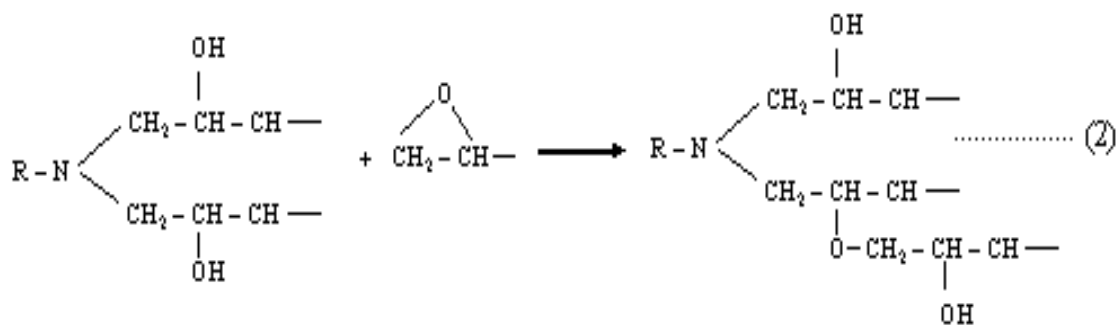
1.1.4 Hardeners used with epoxy resin:

Reacting of an epoxide –containing monomer of prepolymer to produce a linear or cross linked product is called “curing”. The resulting product is often called an epoxy merely because it was made from molecules containing epoxide functional groups and despite the fact that the “cured” epoxies no longer contain such groups.

The curing of the epoxy resin is based on the reaction between the epoxide molecules themselves or the reaction between the epoxide group and other kinds of reactive molecules with or without the help of a catalyst. The former is homopolymerization, and the latter is an addition reaction, but both results in coupling as well as cross linking.

As for example here curing polyamine is taken as a curing agent. The reaction during the curing is shown below.



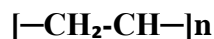


The branching reaction (2) known as Butrification, keep going on increasing and cross linking density of cured resin increases.

1.2 POLYVINYL ACETATE

PVAc is a vinyl polymer. Polyvinyl acetate is prepared by polymerization of vinyl acetate monomer (free radical vinyl polymerization of the monomer vinyl acetate).

PVAc behaves also as homogeneous phase. However PVAc was found to be immiscible with the highly amine-cross-linked epoxy resin. It was found that phase separation in DGEBA+PVAc blends occurred as the conversion reaches a value close to 40%. In the final cured material two phases are present: an epoxy phase and a PVAc phase. It was also found a slowdown of the reaction when PVAc was present. The PVAc component was used as a potential toughness modifier.



|



CHAPTER 2

POLYMER BLEND

POLYMER BLENDS

2.1 INTRODUCTION OF BLENDS

Polymer blends are macroscopically homogeneous mixtures of two or more different species of polymers. In most cases the blends are homogeneous on scales larger than several times the wave length of visible light. The blends combine properties of the components and often lead to applications not achievable by the components when used alone. Quite a majority of the blends are targeted to enhance the toughness of otherwise a very useful polymer. For toughening one need that the combination is semi compatible since molecular miscibility does not lead to micro-phase separation necessary for enhanced energy absorption during an impact. If the major component is a semi crystalline polymer, the blend properties will be critically dependent on the degree of crystallinity in the blend. The blend properties when evaluated considering the crystallinity in the analysis, phase interaction could also be indicated.

Blend Terminology

- Miscible / homogeneous - Mixtures whose components are soluble in one another, and mix at the molecular level.
- Immiscible – Mixtures whose components are completely or partially insoluble in one another, leading to multiple phases.
- Compatible – commercially attractive polymer mixtures that often appear to be homogeneous to the eye and demonstrate properties superior to their purest components.

2.2 Production of Blends

- Polymerization: Several reactors in series are used to prepare a final product that contains a mixture of polymers.
- Solution casting: The polymers are dissolved in a common solvent. Blend is produced by evaporating the solvent and precipitating the resulting polymer mixture.

- Melt blending: High-shear mixers can generate fine dispersions, with droplet diameters $< 1 \mu\text{m}$.

2.3 TYPES OF BLENDS

Thermodynamically there are two classes of blends

- 1.) Miscible polymer blends; and
- 2.) Immiscible polymer blends

Miscibility of Blend Components

- In immiscible blends the constituent polymers do not mix, but remain in separate phases, leading to the formation of a dispersion of one of the polymers in a continuous matrix of the other.
- EXPERIMENTAL EVIDENCE INDICATES THAT MOST POLYMER PAIRS ARE COMPLETELY IMMISCIBLE.
- Note that blends can exhibit complete immiscibility and partial immiscibility, just as in small molecule systems.
- In miscible blends the constituent polymers mix on a molecular level, to form a homogeneous material equivalent to a polymer-polymer solution.
 - The physical, chemical and mechanical properties are generally a weighted average of the mixture components.

Immiscible Blends

- In immiscible polymer blends, the composition, rheological and interfacial properties of the components control phase morphology.

MERITS OF BLENDS

- The mechanical properties required for a given application can be met by blending two polymers (usually an expensive engineering resin with a low-cost commodity material), then the formulation is less expensive. **COST**
- If you wish to recycle polymer products, you will likely encounter issues related to blending, since your polymer sources will vary widely in terms of purity. Some polymer combinations exhibit properties that are superior to their parent polymers. This is called synergism, and it is widely used for toughening of

2.4 BLEND MATERIALS

Polymer blends are consisting of a resin and a hardener or catalyst, which acts as a curing agent. Resins are a type of a plastic and they are classified in two categories.

- ❖ Thermoplastic
- ❖ Thermoset

2.4.1 Thermoplastic

Thermoplastic resins use heat to form the part into the specified shape, and this shape is not permanent that means, if we add heat again it will flow to another shape. So thermoplastics can be used only in area where the temperature does not exceed 400⁰C.

Exemple:- PE, PP, PC, PVAc, Nylon, PET, Polypehylene sulphide.

2.4.2 Thermoset

Thermoset resins use heat to form and set the shape permanently. The plastics one formed, cannot be removed even if heated. Most of structural components are designed of thermoset resins.

Example: - Epoxy resin, Phenolic resin, Vinyl ester, unsaturated polyester.

2.4.3 Epoxy Resin

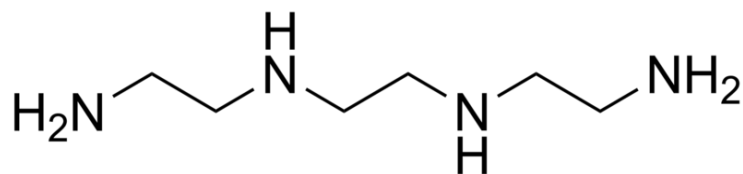
Epoxy resins are one type of thermoset resin. They have good adhesion, strength and resistance to moisture and chemical properties. They are used to bond non-porous and dissimilar materials, like thermoplastic component.

Following are the main property of epoxy resin.

1. Good mechanical properties
2. Good adhesive properties
3. Good toughness properties
4. Good resistance to environmental degradation

2.5 HARDENER

Triethylenetetramine, abbreviated TETA and trien, is an organic compound with the formula $[\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2]_2$. This oily liquid is colourless but, like many amines, assumes a yellowish color due to impurities resulting from air-oxidation. It is soluble in polar solvents and exhibits the reactivity typical for amines. It was primarily used as a cross linker ("hardener") in epoxy curing.



chemical structure of TETA

Triethylenetetramine is produced by the reaction of aqueous ammonia with 1, 2-dichloroethane. This process yields the entire family of ethyleneamines: ethylenediamine, piperazine, diethylenetriamine, triethylenetetramine, tetraethylenepentamine, pentaethylenhexamine and aminoethylpiperazine. These polyamines are produced as their hydrochloride salts, and must be neutralized, typically with aqueous caustic soda, to obtain the free amines. The by-product salt produced in the neutralizations step is separated and the individual products are isolated by fractional distillation.

- In Germany, triethylenetetramine (TETA) is mainly used as
- intermediate for curing agents for epoxy resins (ca.1600 t/a)
- direct curing agent for epoxy resins (ca. 160 t/a)
- intermediary for auxiliary agents used in the paper industry, the textile industry and in
- glues (ca. 330 t/a)
- intermediate for asphalt emulsifiers (ca. 110 t/a)
- The curing agent for the epoxy resins usually is amine. No volatile by-products are generated during the curing process. During curing, epoxy resins can undergo three basic reactions:
- Epoxy groups are rearranged and form direct linkages between themselves.
- Aromatic and aliphatic hydroxyls link up to the epoxy groups.
- Cross-linking takes place with the curing agent through various radical groups.
- The result is a complex three-dimensional molecular structure which is illustrated in **Fig.**

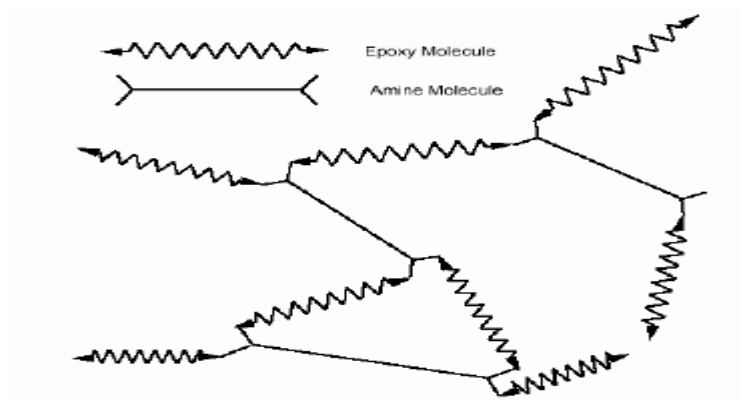


Fig.1 Schematic representation of cured epoxy resin

The advantages of epoxy resins are low polymerization shrinkages, excellent mechanical strength, good electrical properties and chemical resistance. The epoxy molecule also contains two ring groups at its centre which are able to absorb both mechanical and thermal stresses better than linear groups and therefore give the epoxy resin very good stiffness, toughness and heat resistance. The primary disadvantages of the epoxy resins

are that they require long curing times and, in general, their mold release characteristics are poor.

The epoxy resins are characterized by their high adhesive strengths. This property is attributed to the polarity of aliphatic hydroxyl groups and ether groups that exist in both the initial resin and cured system. The polarity associated with these groups promotes electromagnetic bonding forces between epoxy molecules and the substrate.

Table 2.1 Properties Of hardener :

Hardener	Chemical Compositions	Viscosity at 25°C (MPa*s)cst	Density at 20°C (g/cm3)
	Triethylenetetramine(TETA)	21.4	0.981

2.6 Polyvinyl acetate:

Because of its high cold flow, poly(vinyl acetate) is of little value in the form of mouldings and extrusions. However, because of its good adhesion to a number of substrates, and to some extent because of its cold flow, a large quantity is produced for use in emulsion paints, adhesives and various textile finishing operations. A minor proportion of the material is also converted into poly(vinyl alcohol) and the poly(vinyl acetate)s which, are of some interest to the plastics industry.

Poly (Vinyl) acetate(**PVAc**)as a potential toughness modifier.

PROPERTIES OF PVAc:

PROPERTY	UNITS	VALUE
Notched impact strength	Jm ⁻¹	102.4
Elongation at break	%	10-20
Rubbery shear modulus	Nmm ⁻²	13
Tensile strength	MPa	29.4-49.0
Young's modulus	MPa	600
Melting temperature T _m	K	448

CHAPTER 3

LITERATURE REVIEW

LITERATURE REVIEW

The ability of the epoxy ring to react with a variety of substrates gives the epoxy resins versatility. Treatment with curing agents gives insoluble and intractable thermoset polymers. Some of the characteristics of epoxy resins are high chemical and corrosion resistance, good mechanical and thermal properties, outstanding adhesion to various substrates, low shrinkage upon cure, good electrical insulating properties, and the ability to be processed under a variety of conditions. Depending on the specific needs for certain physical and mechanical properties, combinations of choices of epoxy resin and curing agents can usually be formulated to meet the market demands. However, in terms of structural applications, epoxy resins are usually brittle and notch sensitive. As a result, tremendous effort has been focused on toughness improvement during past three decade.

EPOXY\POLYVINYL ACETATE:

Study on Diglycidylether of bisphenol A (DGEBA)/poly (vinyl acetate) (PVAc) blends cured with Triethylenetetramine (TETA). The miscibility and phase behavior were investigated by means of differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA) and scanning electron microscopy (SEM). The study results indicate that the epoxy precursor (DGEBA)/PVAc blends are clearly miscible at the entire composition and the T_g values experimentally obtained are in a good agreement with those predicted by Fox equation. Cured at elevated temperature, all the TETA-cured blends underwent phase separation and display two-phase morphology. When PVAc content is more than 10 wt.%, the thermoplastics-modified resins began to show a co-continuous phase structure. It is the cocontinuous structure that leads to a significantly-improved toughness in K_{Ic} . Morphologic investigation of the surfaces of fracture mechanic measurement specimens indicates that the toughening effect of the thermoplastics-modified epoxy resins may arise mainly from the ductile yielding of PVAc.

Investigated the miscibility and curing behaviour in blends of poly(vinyl acetate) (PVAc) with diglycidyl ether of bisphenol A (DGEBA) resin and Triethylenetetramine (TETA) used as curing agent. The PVAc component was used as a potential toughness modifier. Binary mixtures DGEBA+PVAc show complete miscibility over the whole composition

range. Ternary mixture DGEBA+TETA in stoichiometric ratio +10% (w/w) PVAc behaves also as homogeneous phase. However PVAc was found to be immiscible with the highly amine-cross-linked epoxy resin. It was found that phase separation in DGEBA+TETA+PVAc blends occurred as the conversion reaches a value close to 40%. In the final cured material two phases are present: an epoxy phase and a PVAc phase. It was also found a slowdown of the reaction when PVAc was present.

Cure kinetics and morphology of diglycidyl ether of bisphenol A (DGEBA) modified with polyvinyl acetate (PVAc) using Triethylenetetramine (TETA), as hardener through differential scanning calorimetry (DSC) and environmental scanning electron microscopy (ESEM). Isothermal curing measurements were carried out at 150, 120 and 80° C. The kinetic parameters were obtained using the general autocatalytic chemically controlled model. The comparison of the kinetic data indicates that the presence of PVAc does not change the autocatalytic nature of the cure reaction. Two Tgs were observed in the fully cured samples of the modified systems. ESEM micrographies confirm the biphasic morphology.

Investigated epoxy based on diglycidyl ether of bisphenolA + Triethylenetetramine (TETA) blended with poly (vinyl acetate) (PVAc) was investigated through differential scanning calorimetry (DSC), dynamic mechanical thermal analysis (DMTA) and environmental scanning electron microscopy (ESEM). The influence of PVAc content on reaction induced phase separation, cure kinetics, morphology and dynamic-mechanical properties of cured blends at 180°C are reported. Epoxy/PVAc blends (5, 10 and 15 wt. % of PVAc content) are initially miscible but phase separate upon curing. DMTA α -relaxations of cured blends agree with Tg results by DSC. The conversion-time data revealed the cure reaction was slower in the blends than in the neat system, although the autocatalytic cure mechanism was not affected by the addition of PVAc. ESEM showed the cured epoxy/PVAc blends had different morphologies as a function of PVAc content: an inversion in morphology took place for blends containing 15 wt. % PVAc. The changes in the blend morphology with PVAc content had a clear effect on the DMTA behavior. Inverted morphology blends had Low storage modulus values and a high capability to dissipate energy at temperatures higher than the PVAc glass transition temperature, in contrast to the behavior of neat epoxy and blends with a low PVAc

CHAPTER 4

MATERIALS AND METHODS REQUIREMENT

MATERIALS AND METHODS REQUIREMENT

4.1 REQUIRED RAW MATERIALS

- ❖ Epoxy resin.
- ❖ Amine hardener (TETA).
- ❖ Polyvinyl acetate
- ❖ Beaker.
- ❖ Measuring cylinder.
- ❖ Stirrer.
- ❖ Gloves.
- ❖ Chloroform
- ❖ heater

4.2 REQUIRED INSTRUMENTS

- ❖ Universal Testing Machine
 1. Tensile test
 2. Flexural test
- ❖ DMA
- ❖ SEM

4.3 METHODOLOGY OF WORK

The methodology of work depicts the process and methods undertaken for the fabrication of the epoxy polyvinyl acetate blend in lab. The various processes undertaken to fabricate the blend are,

1. Formation of polyvinyl acetate solution
2. Mixing of epoxy and TETA hardener.
3. Solution blending
4. Curing.

5. Sample preparation.

4.4 Formation of Mixer:

The Polyvinyl acetate is dissolved in to desired amount. The approximate amount of polyvinyl acetate that should be properly measure and mix up to suitable amount. By using the suitable amount of solvent(chloroform) and stir to dissolving PVAc and form solution. Then solution added to heated epoxy form liquid mixture.

Mixing Of Epoxy, PVAc and TETA Hardener:

Mixing is an important part of the whole process because even mixing of the hardener with epoxy resin will decide various properties. The improper ratio of both system changes the curing time, pot life etc. the mixing ratio between Epoxy and Hardener is kept 10:1 respectively to yield the desired properties.

Mixing is done by slowly pouring in the hardener (TETA) in to the beaker having epoxy. The stirrer is slowly but continuously stirred to avoid the formation of bubble.

Preparation of Control Epoxy Sample

- Epoxy Resin has been heated at $90\pm 1^{\circ}\text{C}$ for one hour followed by cooling to $40\pm 1^{\circ}\text{C}$.
- At this stage Triethylenetetramine (TETA) has been added to epoxy where a highly viscous solution has been produced.
- It has been immediately poured into the moulds of specified dimensions.

Preparation of Epoxy Blend (Epoxy + PVAc+TETA)

We use two way to form of Epoxy Blend

1. Epoxy + Teta (9:1) ratio

A	EPOXY 45ml+ TETA 5ml (9:1 ratio)
B	EPOXY+TETA(9:1)+1%PVAc(.50gm)
C	EPOXY+TETA(9:1)+2%PVAc(1gm)
D	EPOXY+TETA(9:1)+3%PVAc(1.5gm)
E	EPOXY+TETA(9:1)+4%PVAc(2.0gm)
F	EPOXY+TETA(9:1)+5%PVAc(2.5gm)

2. Epoxy + Teta (10:1) ratio

G	EPOXY50ml + TETA5ml (10:1 ratio)
H	EPOXY+TETA(10:1)+1%PVAc(.55gm)
I	EPOXY+TETA(10:1)+2%PVAc(1.10gm)
J	EPOXY+TETA(10:1)+3%PVAc(1.65gm)
K	EPOXY+TETA(10:1)+4%PVAc(2.20gm)
L	EPOXY+TETA(10:1)+5%PVAc(2.75gm)

- PVAc being a plastic solid cannot be directly mixed with Epoxy resin so, initially it has been added to chloroform.
- The Solution has been mixed thoroughly until the crystals of PVAc got fully dissolved in Chloroform.
- This Solution has been further mixed with Epoxy resin.
- The mixture of Epoxy and PVAc has been treated in a mechanical stirrer for several hours in order to evaporate the chloroform.
- After the evaporation of Chloroform, Epoxy + PVAc mixture has been heated at $90\pm 1^{\circ}\text{C}$ for one hour followed by cooling to $40\pm 1^{\circ}\text{C}$.
- At this stage TETA has been added to Epoxy + PVAc mixture where a highly viscous solution has been produced.
- It has been immediately poured into the moulds of specified dimensions and left at room temperature for 24 hours until the mixture was hardened.
- When the blend was hardened, it was removed from the mold and placed inside an oven for 3 hours at 40°C and 80°C for 6 hours for post curing.



Fig.2 Mold Used for preparing flate 5 mm thick cured Epoxy/PVAC sheet

4.5 Curing condition:

The sample is allowed to cure under the compressed condition for about 10 to 12 hours at room temperature as the selected hardener system was room temperature cure system. The curing is marked by the complete hardness of the surface. The uniform property can be tested by tapping the coin over its surface and listening to the sound coming out of it. Metallic sound ensures the uniform property of blend.

Molds used in Casting

Mold used in this study were made from plastic sheet and iron frame. The mold has a 300*300*5mm dimension.



Fig.3-The mold has a 300*300*5mm dimension.

4.5 SAMPLE PREPARATION

The sample preparation is a process involving mechanical action like cutting by hack saw and contour cutting etc. the size of the various samples is to be cut according to the standard test to be performed. The deviation in the dimension should be avoided to ensure the best result.

The sample preparation of the blend is done under the ASTM standard. The sample preparation included following steps:

- 1. Marking:** The composite is marked with marker to the respective sizes of the sample. All the marking and sample size was done according to ASTM standard.
- 2. Hacksaw Cutting:** The sample was cut to the required dimension with some tolerance on each side to facilitate contour cutting.
- 3. Contour Cutting:** The contour cutting process is preceded by the process of clamping the composite in the die. The die provides the exact dimensions to be clamped and cut without deviations in the size of the specimen.

CHAPTER 5

TESTING METHODS

DESCRIPTION OF TESTS

5.1 TEST SPECIMEN REQUIREMENTS

Conditioning for testing:

The temperature and humidity environment to which a test specimen can significantly influence its properties. Hence, standardized temperature and humidity conditions are usually specified for conditioning of specimens prior to actual testing. The conditioning requirements as ASTM D 618 are as follows:

Temperature 23 ± 2 ° C

Relative humidity 50 ± 5 %

5.2 TESTING AND PERFORMANCE EVALUATION

Like any other engineering materials, the performance of a polymeric blend materials is judge by its properties and behavior under tensile, compressive, shear and other static or dynamic loading conditions in both normal and adverse test conditions.

There are many tests established by standards organizations which ensure satisfactory performance of blends. The largest standard organization is the International Standards Organization (ISO). In addition; there are other organization, viz American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), British Standard Institute (BSI) and others which publish tests on blend materials periodically.

5.3 MECHANICAL TEST METHOS

Procedures for the measurements of mechanical properties of polymeric blend materials as per ASTM methods are briefly described in the following paragraphs:

5.3.1 Tensile test-

Tensile testing, also known as tension testing, is a fundamental [materials science](#) test in which a sample is subjected to a controlled [tension](#) until failure. The results from the test are commonly used to select a material for an application, for [quality control](#), and to predict how a material will react under other types of [forces](#). Properties that are directly measured via a tensile test are [ultimate tensile strength](#), maximum [elongation](#) and reduction in area. From these measurements the following properties can also be determined: [Young's modulus](#), [Poisson's ratio](#), [yield strength](#), and [strain-hardening](#) characteristics. Uniaxial tensile testing is the most commonly used for obtaining

the mechanical characteristics of [isotropic](#) materials. For [anisotropic](#) materials, such as [composite materials](#) and [textiles](#), [biaxial tensile testing](#) is required.^[12]

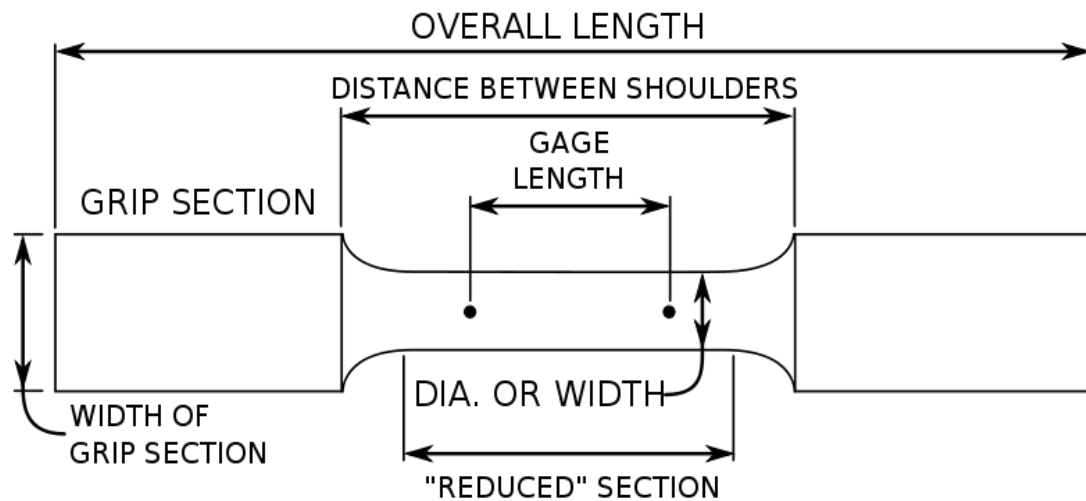


Fig -4

Equipment used:

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types: hydraulic powered and electromagnetically powered machines.

The machine must have the proper capabilities for the test specimen being tested. There are three main parameters: force capacity, speed, and [precision and accuracy](#). Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. Finally, the machine must be able to accurately and precisely measure the gauge length and forces applied; for instance, a large machine that is designed to measure long elongations may not work with a brittle material that experiences short elongations prior to fracturing.

Alignment of the test specimen in the testing machine is critical, because if the specimen is misaligned, either at an angle or offset to one side, the machine will exert a [bending](#) force results on the specimen. This is especially bad for [brittle](#) materials, because it will dramatically skew the results.^[13]



Fig-5

Test process:

The test process involves placing the test specimen in the testing machine and applying tension to it until it [fractures](#). During the application of tension, the [elongation](#) of the gauge section is recorded against the applied force. The data is manipulated so that it is not specific to the geometry of the test sample. The elongation measurement is used to calculate the engineering [strain](#), ϵ , using the following equation:^[4]

$$\epsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

where ΔL is the change in gauge length, L_0 is the initial gauge length, and L is the final length. The force measurement is used to calculate the engineering stress, σ , using the following equation:^[4]

$$\sigma = \frac{F_n}{A}$$

where F is the force and A is the cross-section of the gauge section. The machine does these calculations as the force increases, so that the data points can be graphed into a [stress-strain curve](#).

5.3.2 Flexural test-

The three-point bending flexural test provides values for the modulus of elasticity in bending E_f , flexural stress σ_f , flexural strain ϵ_f and the flexural stress-strain response of the material. The main advantage of a three point flexural test is the ease of the specimen preparation and testing. However, this method has also some disadvantages: the results of the testing method are sensitive to specimen and loading geometry and strain rate.



Fig-6

Testing method:

Calculation of the flexural stress σ_f

$$\sigma_f = \frac{3PL}{2bd^2} \text{ for a rectangular cross section}$$

$$\sigma_f = \frac{PL}{\pi R^3} \text{ for a circular cross section}$$

Calculation of the flexural strain ϵ_f

$$\epsilon_f = \frac{6Dd}{L^2}$$

Calculation of flexural modulus E_f

$$E_f = \frac{L^3m}{4bd^3}$$

In the above formulas the following parameters are used:

- σ_f = Stress in outer fibers at midpoint, (MPa)
- ϵ_f = Strain in the outer surface, (mm/mm)
- E_f = flexural Modulus of elasticity,(MPa)
- P = load at a given point on the load deflection curve, (N)
- L = Support span, (mm)
- b = Width of test beam, (mm)
- d = Depth of tested beam, (mm)
- D = maximum deflection of the center of the beam, (mm)
- m = The gradient (i.e., slope) of the initial straight-line portion of the load deflectioncurve,(P/D), (N/mm)
- R = The radius of the beam, (mm)

5.4 THERMAL CHARACTERIZATION

- **5.4.1) SEM analysis**
- A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The

electrons interact with electrons in the sample, producing various signals that can be detected and that contain information about the sample's surface [topography](#) and composition. The electron beam is generally scanned in a [raster scan](#) pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, low vacuum and in environmental SEM specimens can be observed in wet conditions.^[15]

- In the SEM, specimens must be [electrically conductive](#), at least at the surface, and [electrically grounded](#) to prevent the accumulation of [electrostatic charge](#) at the surface. Metal objects require little special preparation for SEM except for cleaning and mounting on a specimen stub. Nonconductive specimens tend to charge when scanned by the electron beam, and especially in secondary electron imaging mode, this causes scanning faults and other image artifacts. They are therefore usually coated with an ultrathin coating of electrically conducting material, deposited on the sample either by low-vacuum [sputter coating](#) or by high-vacuum evaporation. Conductive materials in current use for specimen coating include [gold](#)/[palladium](#) alloy, [platinum](#), [osmium](#), [iridium](#), [tungsten](#), [chromium](#), and [graphite](#).
- **Test process:**
- In a typical SEM, an electron beam is [thermionically](#) emitted from an [electron gun](#) fitted with a [tungsten](#) filament [cathode](#). Tungsten is normally used in thermionic electron guns because it has the highest melting point and lowest vapour pressure of all metals, thereby allowing it to be heated for electron emission, and because of its low cost.
- The electron beam, which typically has an [energy](#) ranging from 0.2 [keV](#) to 40 keV, is focused by one or two condenser lenses to a spot about 0.4 nm to 5 nm in diameter. The beam passes through pairs of scanning coils or pairs of deflector plates in the electron column, typically in the final lens, which deflect the beam in the x and y axes so that it scans in a [raster](#) fashion over a rectangular area of the sample surface.

- When the primary electron beam interacts with the sample, the electrons lose energy by repeated random scattering and absorption within a teardrop-shaped volume of the specimen known as the interaction volume, which extends from less than 100 nm to around 5 μm into the surface. The size of the interaction volume depends on the electron's landing energy, the atomic number of the specimen and the specimen's density. The energy exchange between the electron beam and the sample results in the reflection of high-energy electrons by [elastic scattering](#), emission of secondary electrons by [inelastic scattering](#) and the emission of [electromagnetic radiation](#), each of which can be detected by specialized detectors. The beam current absorbed by the specimen can also be detected and used to create images of the distribution of specimen current. [Electronic amplifiers](#) of various types are used to amplify the signals, which are displayed as variations in brightness on a computer monitor (or, for vintage models, on a [cathode ray tube](#)). Each pixel of computer videomemory is synchronized with the position of the beam on the specimen in the microscope, and the resulting image is therefore a distribution map of the intensity of the signal being emitted from the scanned area of the specimen. In older microscopes image may be captured by [photography](#) from a high-resolution cathode ray tube, but in modern machines image is saved to a [computer data storage](#).^{[16][17]}

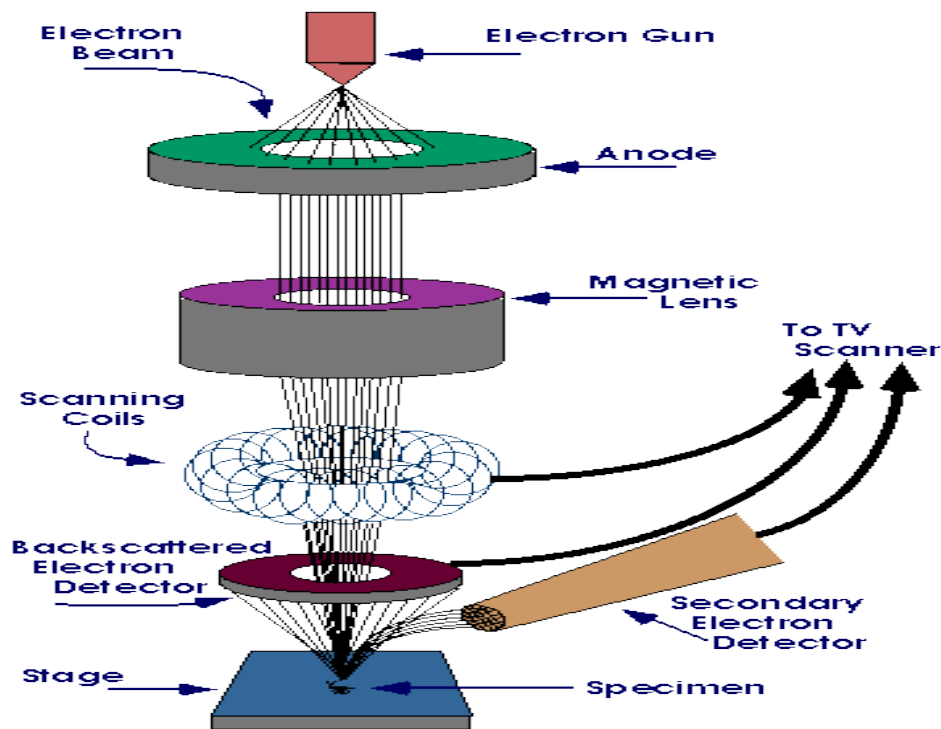
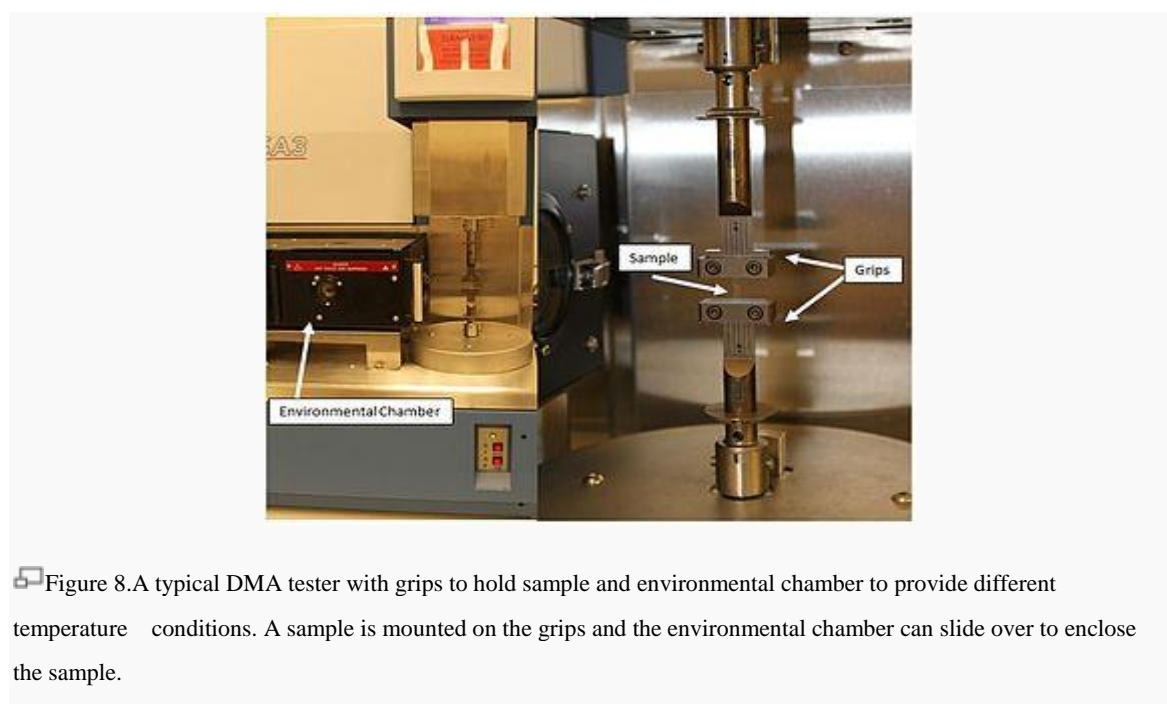


Fig-7

- **5.4.2) DYNAMIC MECHANICAL ANALYSIS-** Dynamic mechanical analysis (abbreviated DMA, also known as dynamic mechanical spectroscopy) is a technique used to study and characterize materials. It is most useful for studying the viscoelastic behavior of polymers. A sinusoidal stress is applied and the strain in the material is measured, allowing one to determine the complex modulus. The temperature of the sample or the frequency of the stress are often varied, leading to variations in the complex modulus; this approach can be used to locate the glass transition temperature of the material, as well as to identify transitions corresponding to other molecular motions.

Theory-

Viscoelastic properties of materials-



Polymers composed of long molecular chains have unique viscoelastic properties, which combine the characteristics of elastic and Newtonian fluids. The classical theory of elasticity describes the mechanical properties of elastic solid where stress is proportional to strain in small deformations. Such response of stress is independent of strain rate. The classical theory of hydrodynamics describes the properties of viscous fluid, for which the response of stress is dependent on strain rate.^[1] This solid like and liquid like behavior of polymer can be modeled mechanically with combinations of springs and dashpots.^[2]

Dynamic moduli of polymers-

The viscoelastic property of a polymer is studied by dynamic mechanical analysis where a sinusoidal force (stress σ) is applied to a material and the resulting displacement (strain) is measured. For a perfectly elastic solid, the resulting strain and the stress will be perfectly in phase. For a purely viscous fluid, there will be a 90 degree phase lag of strain with respect to stress.^[3] Viscoelastic polymers have the characteristics in between where some phase lag will occur during DMA tests.^[3]

- Stress: $\sigma = \sigma_0 \sin(t\omega + \delta)$ ^[3]
- Strain: $\varepsilon = \varepsilon_0 \sin(t\omega)$

where

ω is frequency of strain oscillation,

t is time,

δ is phase lag between stress and strain.

The storage modulus measures the stored energy, representing the elastic portion, and the loss modulus measures the energy dissipated as heat, representing the viscous portion.^[3] The tensile storage and loss moduli are defined as follows:

- Storage Modulus:
$$E' = \frac{\sigma_0}{\varepsilon_0} \cos \delta$$

- Loss Modulus:
$$E'' = \frac{\sigma_0}{\varepsilon_0} \sin \delta$$

- Phase Angle:
$$\delta = \arctan \frac{E''}{E'}$$

Similarly we also define shear storage and loss moduli, G' and G'' .

Complex variables can be used to express the moduli E^* and G^* as follows:

$$E^* = E' + iE''$$
$$G^* = G' + iG''$$

$$\text{Where } i^2 = -1$$

CHAPTER 6

RESULTS AND DISCUSSION

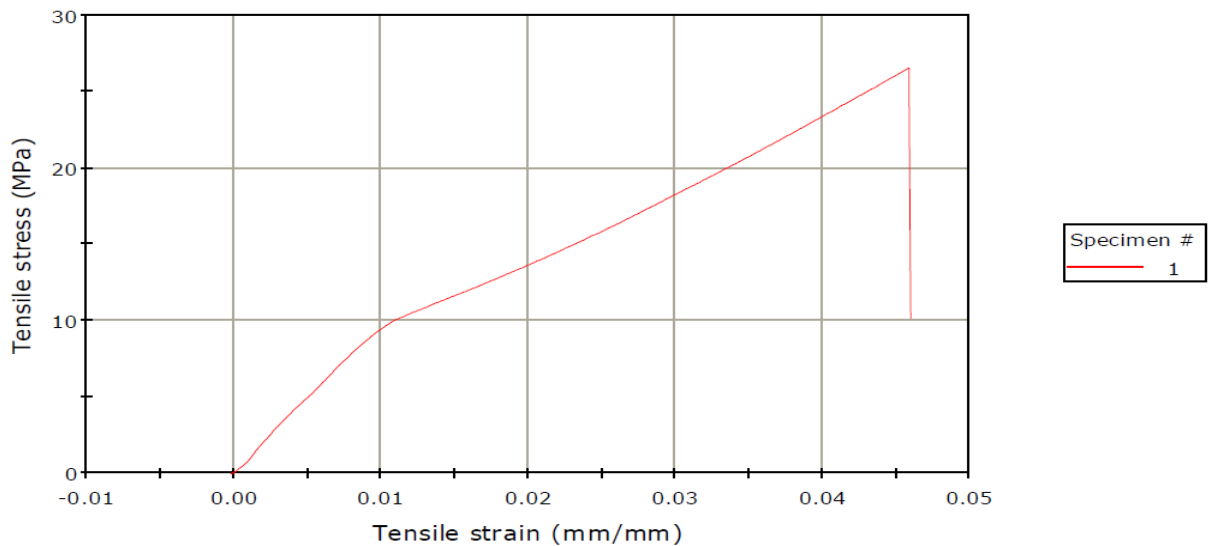
RESULTS AND DISCUSSION

6.1 MECHANICAL ANALYSIS OF BLEND

6.1.1 Tensile Test Result

1. Sample-A

Specimen 1 to 1



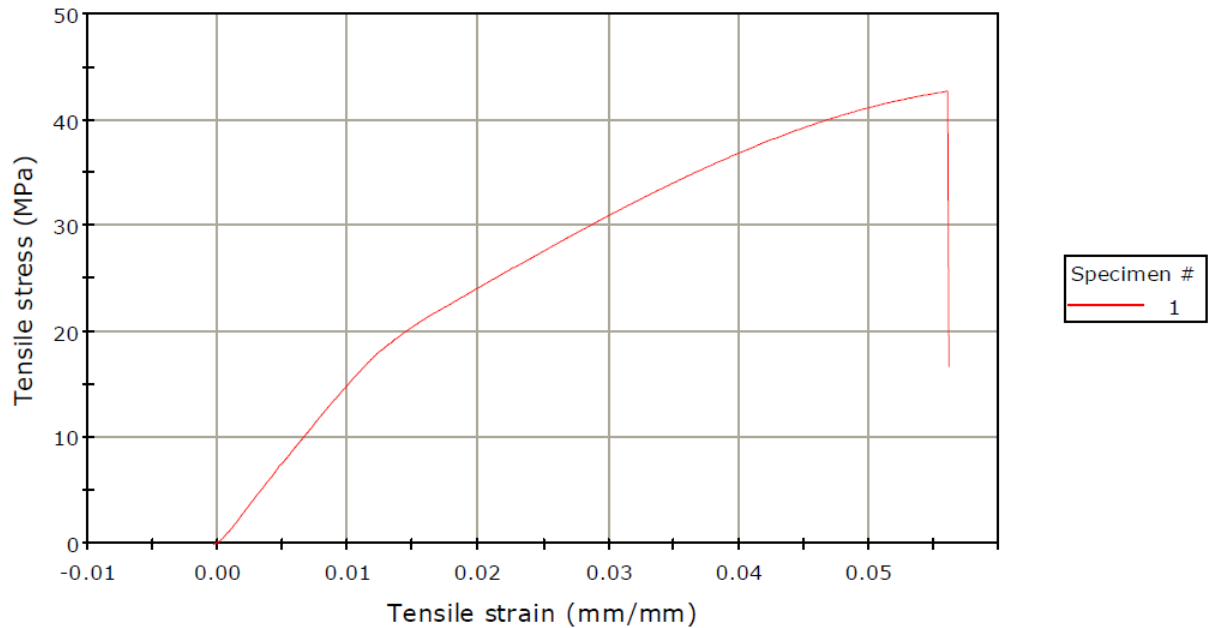
Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.25331	3.16593	10.14231	69.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	5.00000	17.00000	2253.31299	85.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	26.50957	0.04588	3.17494	0.04588
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.18287	862.09616	981.80831	3.17494
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	981.80831	0.03600		

FIG.9 – Graph representing Load vs extension in Tensile test

2. Sample- B

Specimen 1 to 1



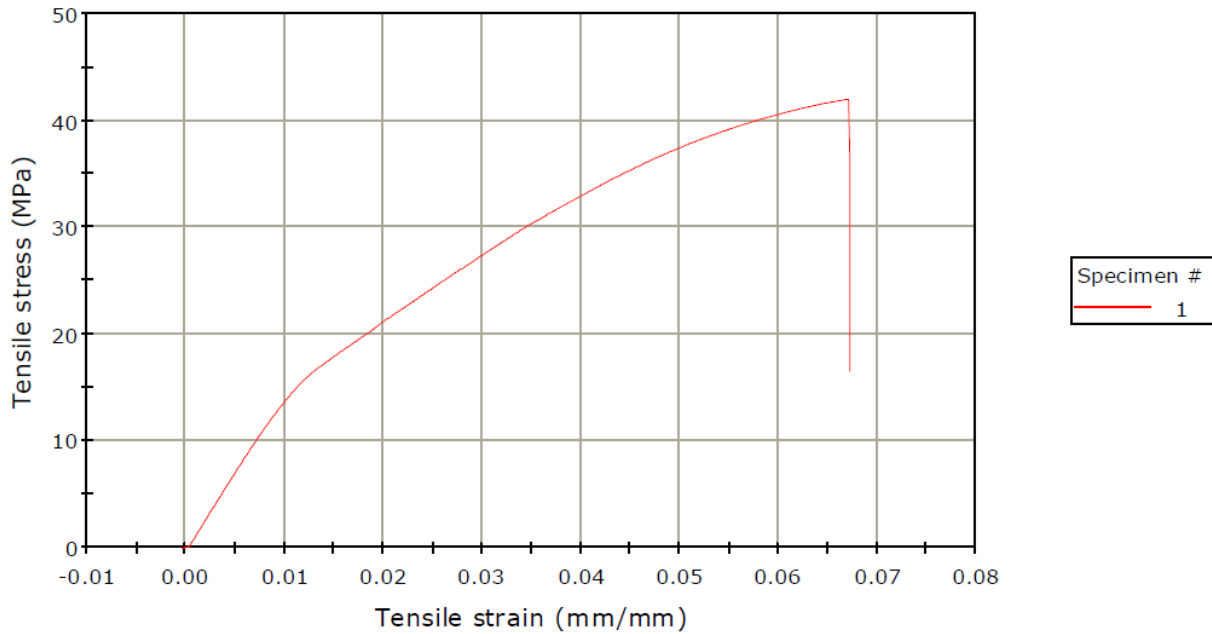
Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.55950	3.97864	16.74642	71.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.00000	15.00000	2559.49590	60.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	42.65826	0.05604	3.99994	0.05604
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	4.00700	1004.78502	1517.90228	3.99994
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	1517.90228	0.03600		

FIG.10 – Graph representing Load vs extension in Tensile test

3. Sample -C

Specimen 1 to 1



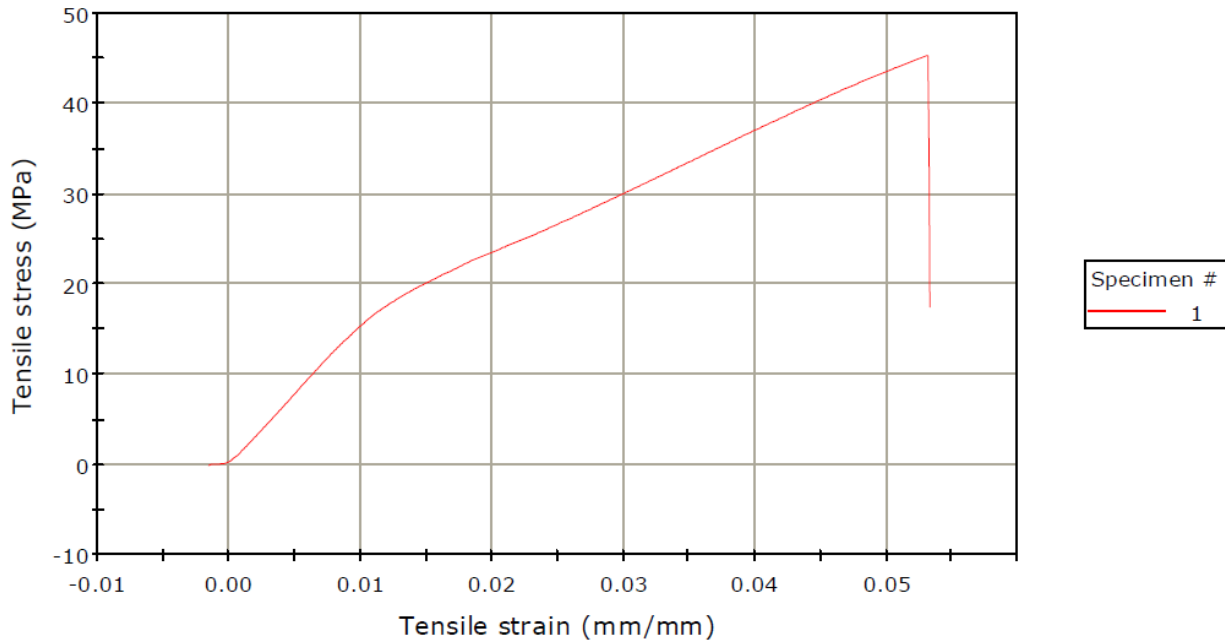
Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.68439	4.89812	16.51700	73.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.00000	16.00000	2684.38663	64.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	41.94354	0.06710	4.92531	0.06721
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	4.92756	1057.08828	1359.66132	4.91675
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	1359.66132	0.03600		

FIG.11 – Graph representing Load vs extension in Tensile test

4. Sample- D

Specimen 1 to 1



Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.89828	3.72032	17.48048	70.00000

	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.00000	16.00000	2898.27604	64.00000

	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	45.28556	0.05315	3.83394	0.05328

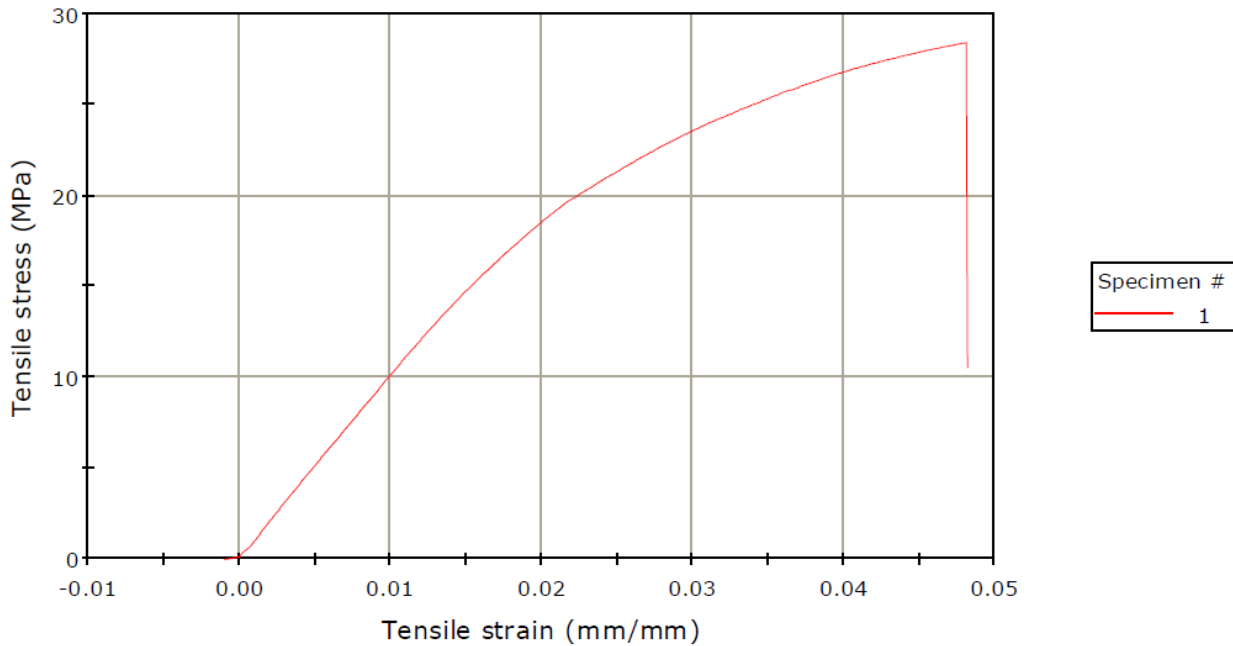
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.83537	1118.75068	1567.42073	3.82494

	Modulus (Automatic) (MPa)	Final area (cm ²)
1	1567.42073	0.03600

FIG.12 – Graph representing Load vs extension in Tensile test

5. Sample -E

Specimen 1 to 1



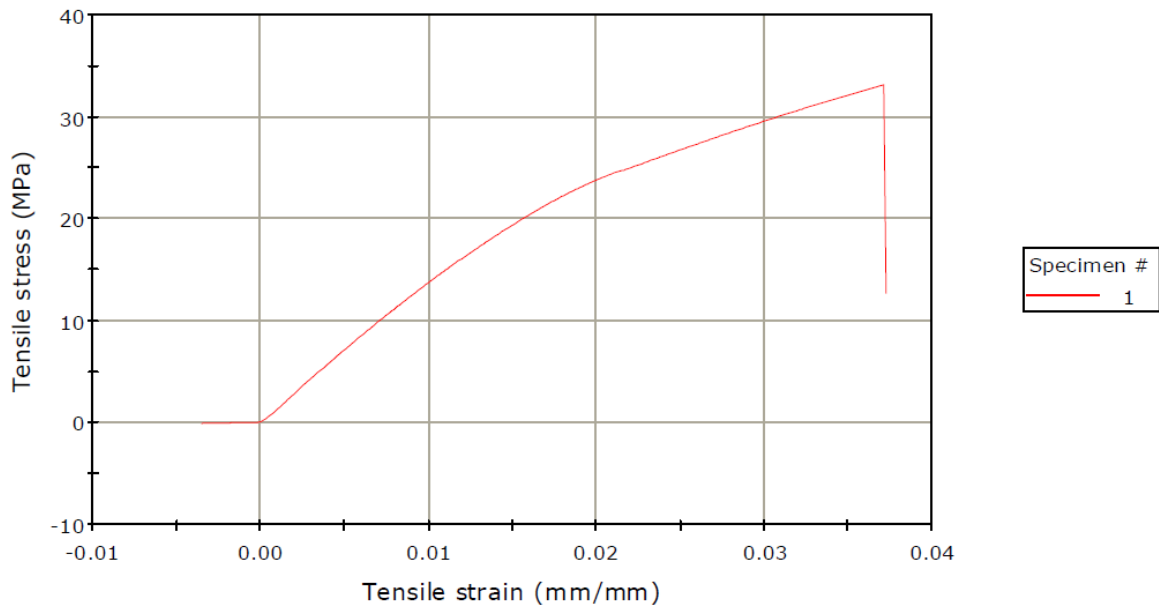
Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.41251	3.32172	10.52698	69.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	5.00000	17.00000	2412.50880	85.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	28.38246	0.04814	3.38350	0.04814
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.38837	894.79294	1012.49206	3.38350
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	1012.49206	0.03600		

FIG.13 – Graph representing Load vs extension in Tensile test

6. Sample-F

Specimen 1 to 1



Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	1.98573	2.59719	12.73042	70.00000

	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.00000	15.00000	1985.72781	60.00000

	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	33.09546	0.03710	2.84162	0.03710

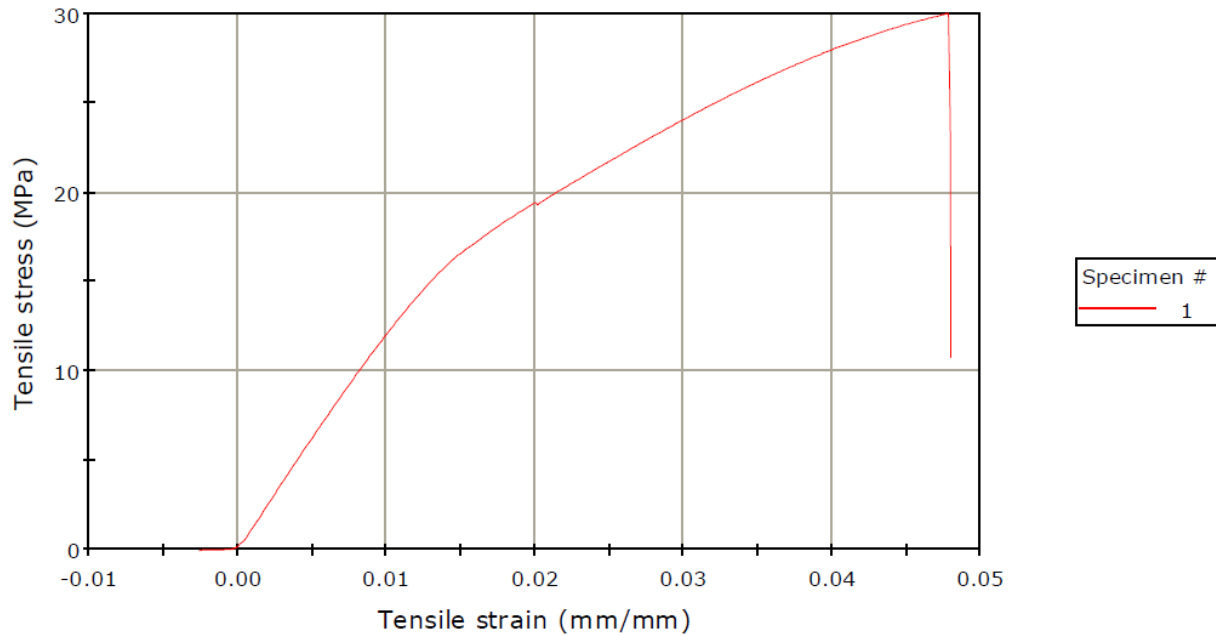
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	2.85037	763.82491	1432.92732	2.84162

	Modulus (Automatic) (MPa)	Final area (cm ²)
1	1432.92732	0.03600

FIG.14 – Graph representing Load vs extension in Tensile test

7. Sample-G

Specimen 1 to 1



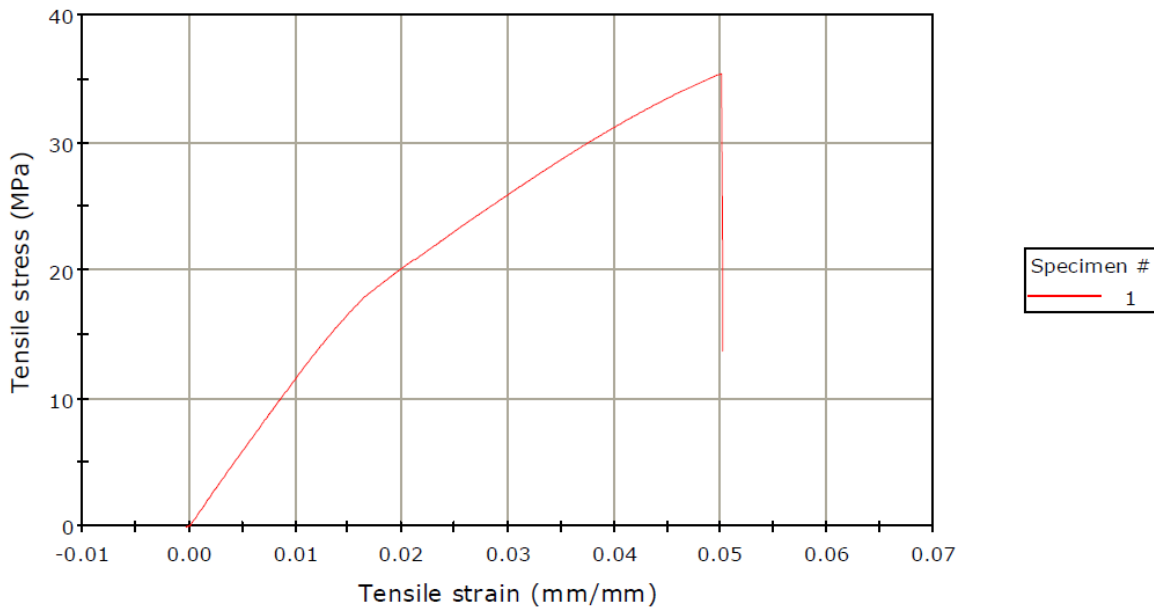
Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.24795	3.34891	10.76058	70.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	5.00000	15.00000	2247.95472	75.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	29.97273	0.04784	3.53375	0.04797
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.53562	807.04363	1228.32761	3.52506
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	1228.32761	0.03600		

FIG.15 – Graph representing Load vs extension in Tensile test

8. Sample-H

Specimen 1 to 1



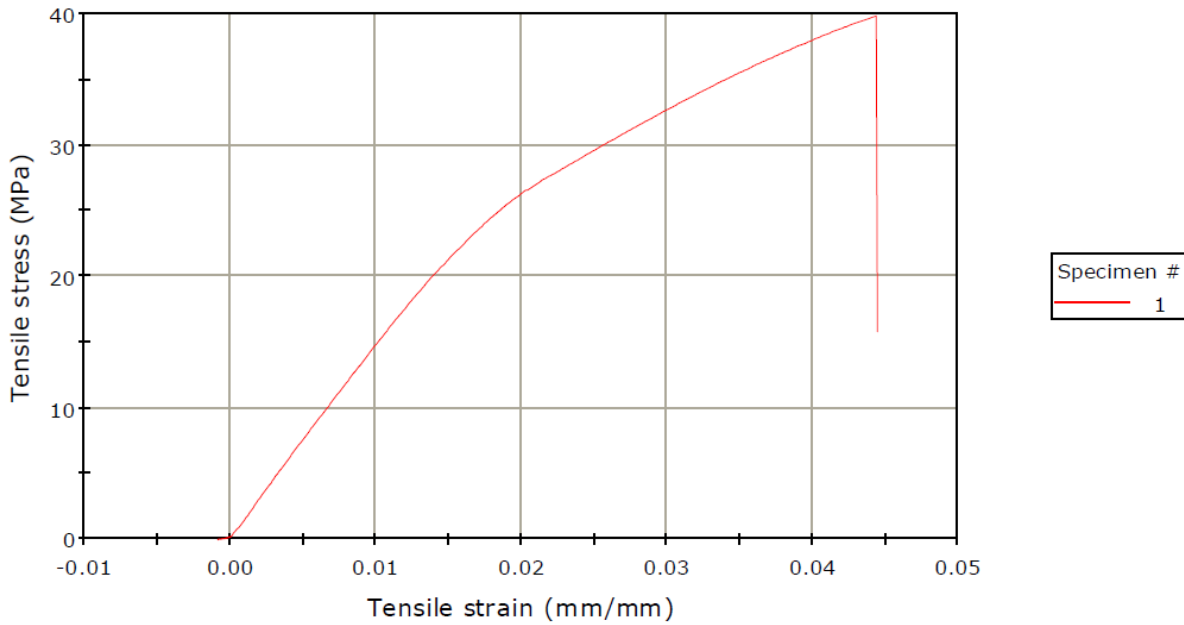
Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.83053	3.45440	13.72705	69.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	5.00000	16.00000	2830.52735	80.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	35.38159	0.05006	3.47575	0.05019
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.47675	1098.16398	1158.18823	3.46687
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	1158.18823	0.03600		

FIG.16– Graph representing Load vs extension in Tensile test

9. Sample-I

Specimen 1 to 1



Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.68553	3.06360	15.79894	69.00000

	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.50000	15.00000	2685.52843	67.50000

	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	39.78561	0.04440	3.11662	0.04440

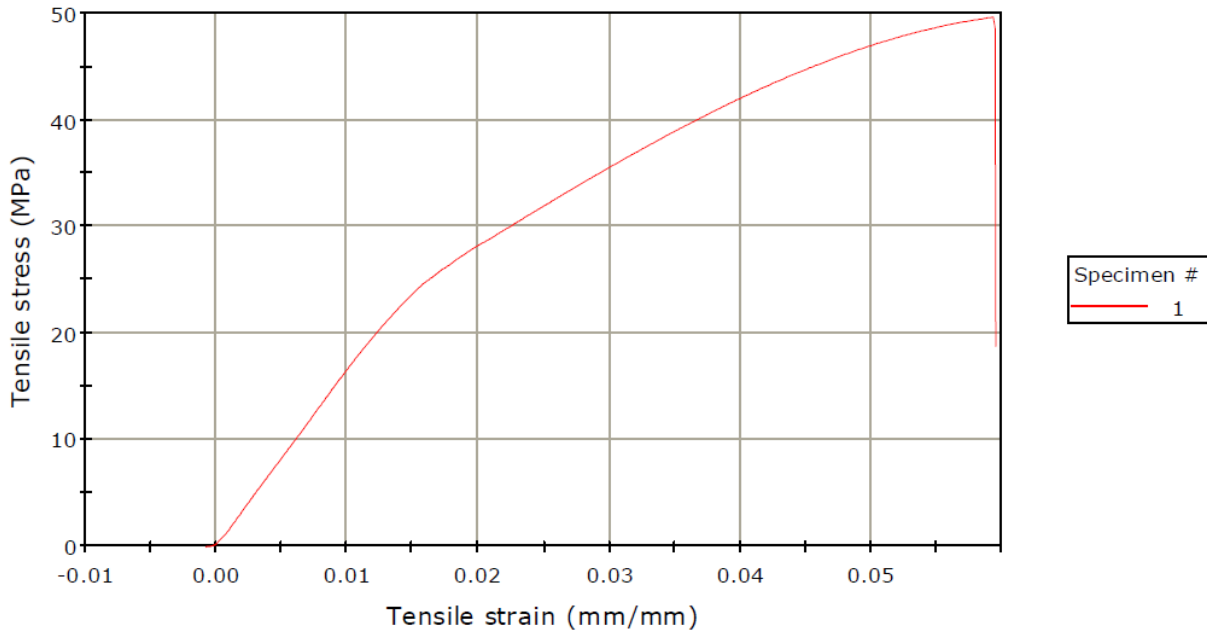
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.12100	1066.42861	1491.09514	3.11662

	Modulus (Automatic) (MPa)	Final area (cm ²)
1	1491.09514	0.03600

FIG.17 – Graph representing Load vs extension in Tensile test

10. Sample- J

Specimen 1 to 1



Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	3.17004	4.15477	18.76505	70.00000

	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.00000	16.00000	3170.04435	64.00000

	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	49.53194	0.05935	4.21669	0.05947

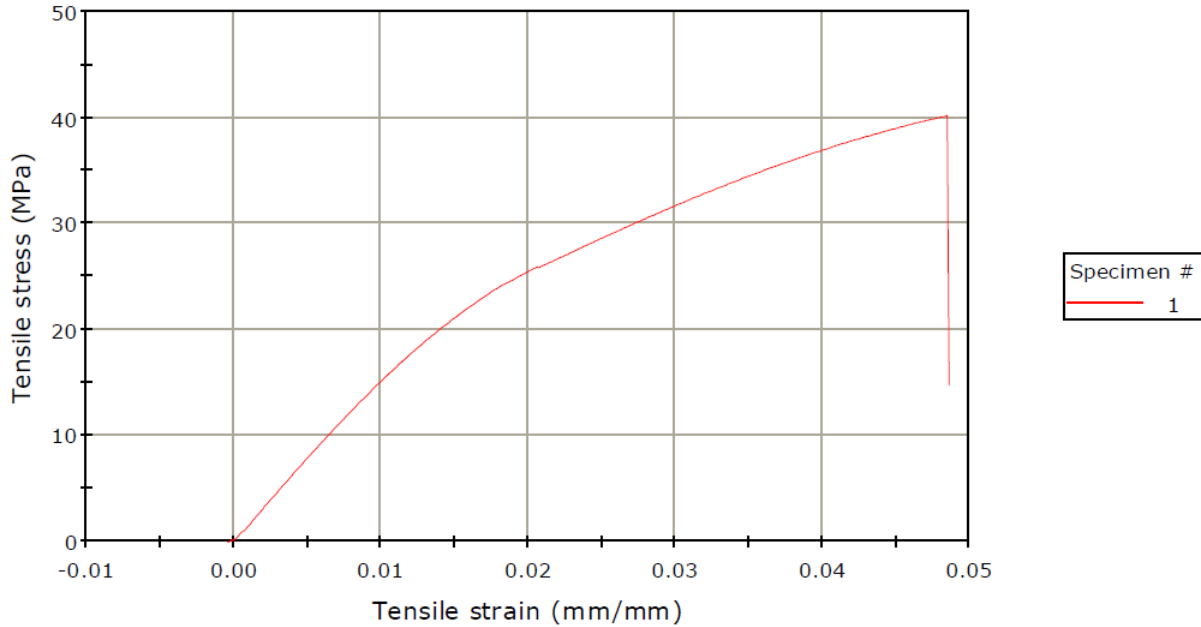
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	4.21987	1200.96356	1655.02495	4.20844

	Modulus (Automatic) (MPa)	Final area (cm ²)
1	1655.02495	0.03600

FIG.18 – Graph representing Load vs extension in Tensile test

11. Sample -K

Specimen 1 to 1



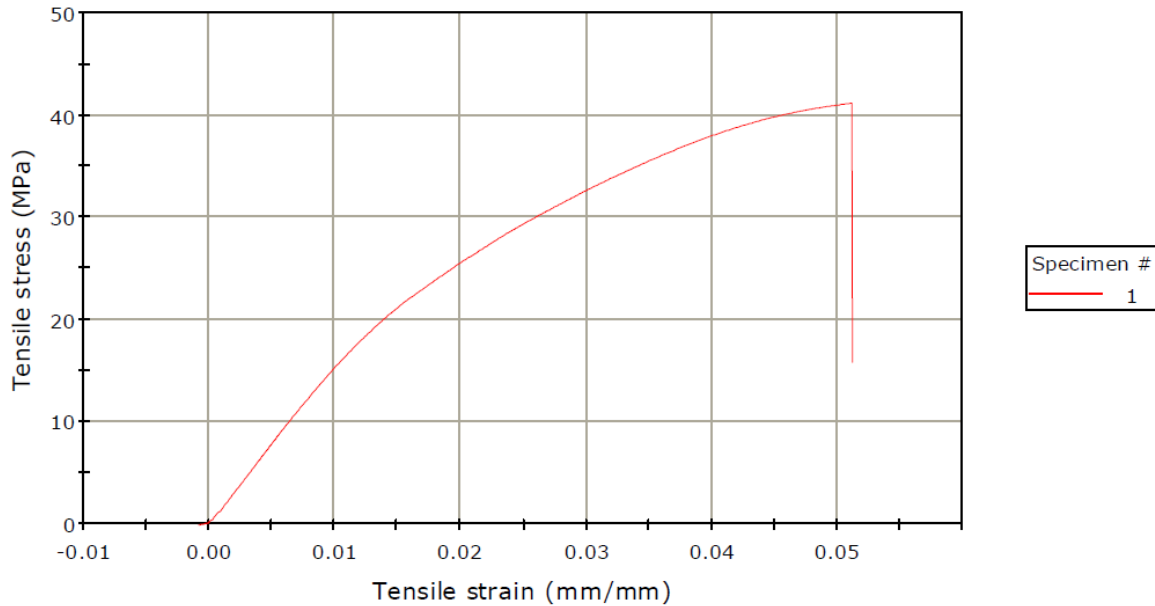
Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.24645	3.39496	14.76990	70.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.00000	14.00000	2246.45473	56.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	40.11526	0.04850	3.41681	0.04850
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.42450	827.11456	1541.11775	3.41681
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	1541.11775	0.03600		

FIG.19 – Graph representing Load vs extension in Tensile test

12. Sample -L

Specimen 1 to 1



Results Table 1

	Maximum Load (kN)	Tensile extension at Maximum Load (mm)	Tensile stress at Maximum Load (MPa)	Length (mm)
1	2.54840	3.47893	15.81762	68.00000
	Thickness (mm)	Width (mm)	Load at Tensile Strength (N)	Area (mm ²)
1	4.00000	15.50000	2548.39733	62.00000
	Tensile stress at Tensile Strength (MPa)	Tensile strain at Tensile Strength (mm/mm)	Extension at Break (Standard) (mm)	Tensile strain at Break (Standard) (mm/mm)
1	41.10318	0.05116	3.53350	0.05116
	Maximum Extension (mm)	Load at Maximum Extension (N)	Modulus (Automatic) (MPa)	Extension at Tensile Strength (mm)
1	3.53856	980.69254	1560.12084	3.53350
	Modulus (Automatic) (MPa)	Final area (cm ²)		
1	1560.12084	0.03600		

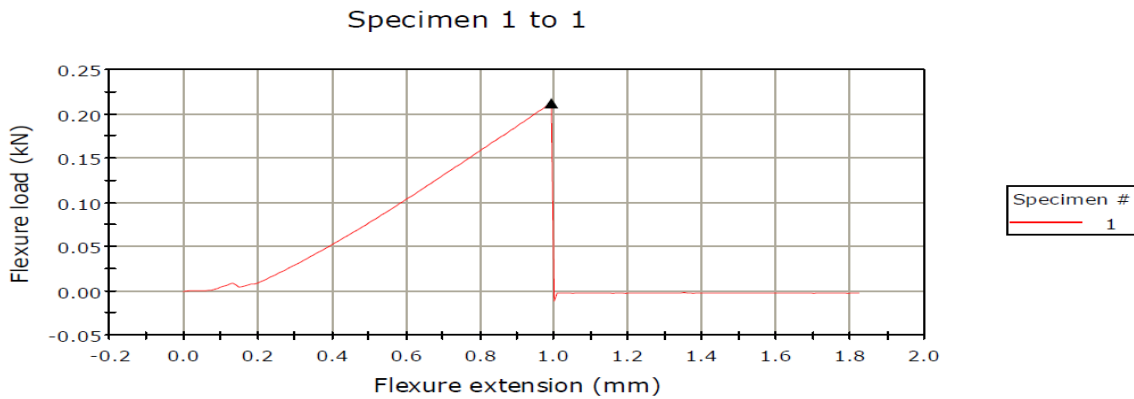
FIG.20 – Graph representing Load vs extension in Tensile test

Tensile Test Analysis-

The tensile strength of the polyvinyl acetate epoxy blend sample was found good and was found increased. Test results are presented in the form of graph between tensile load and extension, which shows that most of the response is linear, followed by brief nonlinearity before fracture. Tensile strength value as functions of loading direction was derived respectively from the gradient of the linear portion and the maximum stress before failure. The relationship between tensile load and extension for the reinforced epoxy composite is as shown and is compared with the un-reinforced normal epoxy sample. The tensile strength of **Sample J** is **49.54194 MPais** more than the un-reinforced epoxy sample.

6.1.2 FLEXURAL TEST RESULTS

1.Sample-A



	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.21227	-0.21227	132.66826	-0.99175
Maximum	0.21227	-0.21227	132.66826	-0.99175

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	0.99175	1.82181	0.91091	21.86200
Maximum	0.99175	1.82181	0.91091	21.86200

Fig -21

2. Sample-B

Specimen 1 to 1

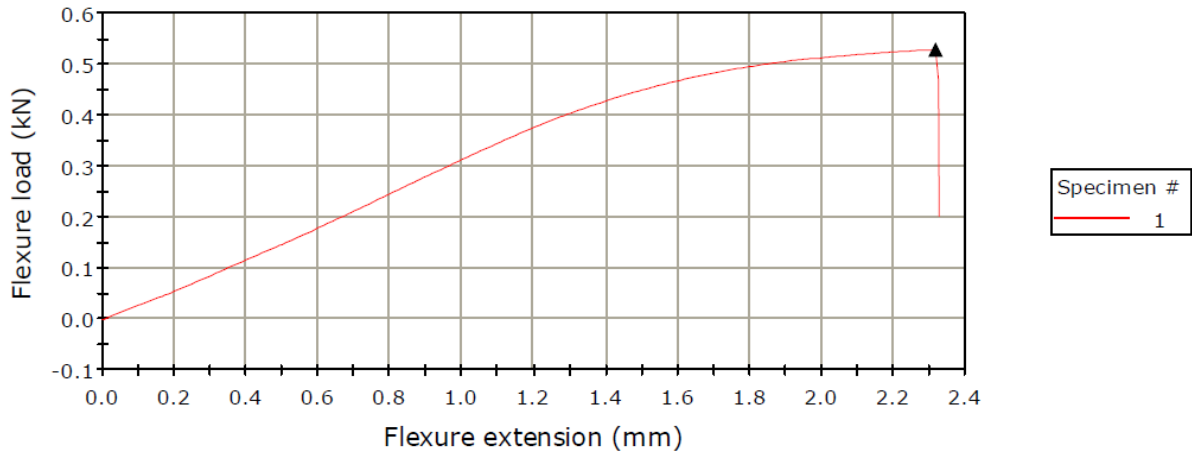


FIG.22 – Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.52866	-0.52866	212.40898	-2.31663
Maximum	0.52866	-0.52866	212.40898	-2.31663

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	2.31663	2.32675	1.55117	27.91800
Maximum	2.31663	2.32675	1.55117	27.91800

Fig -22

3. Sample-C

Specimen 1 to 1

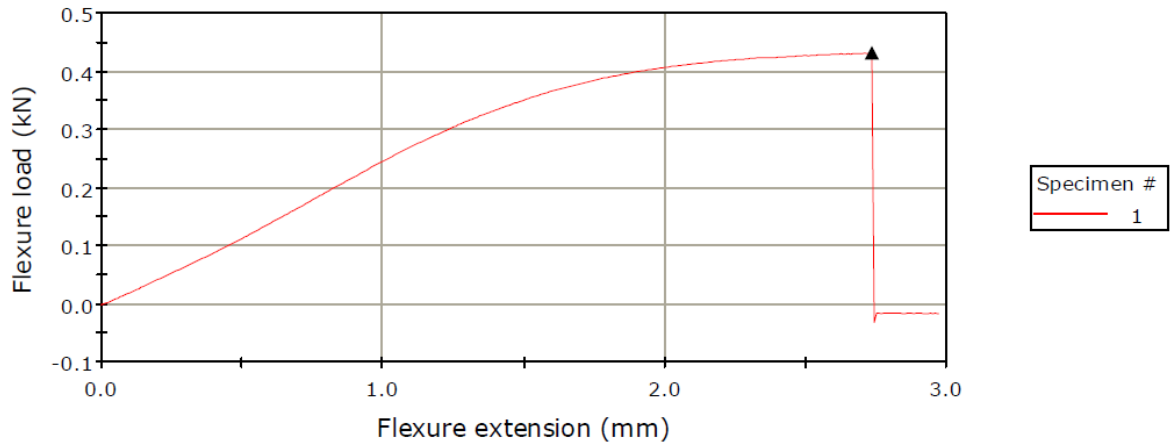


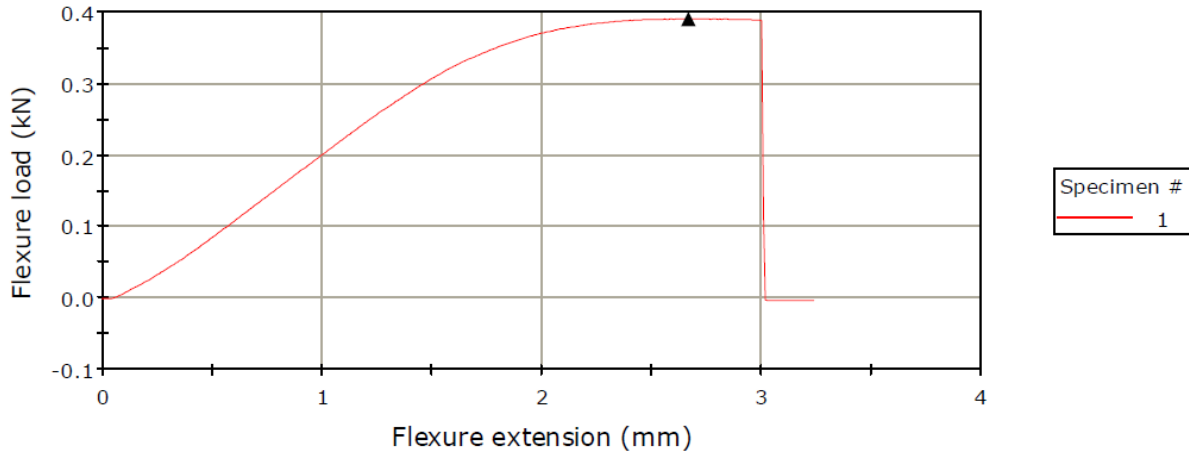
FIG.23 – Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.43205	-0.43205	162.02034	-2.73325
Maximum	0.43205	-0.43205	162.02034	-2.73325

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	2.73325	2.96994	1.97996	35.64000
Maximum	2.73325	2.96994	1.97996	35.64000

4. Sample-D

Specimen 1 to 1



	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.39079	-0.39079	191.40552	-2.66663
Maximum	0.39079	-0.39079	191.40552	-2.66663

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	2.66663	3.23763	1.88861	38.85200
Maximum	2.66663	3.23763	1.88861	38.85200

FIG.24– Graph representing Load vs extension in Tensile test

5. Sample-E

Specimen 1 to 1

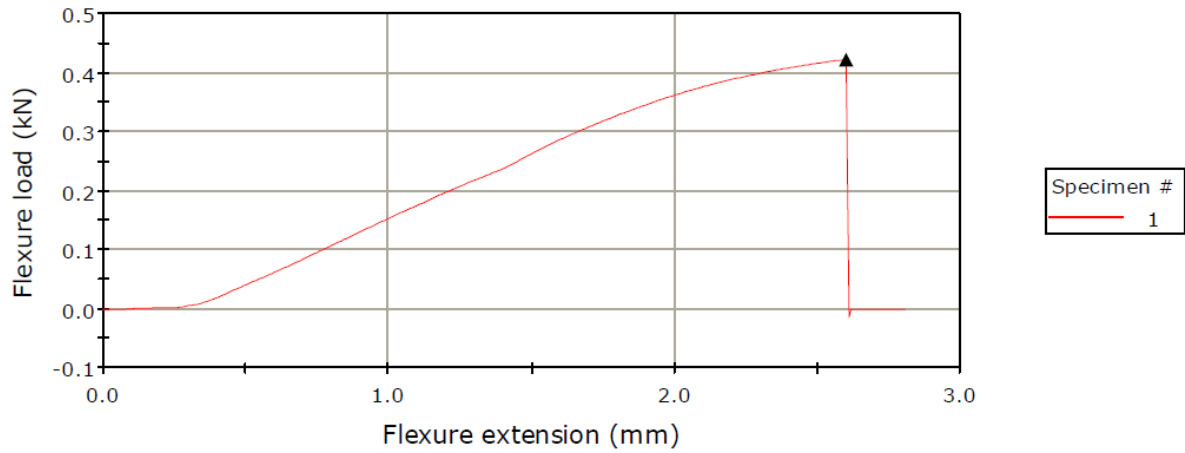


FIG.25 – Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.42237	-0.42237	153.27791	-2.60000
Maximum	0.42237	-0.42237	153.27791	-2.60000

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	2.60000	2.80525	1.87017	33.66400
Maximum	2.60000	2.80525	1.87017	33.66400

6. Sample-F

Specimen 1 to 1

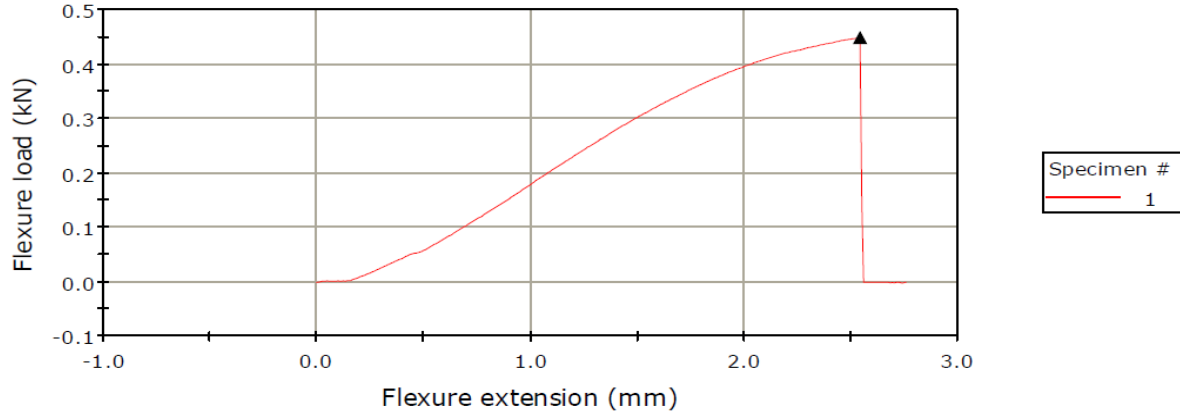


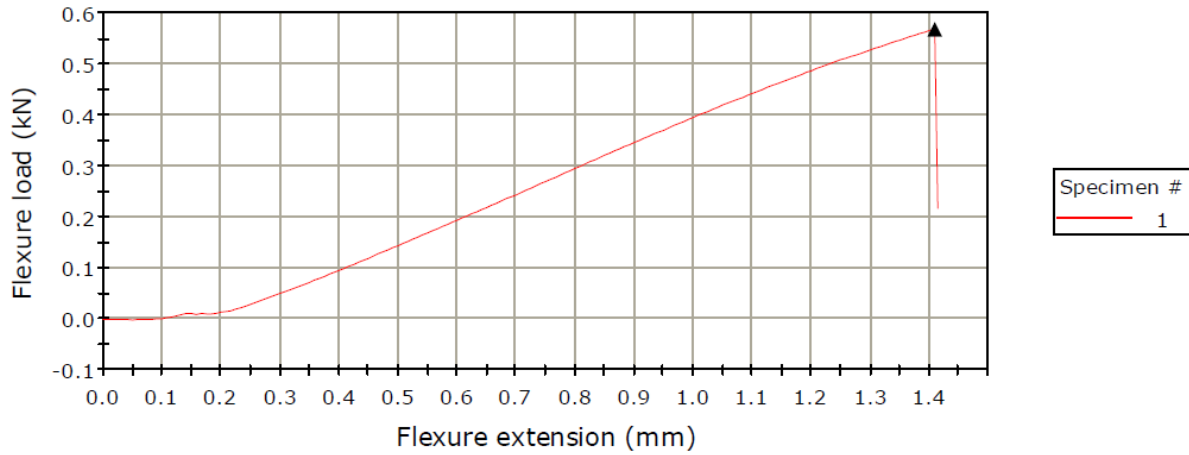
FIG.26 – Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.44929	-0.44929	168.48450	-2.54163
Maximum	0.44929	-0.44929	168.48450	-2.54163

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	2.54163	2.75513	1.83675	33.06200
Maximum	2.54163	2.75513	1.83675	33.06200

7. Sample-G

Specimen 1 to 1



	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.56833	-0.56833	154.36884	-1.40825
Maximum	0.56833	-0.56833	154.36884	-1.40825

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	1.40825	1.41369	1.10739	16.96200
Maximum	1.40825	1.41369	1.10739	16.96200

FIG.27 – Graph representing Load vs extension in Tensile test

8.Sample-H

Specimen 1 to 1

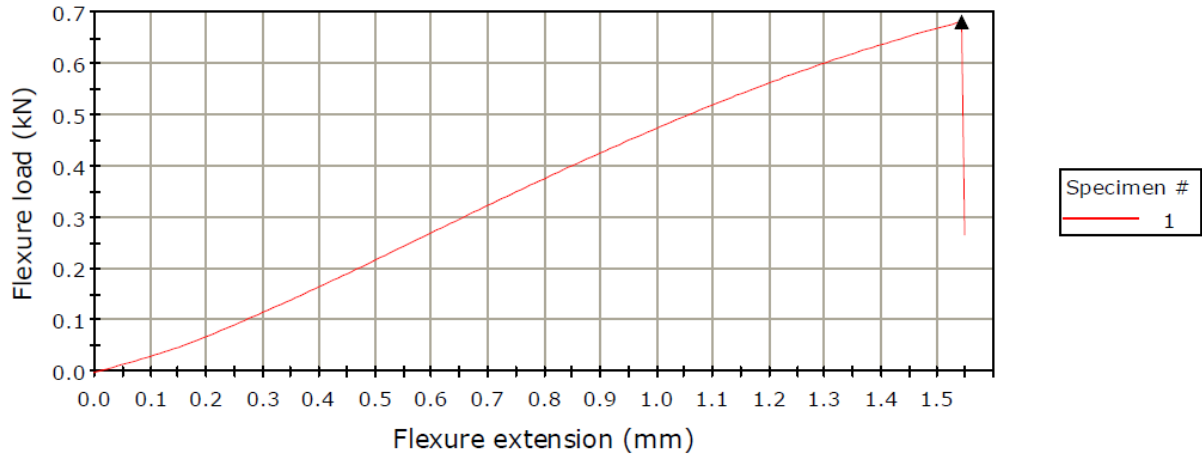


FIG.28– Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.68169	-0.68169	630.93579	-1.54181
Maximum	0.68169	-0.68169	630.93579	-1.54181

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	1.54181	1.54650	0.81191	18.55600
Maximum	1.54181	1.54650	0.81191	18.55600

9.Sample-I

Specimen 1 to 1

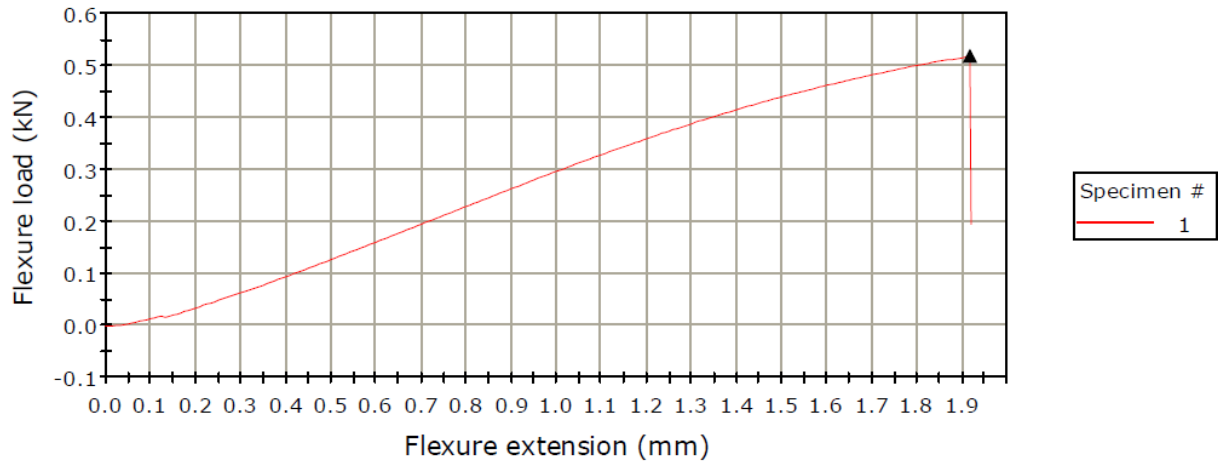


FIG.29 – Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.51824	-0.51824	188.06979	-1.91669
Maximum	0.51824	-0.51824	188.06979	-1.91669

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	1.91669	1.91963	1.27975	23.03400
Maximum	1.91669	1.91963	1.27975	23.03400

10.Sample- J

Specimen 1 to 1

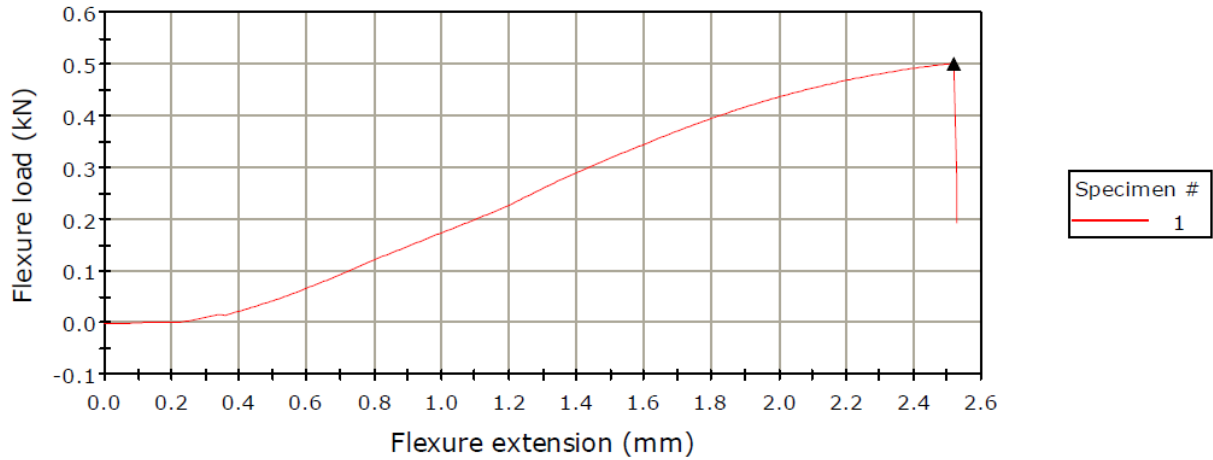


FIG.30– Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.50122	-0.50122	194.43999	-2.51650
Maximum	0.50122	-0.50122	194.43999	-2.51650

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	2.51650	2.52569	1.68379	30.30600
Maximum	2.51650	2.52569	1.68379	30.30600

11. Sample-K

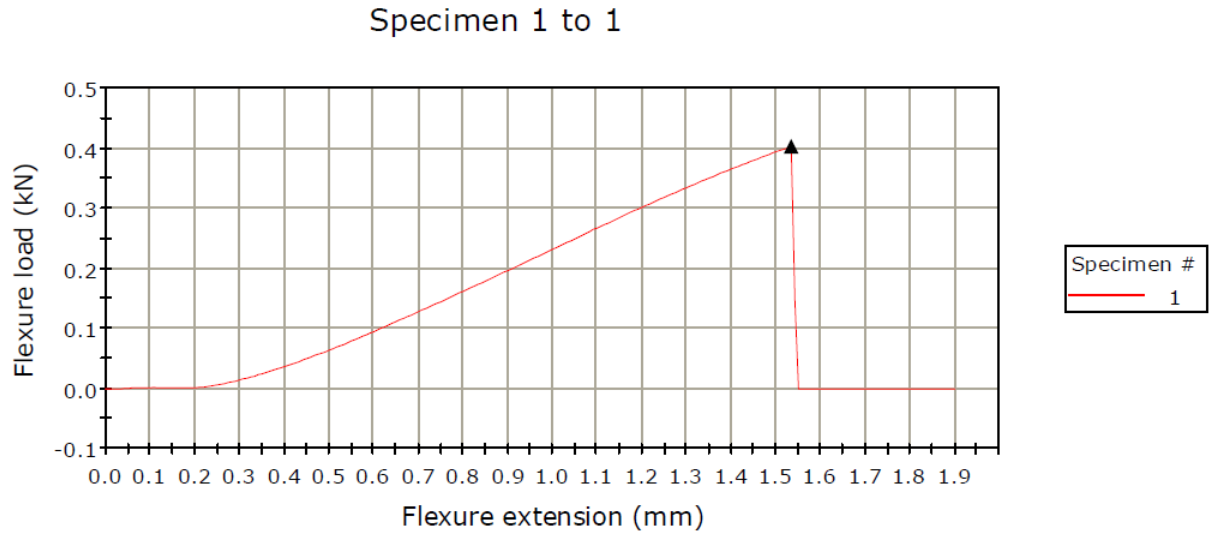


FIG.31 – Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.40263	-0.40263	138.79924	-1.53338
Maximum	0.40263	-0.40263	138.79924	-1.53338

	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	1.53338	1.90006	1.33004	22.80000
Maximum	1.53338	1.90006	1.33004	22.80000

12.Sample-L

Specimen 1 to 1

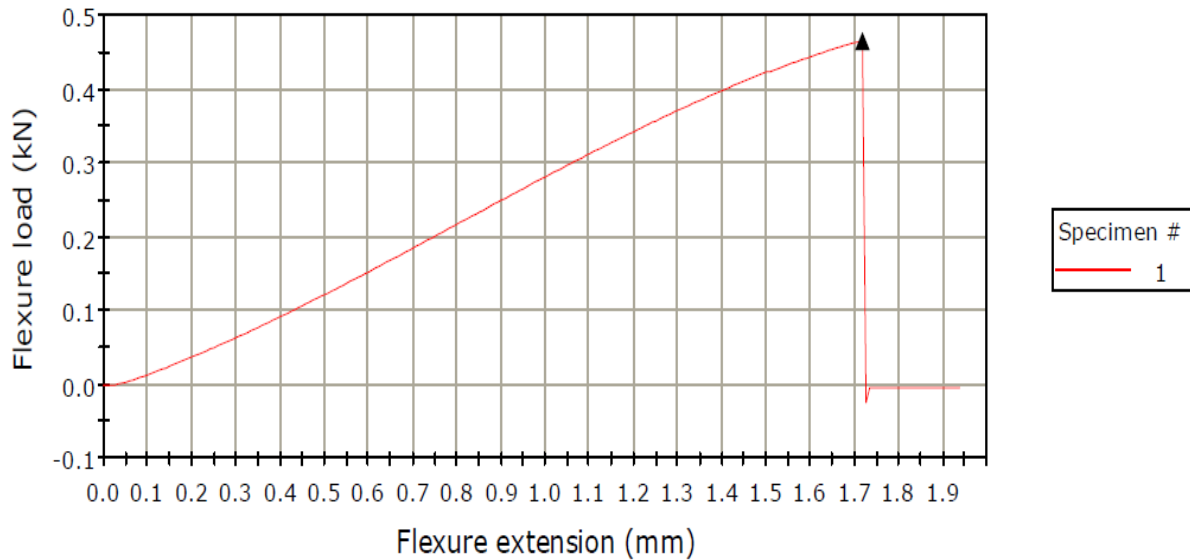


FIG.32 – Graph representing Load vs extension in Tensile test

	Maximum Flexure load (kN)	Load at Maximum Flexure load (kN)	Flexure stress at Maximum Flexure load (MPa)	Extension at Maximum Flexure load (mm)
1	0.46589	-0.46589	150.44357	-1.71675
Maximum	0.46589	-0.46589	150.44357	-1.71675

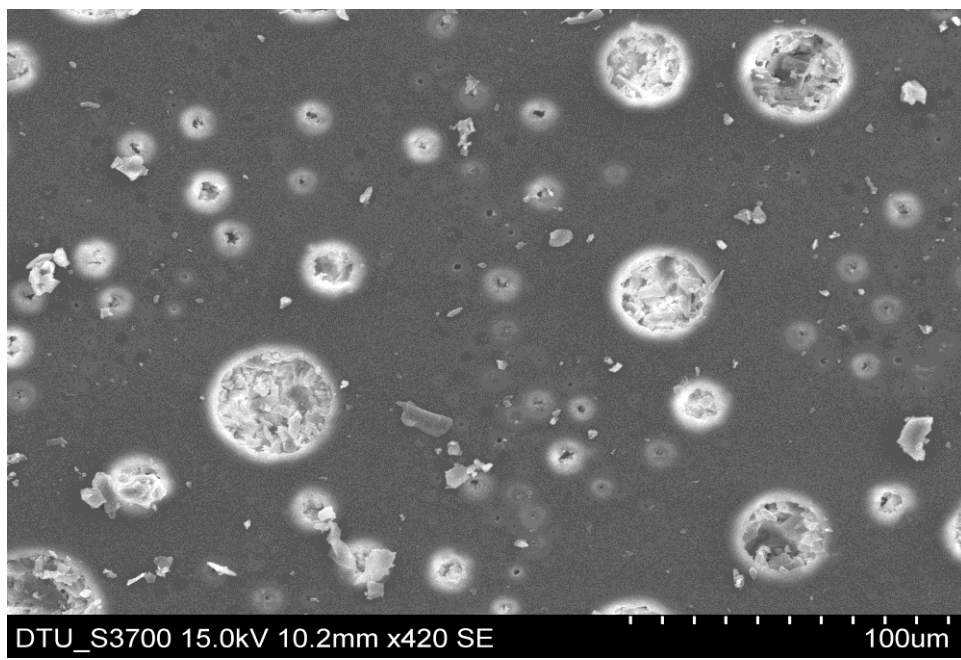
	Flexure extension at Maximum Flexure load (mm)	Maximum Flexure extension (mm)	Flexure strain at Maximum Flexure extension (%)	Time at Maximum Flexure extension (sec)
1	1.71675	1.93663	1.35564	23.24000
Maximum	1.71675	1.93663	1.35564	23.24000

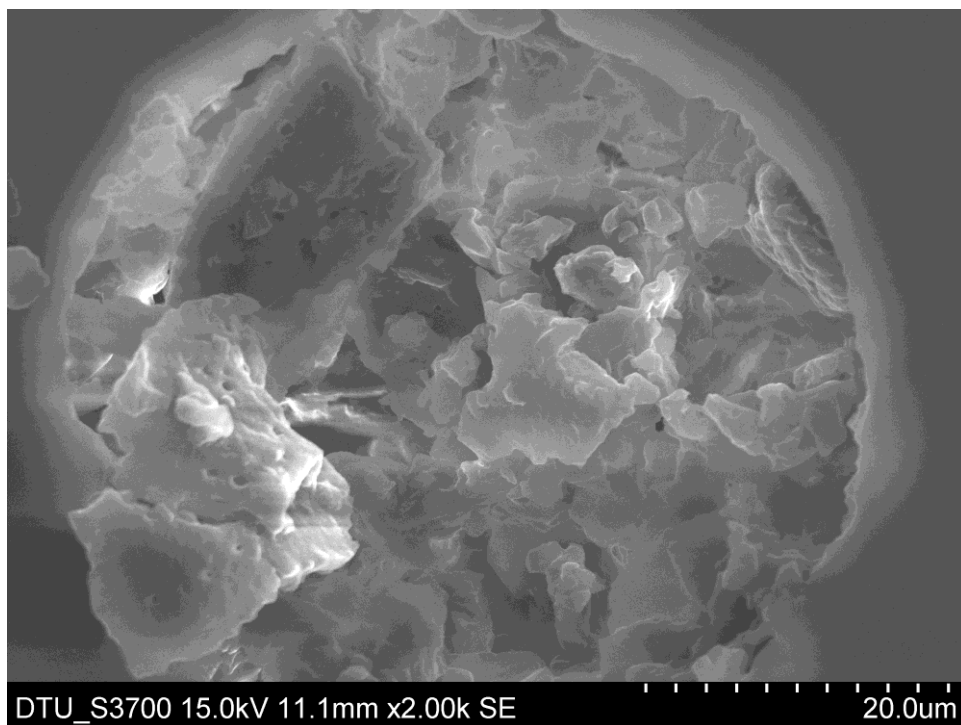
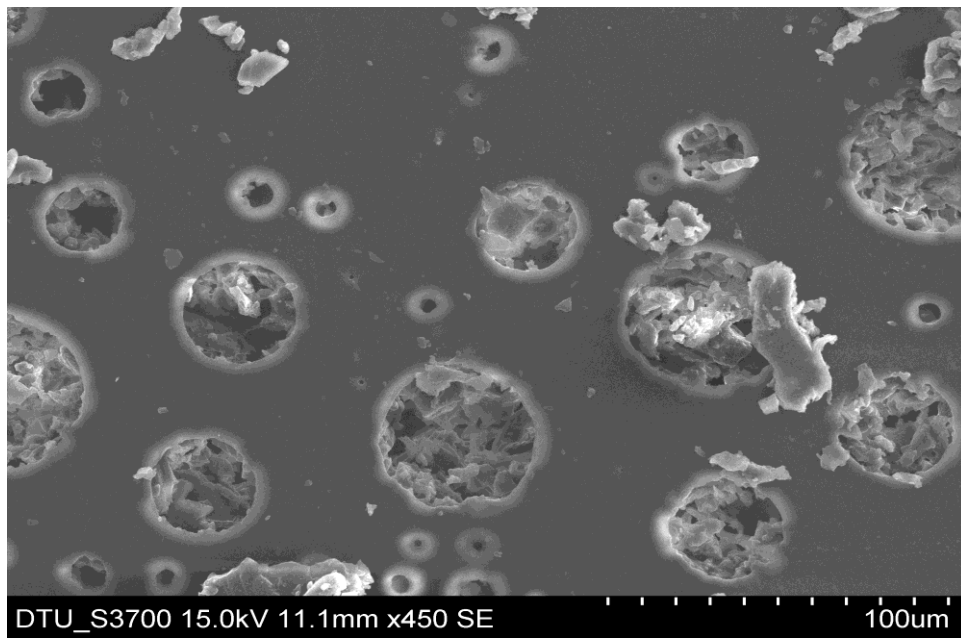
Flexural Test Analysis-

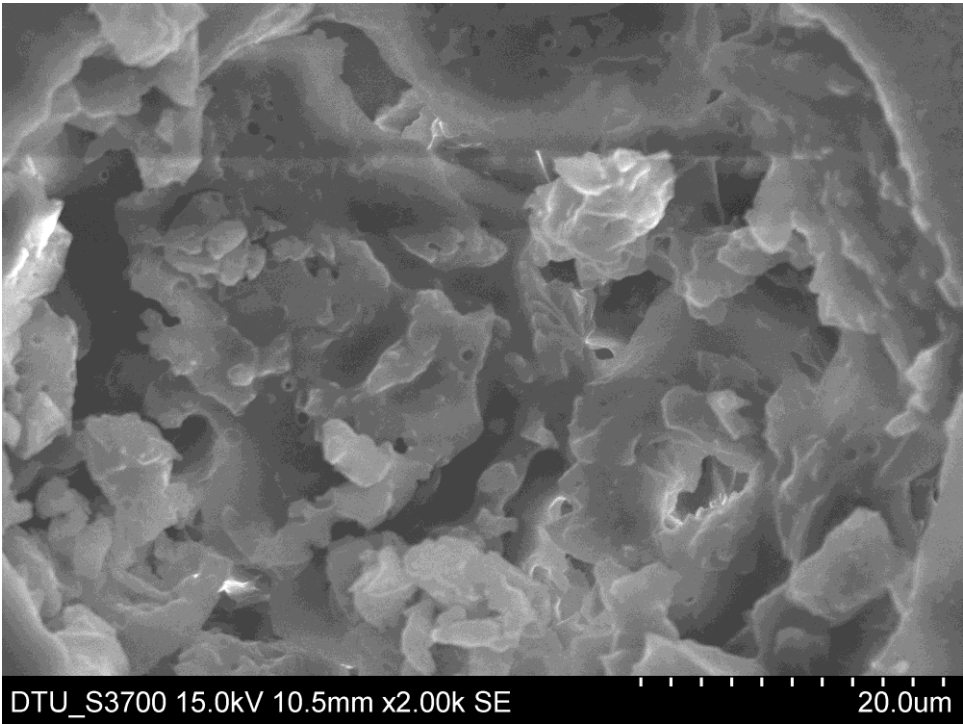
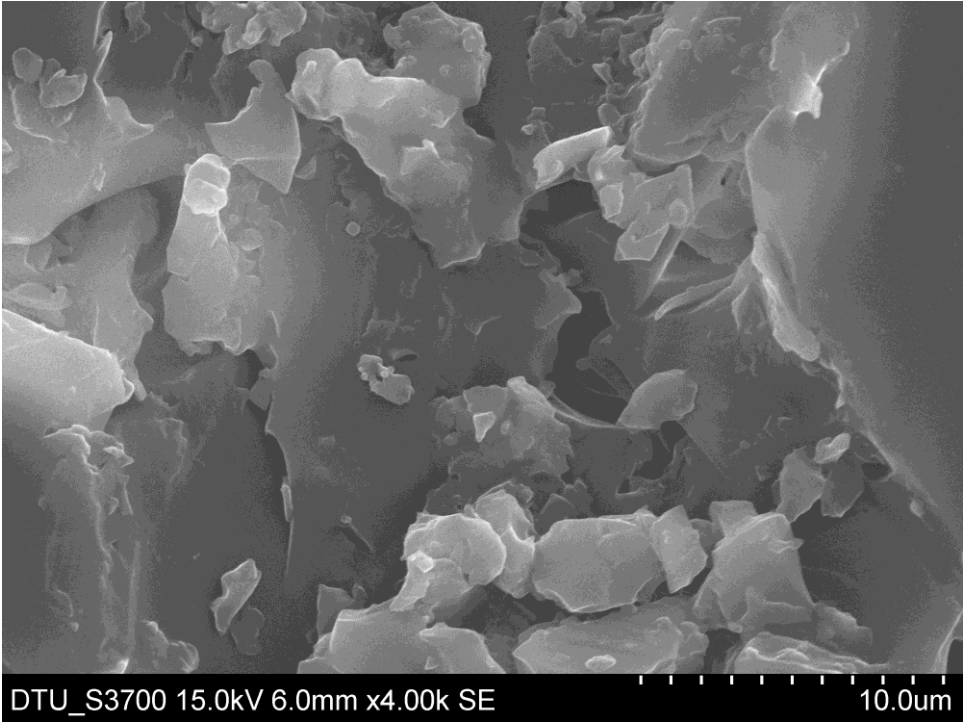
Flexural stress at maximum load (212.40 Mpa) was higher in case of .5 gm. Polyvinyl acetate epoxy blend as compare to 1 gm., 2 gm. 3gm. 4gm. And 5gm, polyvinyl acetate epoxy blend and unreinforced epoxy. Flexural strength, modulus, and the strain at maximum strength for polyvinyl acetate epoxy blend were larger than those of the neat sample.

6.1.3 SEM analysis result-

In general, the physical properties of Blend do not only depend on the rigidity of the polymer matrix, but are also related to the Blend cell structure. Thus, it is of interest to observe the structure of the Blend specimen using SEM. The cell structures of the samples were characterized with a Hitachi S3700 SEM (Scanning Electron Microscope) using an acceleration of 15 kV.



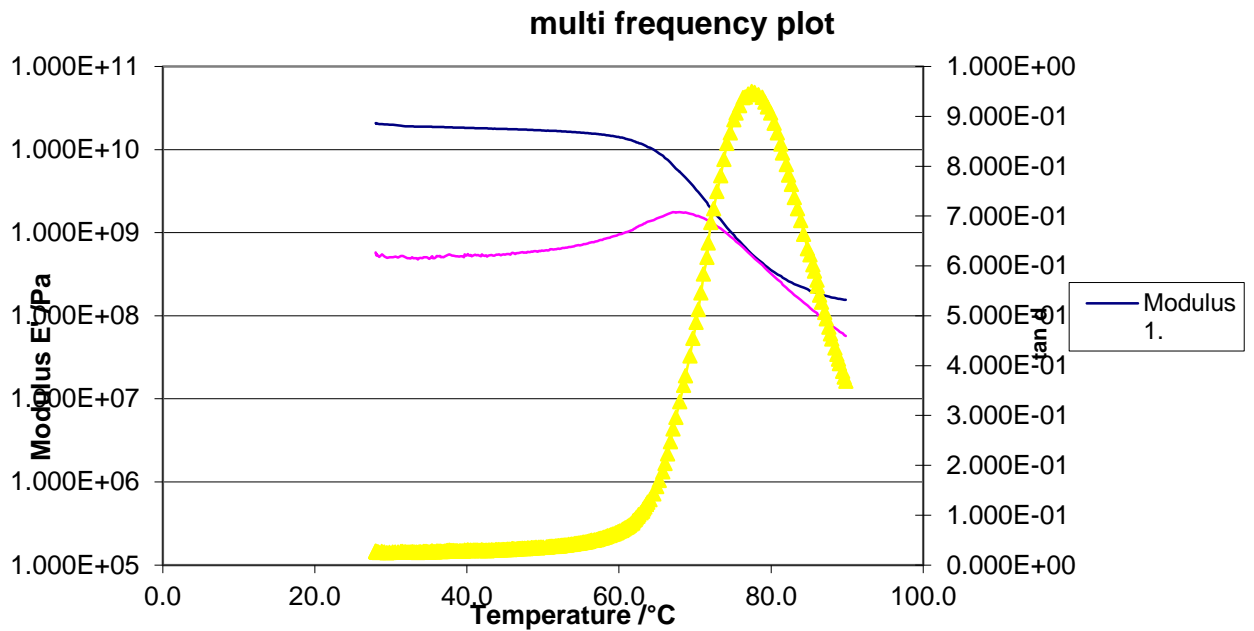




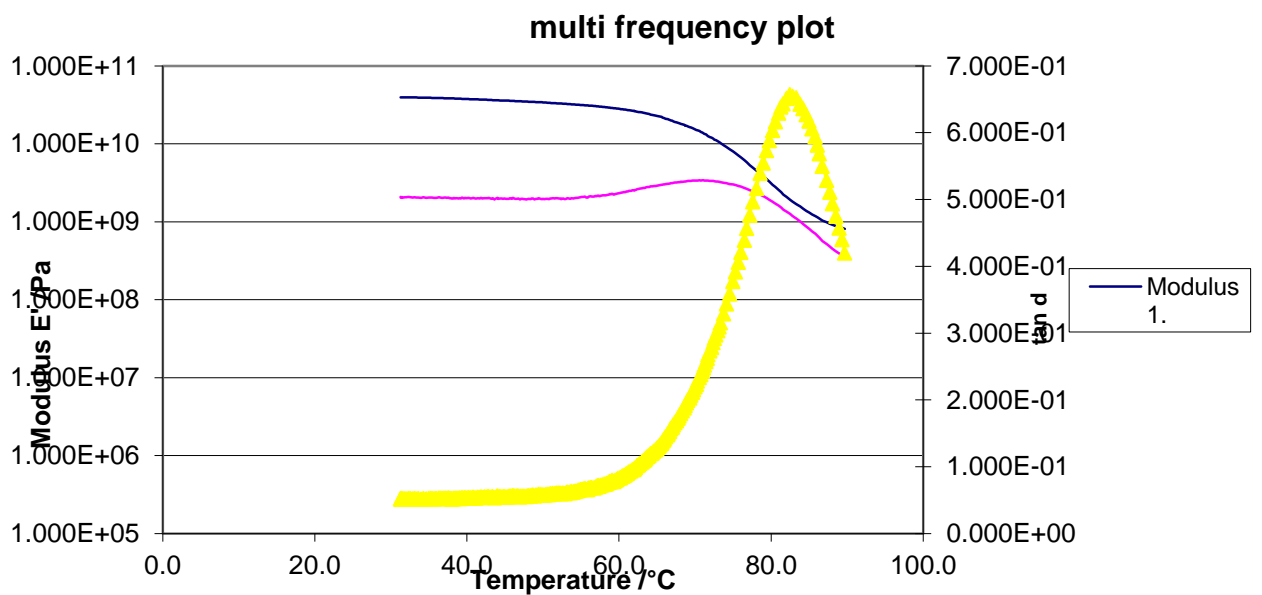
In This Image of SEM Analysis show that the mixing of Poly Vinyl acetate is properly mixed with epoxy resin

6.6.2-DYNAMIC MECHANICAL ANALYSIS

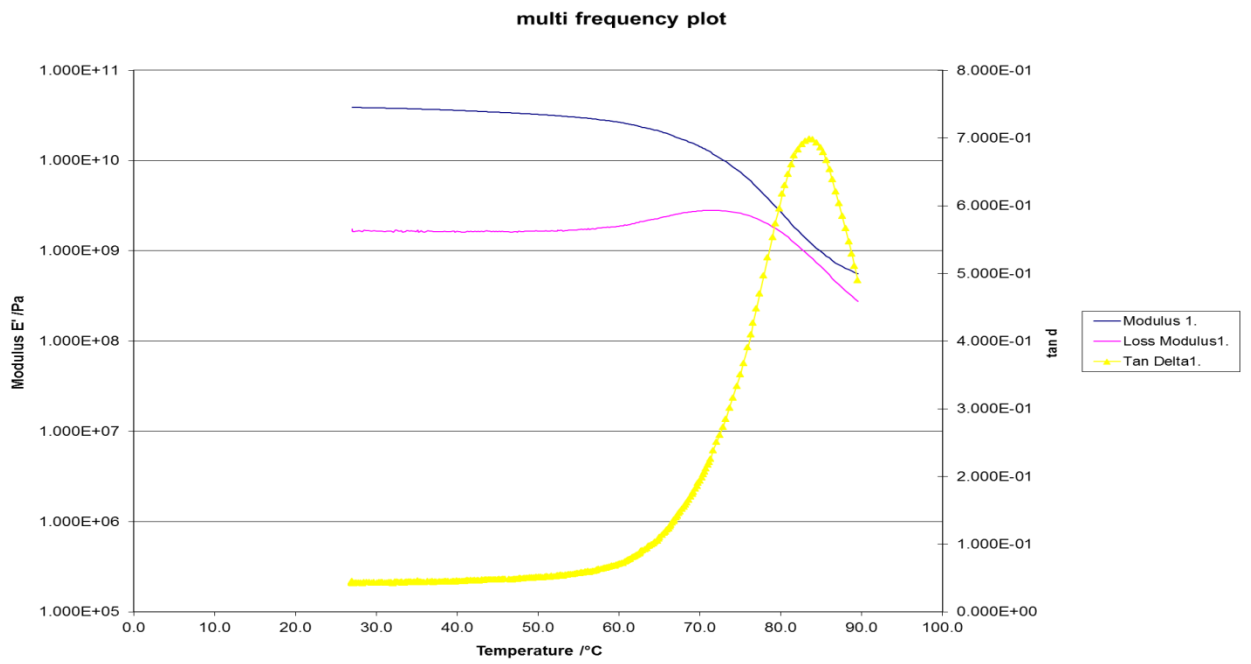
Sample A (neat epoxy+ hardener 9:1 ratio)



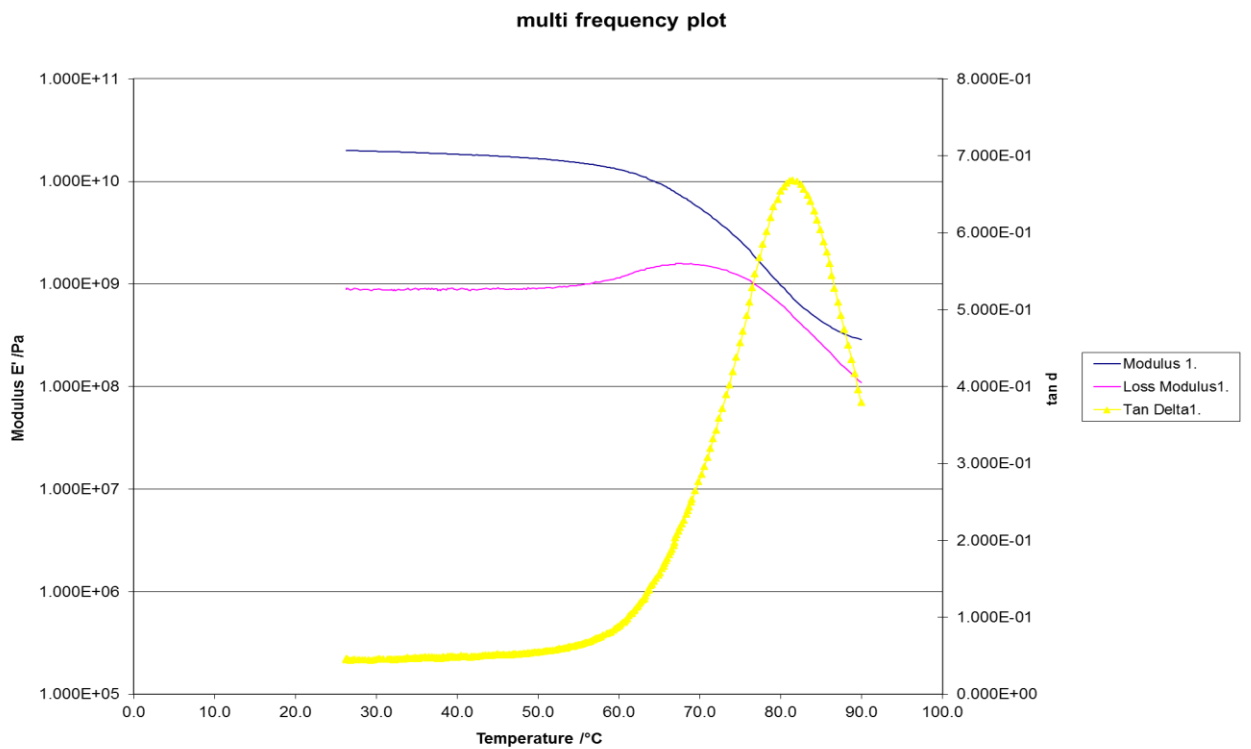
SampleB-(epoxy + hardener (9:1 ratio) + 1 % polyvinyl acetate)



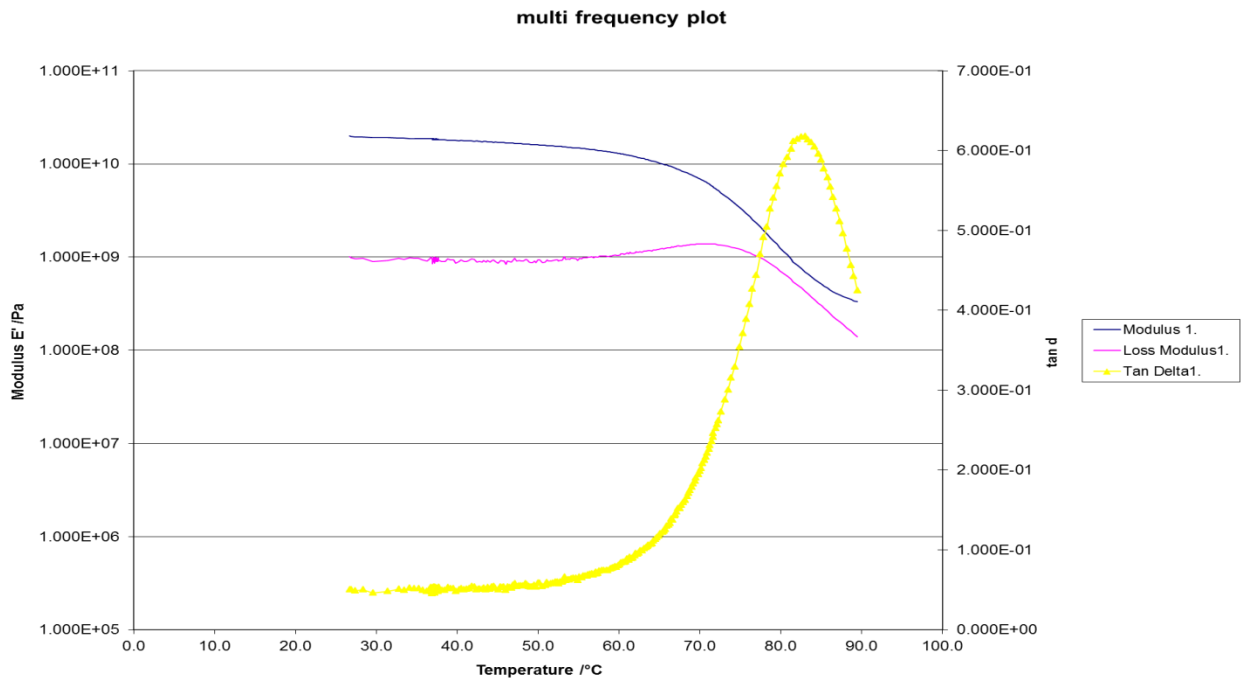
Sample C-(epoxy + hardener (9:1 ratio) + 2 % polyvinyl acetate)



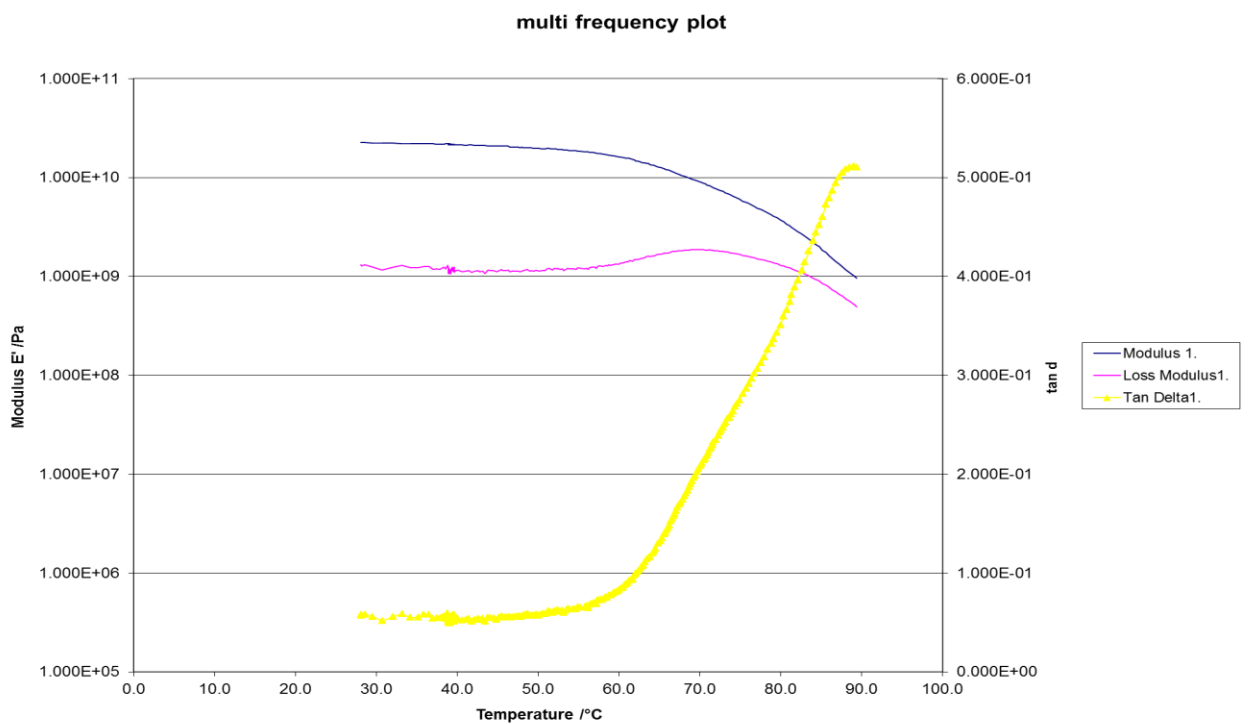
Sample G-(epoxy + hardener (10:1 ratio))



Sample H-(epoxy + hardener (10:1 ratio) + 1 % polyvinyl acetate)



Sample I-(epoxy + hardener (10:1 ratio) + 2 % polyvinyl acetate)



Dynamic mechanical analysis (DMA) shows that the epoxy and polyvinyl acetate blend sample has higher glass transition temperature T_g than the neat epoxy sample . and Fig. 11 shows the DMA curve for reference sample and the blend sample.

The DMA curve of the reference sample shows the glass transition temperature of the reference **sample A (epoxy + hardener (9:1 ratio) is 76.6°C.** and **sample B (epoxy + hardener (9:1 ratio) + 0.5% polyvinyl acetate)** show the glass transition temperature is **82.1°C** and Sample **C (epoxy + hardener (9:1 ratio) + 1.0 % polyvinyl acetate)**

The DMA curve of the **sample C** shows the glass transition temperature of the **sample C is 83.5°C.**this value of glass transition temperature is significantly higher than the glass transition temperature of the reference **sample A is 76.6°C.**

The DMA curve of the reference sample shows the glass transition temperature of the reference **sample G (epoxy + hardener (10:1 ratio) is 80.8°C.** and **sample H (epoxy + hardener (10:1 ratio) + 0.55% polyvinyl acetate)** show the glass transition temperature is **82.2°C** and **Sample I (epoxy + hardener (10:1 ratio) + 1.10 % polyvinyl acetate)** show the glass transition temperature is **88.9°C**

The DMA curve of the **sample I** shows the glass transition temperature of the **sample I is 88.9°C.**this value of glass transition temperature is significantly higher than the glass transition temperature of the reference **sample G is 80.8°C.**

Now we compare both different ratio samples in which sample I have higher the glass transition temperature as compare to other samples. i.e. 88.9°C.

CHAPTER-7

APPLICATION

Applications of Polymer Blend-

The use of polymer blend is diverse and far reaching touching all industry sectors with applications ranging from commercial aircraft to bath tubs.

Applications include:

- Boat decking - boat hulls, submersibles pressure hull, propeller shafts, masts, bulkheads, rudders
- Transport – car & rail body panels, bumper fascia, radiator grills, instrument panels, engine components, fuel lines
- Civil engineering – bridges, column wraps, cladding.
- General engineering – pipe systems, air ductwork, power transmission drive shafts, storage tanks, pressure vessels
- Aerospace – General & military aviation fuselage, cargo liner, wings, landing gear, doors, satellite structure
- Sport – bike frames, canoes, fishing rods, archery bows, golf clubs, ski poles & skis, surf boards, racquets
- Domestic consumer – sanitary ware – baths & shower units, furniture.

CHAPTER 8

CONCLUSIONS

CONCLUSION

7.1 CONCLUSION:

Epoxy Polyvinyl acetate Blend was processed with enhancement in properties like mechanical and thermal characteristics.

A slight improve in the mechanical properties was observed when tested with tensile testing, flexural testing. Thermal test like DSC showed that the thermal stability of the blend.

In SEM analysis it has been found that polyvinyl acetate has been uniformly segregated.

In DMA analysis it has been found that the glass transition temperature of Blend is higher than simple epoxy sample.

This shows that the blend have high impact strength be use at higher temperature than usual cured epoxy without PVAc. This depicts that this composite paves the way for using this composite to a great extent at higher temperature without failure.

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