Effect of Nano Acrylonitrile Butadiene Rubber on Damping Properties of Epoxy Glass Fibre Reinforced Polymer Composites

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Abstract--The use of polymer fiber reinforced composite materials is growing day by day in all types of engineering structures such as aerospace, automotive,aircraft,chemical,constructions etc, because of their tailorable properties though these materials are tailorable, improvement in its properties is demanded.

In the present work some investigation on enhancement of damping properties of epoxy glass fiber composites are carried out through the addition of nano acrylonitrile butadiene rubber particles. The specimens are fabricated with different weight fractions of nano rubber using hand lay-up technique. The morphology studies of nano rubber dispersion in epoxy glass fiber composite studied using scanning electron microscope (SEM). Experimental studies on associate properties like structural damping and material damping are carried out. The influence of weight fractions of nano rubber on structural damping in fixed free method. Material damping was evaluated using Dynamic Mechanical Analysis (DMA) in dual cantilever mode. The present work concludes that, 4% weight fraction of nano rubber exhibits better damping properties than neat composite has been observed.

Keywords

***t* thickness of crystalline**

***K* constant dependent on crystalline shape (0.89)**

***λ* x-ray wavelength**

***B* FWHM (full width at half max) or integral breadth**

***Θ_B* Bragg angle**

***Ws* Specific wear rate**

***P* Density of the specimen**

***F* Normal load applied**

1. MATERIALS AND METHODS

This chapter mainly provides complete details and furnishes all the information associated with the preparation of the sample for performing the desired experimentation on it. Details of the materials used, fabrication technique employed and the specification of the equipments and instruments used are also presented in brief. The Experimental procedure employed on the sample and the corresponding processes of acquiring the data along with the related block diagram of whole experimental set-up is provided.

1.1 MATERIALS

1.1 Epoxy resin system

Epoxy resin systems are made up of an epoxy resin and a curing agent (also called a hardener or catalyst). Many epoxy products also contain additives such as organic solvents, fillers such as fiberglass or sand, and pigments.

Epoxy resin properties (araldite ly 556)

Chemical name: bisphenol of A diglycidyl ether
Viscosity - 1350-2000 mpa*s
Specific gravity - 1.1-1.2 g/cm^3
Epoxy content - 4.20-4.35 eq/kg

Epoxy hardener properties (araldite hy 951)

Viscosity - 10-20 mpa*s
Specific gravity - 0.98 g/cm^3
Appearance - clear liquid
Flash point - 110^{0}c

1.2 Glass fiber:

Over 95% of the fibers used in reinforced plastics are glass fibers, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced. Their low density, resistance to chemicals, insulation capacity are other bonus characteristics, although the one major disadvantage in glass is that it is prone to break when subjected to high tensile stress for a long time. However, it remains break-resistant at higher stress-levels in shorter time frames. This property mitigates the effective strength of glass especially when glass is expected to sustain loads for many months or years continuously. But all this can be easily overlooked in view of the fact the wide range of glass fiber variety lend themselves amicably to fabrication processes like matched die- moulding , filament winding lay-up and so on. Glass fibers are available in the form of mates, tapes, cloth, continuous and chopped filaments, roving and yarns. Addition of chemicals to silica sand while making glass yields different types of glasses.

Materials	Density (g/cm^3)	Tensile Strength (MPa)	Young modulus (GPa)
E-Glass	2.55	2000	80
S-Glass	2.49	4750	89
Alumina (Saffil)	3.28	1950	297
Carbon	2.00	2900	525
Kevlar 29	1.44	2860	64
Kevlar 49	1.44	3750	136

Table: Comparison of typical properties for some common fibers.

Fig: Bi directional s-glass woven fiber

1.3 Nitrile butadiene rubber

Nitrile rubber, also known as Buna-N, Perbunan, or NBR, is a synthetic rubber copolymer of acrylonitrile (ACN) and butadiene. Trade names include Nipol, Krynac and Europrene.

Nitrile butadiene rubber (NBR) is a family of unsaturated copolymers of 2-propenenitrile and various butadiene monomers (1,2-butadiene and 1,3-butadiene). Although its physical and chemical properties vary depending on the polymer's composition of nitrile, this form of synthetic rubber is generally resistant to oil, fuel, and other chemicals

It is used in the automotive and aeronautical industry to make fuel and oil handling hoses, seals, and grommets. NBR's ability to withstand a range of temperatures from -40 °C to +108 °C makes it an ideal material for aeronautical applications. Nitrile butadiene is also used to create moulded goods, footwear, adhesives, sealants, sponges, expanded foams, and floor mats.

Mechanical properties

Young's modulus - 2-5 Mpa

Tensile strength - 10-20 Mpa

Elongation - 200-500%

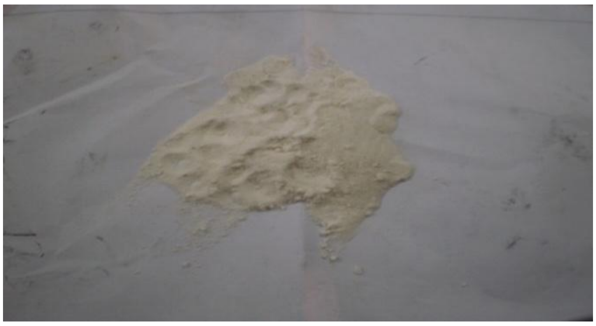


Fig: acrylonitrile butadiene rubber

2. FABRICATION OF COMPOSITES

2.1 Fabrication of dies**:** The below die is a stainless steel material of 316L grade type from Andhra steel pvt.ltd (Hyderabad). This material undergoes plasma cutting in order to get the desired shape of the die. There after BUFFING is done on the material for fine and smoother surface finish.

The specification for the die and its corresponding frame are given as

Specification: 2 dies 200×300×4mm

1 die 190×280×4 mm (outer die size)

1 die 160×250×4(inner die size)

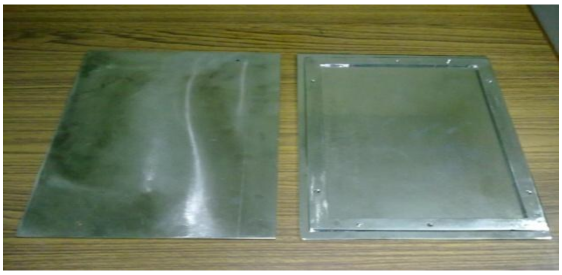


Fig: Dissembled dies

2.2 Fabrication of Material

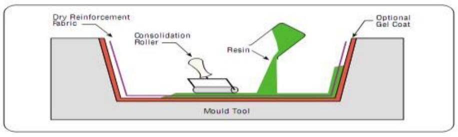


Fig : Hand Lay-up Technique

The technique, also called contact lay-up, as shown in Figure is an open-mold method of molding thermosetting resins (polyesters and epoxies) in association with fibers (usually glass-fiber mat, fabric, or woven roving). A chemical reaction initiated in the resin by a catalytic agent causes hardening to a finished part. Hand lay-up techniques are best used in applications where production volume is low and other forms of production would be prohibitive because of costs or size requirements. The fabricated glass fiber epoxy resin composite plate of dimension 300 mm X 180 mm is placed in the appropriate position in the press and processed under a specified pressure range of (150-200 kPa) for period of 24 hours. An image of the press used in the process of preparation of the composite model is as shown below in Fig.

Fig: The Hydraulic Press

Description of the Equipment Used

Vibration exciter – type 4809

The Vibration Exciter Type 4809 is a small versatile instrument with an impressive performance and since it is made of high quality materials hence ensures long term constructional reliability and strict quality control results in a consistent high performance. The 4809 can be driven by any small power amplifier, with an input current up to a maximum of 5A and a sufficient voltage rating, without assisted cooling. The Bruel & Kjaer Power Amplifier type 2706, rated at 75 VA has been designed specifically to drive the 4809. Their frequency response can be determined in the frequency range 10 Hz to 20 kHz. An image showing the manner and experimental set up of the test is shown below in Figure.

Fig: a composite plate placed on vibration exciter 4809

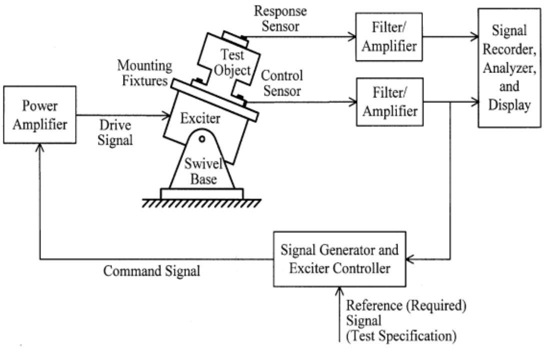


Fig: block diagram of typical procedure for vibration measurement.

Dynamic Mechanical Analysis

The instrumentation of a DMA consists of a displacement sensor such as a linear variable differential transformer, which measures a change in voltage as a result of the instrument probe moving through a magnetic core, a temperature control system or furnace, a drive motor (a linear motor for probe loading which provides load for the applied force), a drive shaft support and guidance system to act as a guide for the force from the motor to the sample, and sample clamps in order to hold the sample being tested. Depending on what is being measured, samples will be prepared and handled differently. A general schematic of the primary components of a DMA instrument is shown

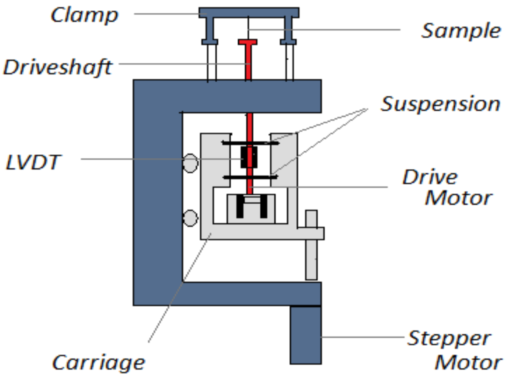


Fig: General schematic of a DMA instrument

Types of analyzers

There are two main types of DMA analyzers used currently: forced resonance analyzers and free resonance analyzers. Free resonance analyzers measure the free oscillations of damping of the sample being tested by suspending and swinging the sample. A restriction to free resonance analyzers is that it is limited to rod or rectangular shaped samples, but samples that can be woven/braided are also applicable. Forced resonance analyzers are the more common type of analyzers available in instrumentation today. These types of analyzers force the sample to oscillate at a certain frequency and are reliable for performing a temperature sweep.

Test modes

Two major kinds of test modes can be used to probe the viscoelastic properties of polymers: temperature sweep and frequency sweep tests. A third, less commonly studied test mode is dynamic stress-strain testing.

Temperature sweep

A common test method involves measuring the complex modulus at low constant frequency while varying the sample temperature. A prominent peak in tan δ appears at the glass transition temperature of the polymer. Secondary transitions can also be observed, which can be attributed to the temperature-dependent activation of a wide variety of chain motions. In semi-crystalline polymers, separate transitions can be observed for the crystalline and amorphous sections. Similarly, multiple transitions are often found in polymer blends.

3. RESULTS AND DISCUSSIONS

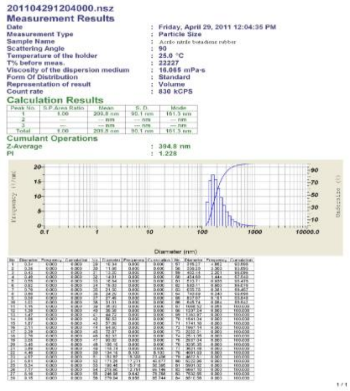
Evaluation of weight fractions

Burn out test is carried out as per ASTM standards D618 to find the weight fractions of fibers and matrix present in composites. Three specimens are tested using electric muffle furnace. The specimens of size 20mm X 20mm are considered for the test. The average fiber weight fraction is found as 40 % of the total weight of the each sample.

Fig: weight of the specimen

Fig: specimen in muffle furnace

3.1 Morphology Studies of Particle Size Analyzer:



3.2 Morphology Studies of scanning electron microscope (SEM):

The morphology of the cross section of nitrile butadiene rubber filled epoxy glass fiber composites were examined using Scanning electron microscopy (SEM), ZEISS EVO® MA15, in order to examine distribution of rubber particles in the composite. Samples are coated with gold using plasma sputter apparatus. Morphology studies reveal the aspects of fiber bonding, adhesion between fiber and matrix and distribution of particle rubber in the glass epoxy composite. SEM micrograph of the cut surface of glass fiber-reinforced epoxy resin composite specimen with rubber particles. It is reviled that rubber particles are well distributed in the matrix.

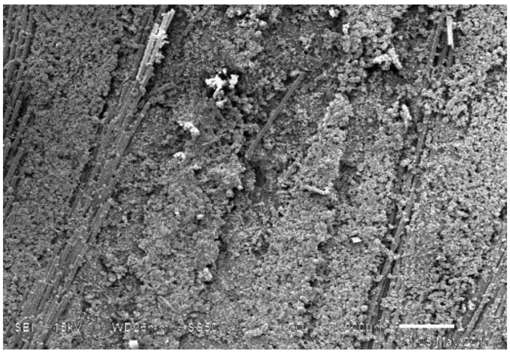


Fig: Nano rubber filled epoxy with glass fiber composite

This chapter mainly deals with the mathematical calculations and analysis of the numerical data obtained from the experimentation. The Half Power Band Width Method has been utilized for the calculation of the damping ratio of each plate subjected to the experimentation.

4. EXPERIMENTATION ON VIBRATION SET UP

During the experimentation process of various plates with and without rubber particles using the Vibration Accelerometer, with the help of Fast Fourier Transform (FFT) Software, the numerical data corresponding to the experiment are obtained. The Fast Fourier Transform Software has been already installed and incorporated into the experimental setup system. The purpose of this software is to convert the time and acceleration responses developed because of the experimentation into frequency and acceleration responses. Thus, the Fast Fourier Transform software performs the operation of converting the required results from the Time domain to Frequency domain, and thereby makes the calculations and analysis simpler.

Initially, the experimentation of all the five plates (which include both the plates with and without the rubber particles) is performed and completed. After the completion of the experimentation process, the numerical data (in the form a tabular form between the frequency and acceleration) is acquired through the FFT Software which has already incorporated into the system.

Now, a graph has been plotted between the experimental values of frequency and acceleration, with frequency on the X-axis and acceleration on the Y-axis. This graph provides a medium to determine the numerous peak frequencies and the corresponding responses on the Y-axis associated with the plates. Thus, with the utilization of the Half Power Band Width method, the damping ratio associated with each peak frequency of plates will calculated. Once the damping ratio for a particular set of peak frequencies are calculated, a tabular form is developed with the determined peak frequencies and calculated damping ratio, then a graph has been plotted with peak frequency values on X-axis and damping ratio on Y-axis and further results are declared from the graph.

4.1 Half Power Bandwidth Method:

Half power bandwidth method is one among the several techniques which are used to quantify the level of damping in a structure. The name 'Half Power Bandwidth method' originated from the response vector voltage of an electrical circuit, which is usually plotted in logarithmic scale. The response amplitudes at two particular points have approximately the same value, which is a $1/\sqrt{2}$ fraction of the resonant amplitude. Since power is proportional to the square of the voltage, those two points also represent the half power points of voltage. The voltage or displacement amplitude ration $1/\sqrt{2}$ corresponds to approximately a 70% or 3dB amplitude reduction. Thus, the points defined by that ratio are called the 70% or 3dB amplitude points, as well as the half-power points.

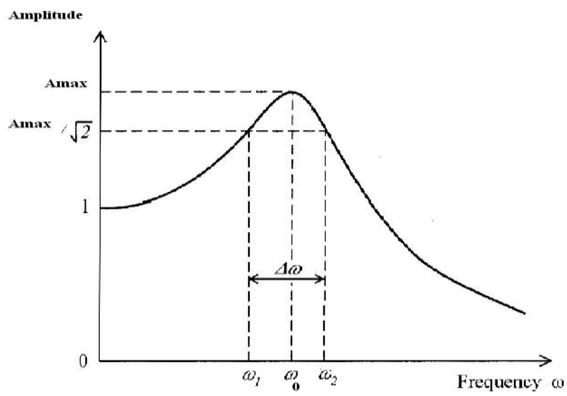


Fig: Bandwidth method of damping measurement in a single-degree-of-freedom system.

4.2 Procedure to Calculate Damping Ratio using Half Power Bandwidth Method:

The single degree of freedom (SDOF) structures which are usually defined by second degree equation have the capability to possess a classic compliance response as shown in figure the level of damping can be subjectively determined by noting the sharpness of the resonant peak at ωo, the more rounded the shape, the more damping present in the structure. For a quantitative measure of damping, the half-power bandwidth method can be employed. The damping ratio (ξ) of the structure can be determined from the ratio of Bandwidth (Δω) to Peak Frequency (ωo), while Δω is determined from the half-power point down from the resonant peak value, Amax. Initially, the peak amplitude Amax corresponding peak frequency (ωo) is determined, then at Amax/√2 value on the Y-axis, lets draw a horizontal line parallel to X-axis such that it intersects the peak frequency ωo curve at two points ω_1 and ω2 where the corresponding frequencies are determined, now by using the below mentioned mathematical equations 1 & 2 the bandwidth and consequently the damping ratio of the composite plate can be calculated.

Equations are given below:

Bandwidth $\Delta\omega = \omega 2 - \omega_1$ ---------------------- Eq. 1

Where ω_1 and ω_2 are the corresponding frequencies defined by the bandwidth. Thus, the damping ratio is calculated by using the formula as given below:

Damping Ratio (ξ) = $\dfrac{\omega_2 - \omega_1}{\omega_n}$ ---------------------- - Eq. 2

Thus using the mathematical equations and expression as derived from half power bandwidth method, we can determine the damping ratio of the composite plate under consideration. Now, utilizing the peak frequency values and the corresponding damping ratio values as obtained from the half power bandwidth method, a graph has been plotted with peak frequency values on the X-axis and the corresponding damping ratio values on the Y-axis. The graph from these values has been shown below in Figure. This graph indicates with increase in peak frequency values the damping ratio gradually decreases. Also, the damping ratio is high when the peak frequency is low.

4.3 Determination of Damping Ratio

Let's consider the composite plate No.1 (i.e. composite plate without rubber particles). When this plate is subjected to experimentation on the vibration accelerometer, then with the Fast Fourier Transform software which has already been installed with the experimental setup the numerical data associated with the composite plate can be obtained. The numerical data basically gives a detailed information regarding the frequencies to which the composite plate is subjected and the corresponding responses of the plate to the applied frequencies. Now with the help of this data, a graph has been plotted with frequencies to which the plate is subjected to on the X-axis and the responses of the plate with these frequencies on the Y-axis. The motive behind the plotting of the graph is to determine the peak frequencies associated with the composite plate. The plotted graph is as shown below. Thus by using the Half Power Bandwidth method and the peak frequencies the damping ratio of the plate can be calculated.

(i). for 1% weight fraction of nano rubber in mode 1 for the composite plates the damping ratio is high. The peak value or damping ratio obtained is 0.034; mode 1 has the highest damping ratio compared to mode 2 and mode 3. As the weight fraction of nano rubber increases the damping ratio also further increases, Inclusion of rubber particles improves damping.

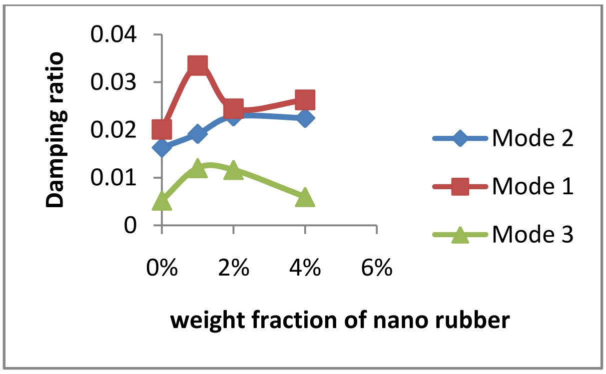


Fig (i): Plot of weight fraction of nano rubber Vs damping ratio of various weight fractions of composite plates

(ii). This graph is for frequency Vs damping ratio, here for the 4% inclusion of nano rubber the damping ratio is high compared to 0%, 1% and 2% weight fractions of nano rubber particles in the composite materials. Mode 1 has the highest value of damping compared to other three weight fractions. For 4% weight fraction all the three modes shows the highest damping value compared to the remaining three weight fractions of composites . Here at 4% weight fraction at mode 1, the damping ratio is high and the frequency is low.

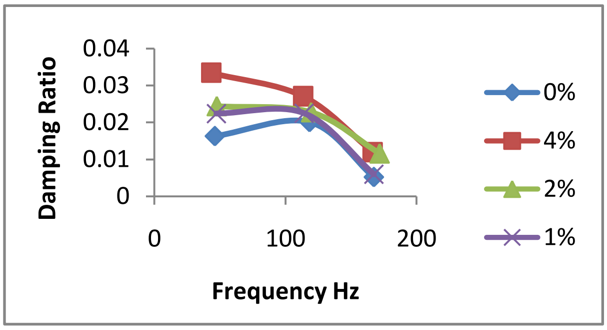


Fig (ii): Plot of frequency Vs damping ratio of the composite plates for various weight fractions of nano rubber

(iii). This graph is for the weight fraction of nano rubber Vs increment in damping, the increment is plotted for three individual modes . mode 1 shows good damping properties compared to mode 2 and mode 3. In this graph it is seen that 4% weight fraction of nano rubber exhibits good damping properties.

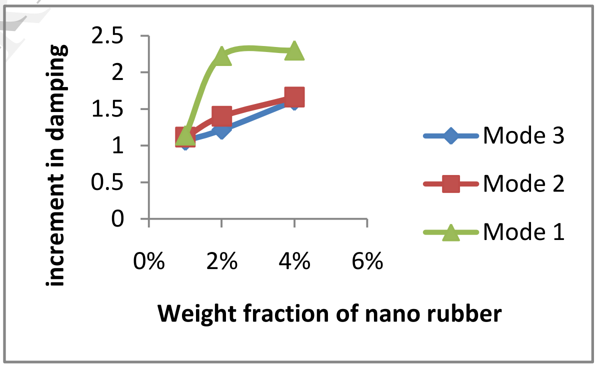


Fig (iii) : Plot of weight fraction of nano rubber Vs increment in damping of the composite plates

Dynamic Mechanical Analysis test and its Results

The glass fiber reinforced polymer composites are of 0%, 2%, and 4% nano rubber inclusions respectively. Main objective for DMA tests is to find the glass transition temperature of the polymers and also to find the tan delta value (damping ratio). Storage modulus measures the energy stored representing the elastic portion, and loss modulus gives the energy dissipated as heat representing the viscous portion. At the glass transition temperature the storage modulus decreases dramatically and loss modulus reaches a maximum.

(i). Storage modulus is higher in 4 % inclusion of nano rubber compared to 0% and 2% inclusions of nano rubber. Storage modulus for 4% is observed as 8890 Mpa, at temperature of 35 ºc. Storage modulus for 2% is observed as 7000 Mpa, at temperature ranging from 35ºc-40ºc. Storage modulus for 0% inclusion of nano rubber is observed as 1800 Mpa, at temperature ranging from 35ºc-40ºc.

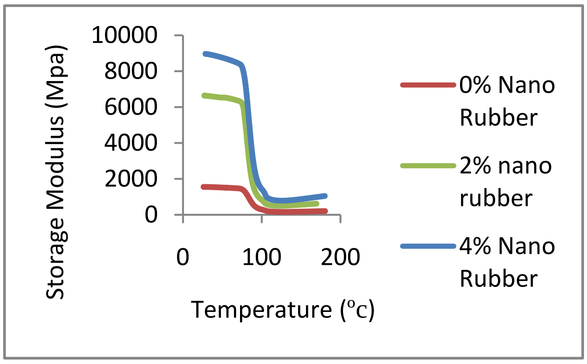


Fig (i): Plot of Storage modulus Vs Temperature

(ii). The ratio of the loss modulus to the storage modulus gives the tanδ value and this is often called as Damping. The tanδ value i.e.., the damping value is higher in 4% inclusion of nano rubber compared to 0% and 2% inclusions. That means the 4% inclusion of nano rubber exhibits good damping properties.

For 0% tanδ= 0.35

For 2% tanδ= 0.36

For 4% tanδ= 0.38

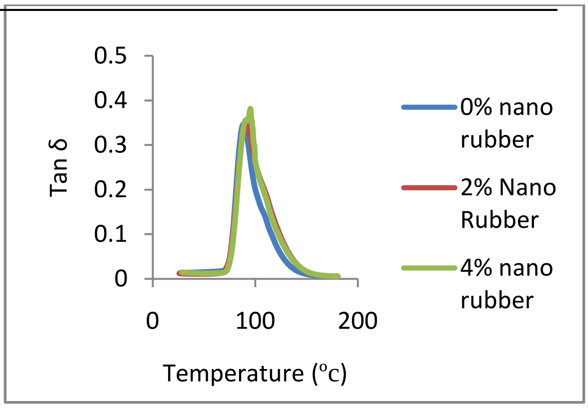


Fig (ii): plot of tan δ Vs Temperature

Hence tanδ value is observed higher in 4% inclusion of nano rubber when compared to 0% and 2% inclusions of nano rubber. Hence material damping properties are good when nano rubber is mixed with the glass fiber reinforced composite materials.

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