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Mechanical and Damping Properties of Epoxy Cyanate Matrix Composite Under Varied Temperatures

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Abstract: Mechanical and Damping properties of cyanate modified epoxy/glass fibre composites are investigated under varied temperatures. The tensile properties are investigated using UTM. The increase in tensile strength of cyanate modified epoxy system with increase in cyanate loading is 320-401 MPa. Free vibration method is used to experimentally measure frequency response and damping factor. The viscoelastic properties such as storage modulus (E'), loss modulus (E'') and stiffness (K) were obtained for cyanate modified epoxy/glass fibre composites.

Key words: Composite, damping factor, vibration, frequency, stiffness, storage modulus

INTRODUCTION

Damping materials have good ability to dissipate elastic strain energy when subjected to vibratory loads and have been widely used in the fields of high performance structural applications such as aerospace, marine, construction, etc. Damping is an important modal parameter for the design of structures for which vibration control and cyclic loading are critical. Damping is also a significant factor for the fatigue life and impact resistance of structures. All engineering materials dissipate energy under cyclic load. Some of them such as elastomeric, plastic and rubber dissipate much more energy per cycle than metallic materials. Damping varies with different environmental effects, such as frequency, amplitude of stress, temperature and static preload. Damping is also affected by corrosion fatigue, grain size, porosity and number of fatigue cycles, especially for metallic materials (Colakoglu, 2004). There is a functional relationship between damping and all the effective factors. In addition, temperature is usually one of the most important factors for damping in polymers and polymeric materials.

In aerospace and many other lightweight structures, there are many vibration inputs that can lead to resonance, so it is necessary to have a sound methodology to control the vibration. During the past few decades, it has become technically and ecologically important to suppress vibration and impact noise (Zhang and Jia, 2006). From this scope, many mechanical dampers have been investigated and developed and there, the exploitation of damping materials is a key point to produce efficient damping to eliminate vibration and noise (Cabanelas *et al.*, 2005). In particular, the polymer composite as a novel damping material has attracted great interest in the development because of its excellent stiffness and damping characteristics. Among the thermosetting polymers, epoxy resins are the most widely used for high-performance applications such as matrices for fibre reinforced composites, coatings, structural adhesives and other engineering applications. Epoxy resins are characterized by excellent mechanical and thermal properties, high chemical and corrosion resistance, low shrinkage on curing and the ability to be processed under a variety of conditions (Pickering, 2006). Once fully cured epoxies form highly cross linked three dimensional networks. The densely cross linked nature of the material enables many of its superior properties. However, the high level cross linking in epoxy networks leads to inherent brittle materials and that constraints many of its applications. Several studies have been made to improve the toughness and crack resistance of epoxy resin. One successful modification method is the incorporation of secondary rubbery phase that separates from the matrix during curing, leading to different morphologies (Kim *et al.*, 2006; Boyard *et al.*, 2007). The advantage of rubber toughening in thermosets is that fracture toughness can be improved dramatically. However, elastomer modification will lead to significant reduction in the modulus and thermal stability of the material. In recent years, high-performance thermoplastics have been used to modify epoxy resin such as PES, PEI, PEEK, ABS, etc., because of their high modulus and glass

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transition temperatures. The incorporation of thermoplastic, initially miscible which phase separates during the epoxy-hardener curing reaction, leads to toughness improved epoxy networks. But processing of thermoplastic resin is difficult. Thermosets have historically been the principal matrix material for composites, although thermoplastics are used in many applications. The properties of the composites and the factors influencing their properties were extensively studied. The use of epoxy resin as the matrix for fibre reinforced composites in structural applications has been increased significantly (Dinakaran *et al*., 2003; Mathew *et al*., 1999). High specific stiffness, strength, dimensional stability, selective electrical properties, lightweight and excellent corrosion resistance make them valuable for automobile and aerospace industries. Most of the fibre-reinforced composites offer a combination of strength and modulus that are either comparable or better than many of the conventional and traditional metallic materials.

The extent of adhesion of polymer blend matrix to the reinforcing elements, especially fibre is very important. It is well known that stress passes from the fibres to the matrix through the interface. Therefore, the adhesive force affects the strength and rigidity of the reinforced plastics and their fracture behavior. Glass fibre is one among the high strength and high modulus material used for the preparation of large varieties of composites. Glass fibres have found very extensive use in plastics, most commonly in continuous form in catalyst-activated thermosetting resins and in short form in thermoplastics. The principal advantages of glass fibres are low cost, high tensile strength, high chemical resistance and excellent insulating properties.

There are mainly two types of glass fibres commonly used in fibre reinforced plastic industry, namely E-glass and S-glass. E-glass has the lowest cost of all commercially available reinforcing fibres which is the reason of its widespread application in Fibre Reinforced composite (FRP) industry.

Current research is also directed towards the use of thermoset-thermoset polymer blends in particular the incorporation of inherently tough polymers into brittle polymer systems in order to impart improvements in fracture toughness in the resulting blends (Derrick *et al*., 2006). Here toughening of epoxy resin is tried with an inherent tough polymer cyanate ester resin. The objective of this study is to investigate the natural frequency, damping factor, storage modulus (E'), loss modulus (E'') and stiffness (K) for cyanate modified epoxy/glass fibre composites under varied temperature.

Theoretical analysis: A theoretical analysis of internal damping and dynamic stiffness for aligned continuous fibre composite was developed based on micromechanics models for the complex modulus. The free vibration method results generally present a logarithmic damping (Δ) given by Eq. 1:

$$\Delta = \ln\left(\frac{\delta_1}{\delta_n}\right) = \frac{1}{n}\ln\left(\frac{\delta_1}{\delta_2}\right) \quad (1)$$

Where:

n = The number of peaks

δ_1 = The amplitude of the first peak

δ_n = The amplitude of the final peak analyzed

The storage modulus (E') was obtained for a rectangular specimen having 300 mm of length, 30 mm of width and 3 mm of thickness as shown in Fig. 1.

$$E' = \frac{4\pi^2 f^2}{3I}\left[M + \frac{33}{140}m\right]L^3\left[1 + \frac{\Delta^2}{4\pi^2}\right] \quad (2)$$

Where:

E' = The elastic modulus

f = The natural frequency

I = The inertial moment

M = The accelerometer weight

m = The specimen weight

L = The specimen length

The loss factor, tan δ can be calculated from the decaying-oscillatory damping curve as follows:

$$\tan\delta = \frac{\ln(\delta_1/\delta_n)}{n\pi} \quad (3)$$

Loss modulus (E") can be calculated by Eq. 4:

$$\tan\delta = \frac{E''}{E'} \quad (4)$$

The term $[\ln(\delta_1/\delta_2)]/n$, also known as the logarithmic decrement Δ can be obtained by fitting the experimental data. Tan δ values can also be obtained theoretically by using the rule of mixtures. So, the parameters found in this research were the E', E" (loss modulus) and tan δ values.

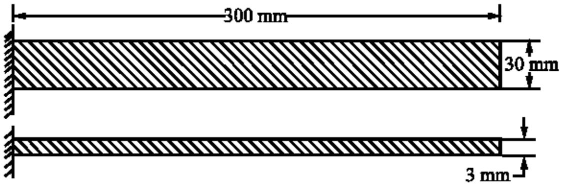

Fig. 1: Cantilever composite

MATERIALS AND METHODS

Epoxy resin LY556 (diglycidyl ether of bis phenol A), curing agent HT972 (DDM-Diamino Diphenyl Methane), Arocy b 10 (bis phenol dicyanate), E-glass fibre. All chemicals were used as purchased.

Fabrication of polymer composite laminates: The composites are fabricated from E-glass fiber and commercial epoxy resin/cyanate modified epoxy resin. The glass fiber with an aerial density of 200 g m^{-2} was used as the reinforcement for composite laminate. The liquid epoxy was taken in a beaker which was heated to 90°C to lower the resin viscosity and desired amount of cyanate was added into resin. The Cyanate loading was varied between 0, 20, 40 and 60% by weight of epoxy shown in Table 1. The mixture was degassed in a vacuum oven followed by addition of DDM (curing agent) in 27% by weight of epoxy and stirred for 3 min at 90°C. A steel cylindrical mould was coated with silicone release agent and then a layer of the resin was applied using a brush. Necessary precautions were taken to keep the fabric well aligned. This process was repeated to construct a 14 ply laminate. The fabricated sheet was then cured at 120°C for 1 h and 180°C for 1 h in a hydraulic press. The laminate was then demoulded and post cured at 220°C for 1 h an oven (Jayakumari *et al*., 2007). The tensile properties were investigated by using universal Testing Machine (Model H50K-S, Hounsfield Test Equipment Ltd, UK). The cross head speed was 1 mm/min The span length of the specimen was 150 mm. Tensile modulus studies were evaluated as per ASTMD 3039.

Vibration analysis: The damping factor and natural frequency are measured experimentally using vibration testing equipment containing an accelerometer, (dytron model 3055B2), impulse hammer (dytron model 5800B3), dynamic signal analyzer (dytron model photon 200), vibration analyses software (lab view) and a computer with RT-Pro software to display the analysis result. In this equipment, the specimen is attached to cantilever configuration.

The equipment is shown in Fig. 2. The vibration test gives the free vibration damping decay and the Frequency Response Function (FRF), simultaneously as a result. Considering a linear system of a single degree of freedom, the FRF response is the decomposition of the natural frequencies of a structure or specimen which corresponds to a typical fingerprint identify of the vibration modes. The number of vibration peak frequencies (vibration modes) and the shape of the FRF response are a direct result of the rigidity of the material.

Table 1: Material composition (cyanate loading)

Name	Epoxy (g)	Cyanate (g)	DDM (g)
EP	100	-	27
20 EPCY	100	20	27
40 EPCY	100	40	27
60 EPCY	100	60	27

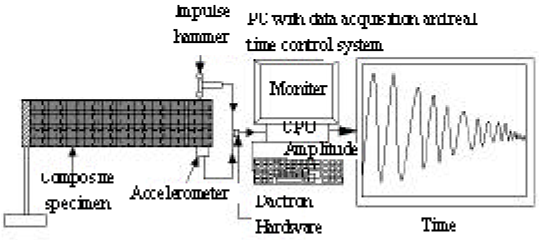

Fig. 2: Experimental setup for vibration analysis

RESULTS AND DISCUSSION

Effect of cyanate loading on mechanical properties of cyanate modified epoxy/glass fibre composite: Table 2 shows the mechanical properties of epoxy/cyanate modified glass fiber composites. From the Table 2, it is seen that the tensile strength values of epoxy composite is 320 MPa and for cyanate modified epoxy composite the values are 350, 372 and 401 MPa, respectively for 20, 40 and 60% loading. It is observed that the cyanate modified epoxy has better tensile strength when compared to epoxy composite.

The enhanced flexural properties are due to the formation of a network structure between cyanate ester and epoxy matrix. The formation of aliphatic oxazolidinone exhibits more thermoplastic character which imparts resistance to bending stress (Wu *et al*., 2000; Barton *et al*., 1999). The fracture toughness (G_{IC}) of pure epoxy composite and the blend composite were obtained by compliance method and the values are shown in Fig. 3 by plotting fracture toughness against composition of resin. From the Fig. 3, it is observed the fracture toughness increases with increase in cyanate content. The increase in fracture toughness with cyanate content may be due to the presence of oxazolidinone and cyanurate ring which imparts toughness to the resin system (Hillermeier and Seferis, 2000; Ganguli *et al*., 2002).

Effect of cyanate loading on natural frequency of cyanate modified epoxy/glass fibre composites with increasing temperature: The first natural frequencies under varied temperature for epoxy/glass fibre composites and cyanate modified epoxy/glass fibre composites are experimentally determined using free vibration method. The natural frequencies are measured 5 times for each temperature are

Table 2: Effect of cyanate loading on mechanical properties of cyanate modified epoxy/glass fibre composite

Code name	Tensile strength (Mpa)	Tensile modulus (Gpa)	Flexural strength (Mpa)	Flexural modulus (Gpa)
EP	320	3.8	402	8.5
20 EPCY	350	4.3	445	9.1
60 EPCY	372	5.0	476	9.7
60 EPCY	401	5.3	503	11.2

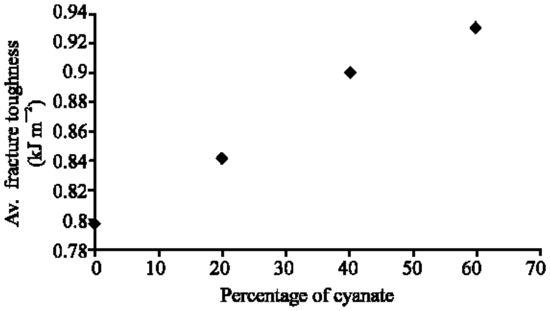

Fig. 3: Effect of cyanate loading on average fracture toughness of cyanate modified epoxy composites

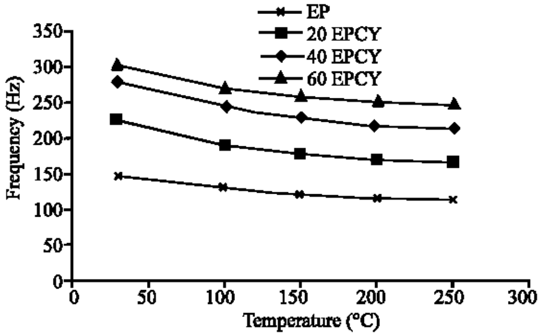

Fig. 4: The first natural frequencies of EP and cyanate modified EP with temperature and cyanate loading

measured. Figure 4 shows the response of the natural frequency of the composite of EP, 20, 40 and 60 EPCY at 30°C. From the Fig. 4, it is observed that the natural frequency increases with increasing in percentage of cyanate loading also that the peak amplitude decreases with increasing in percentage of cyanate loading. For the neat epoxy/glass fibre composite the first natural frequencies are 148, 131.06, 121.6, 115.38 and 113.89 Hz at 30, 100, 150, 200 and 250°C, respectively. The decrease in natural frequency with increase in temperature may be attributed to the softening of polymer system. The same decreasing trend in natural frequencies is observed in the case of cyanate modified epoxy/glass fibre composites. But the cyanate modified epoxy/glass fibre systems have higher natural frequency than the neat EP system. The natural frequencies of 20, 40 and 60 EPCY are 166.06, 213.8 and 247.1 Hz, respectively when compared to neat EP system with a natural frequency of 113.89 Hz at 250°C. The increase in natural frequency of cyanate modified system with increase in cyanate loading may be attributed to the symmetrical triazine ring which offers better damping characteristic to the epoxy system.

Effect of cyanate loading on damping factor of cyanate/epoxy/glass fibre composite with increasing temperature: Figure 5a-d shows the time response of the cyanate modified epoxy/glass fibre composites obtained for (30, 100, 150, 200 and 250°C) five different temperature. The amplitude increases when the test temperature increased, so the damping factor also increases. In addition similar to the time response of the peak amplitude of (20, 40 and 60 EPCY) composite is decreased with increasing cyanate content as shown in Fig. 5a-d. The mean of the first natural frequency of epoxy-cynate matrix composite is f_1 = 148 Hz and the corresponding damping factor is ζ_1 = 0.01326 at 30°C. Those values for a 1018 hot-rolled carbon steel with different sizes are measured as f_1 = 65 Hz and ζ_1 = 0.0044 (Colakoglu, 2004). $F_1\ \zeta_1$ gives a constant independent of size to compare the damping capacity with other materials. This constant for epoxy cyanate is approximately 3 times more than that of the 1018 hot rolled carbon steel. There is also a functional relationship between temperature and damping factor which is shown in Fig. 6. From the Fig. 6, it is seen that the damping factor increases with increase in temperature. The neat epoxy system has a damping factor of 0.01326 and 0.01721 at 30 and 250°C. A similar increasing trend is observed for 20, 40 and 60 EPCY systems. The damping factors of 20, 40 and 60 EPCY systems at 250°C are found to increased by 16.56, 29.58 and 45.20%, respectively when compared with EP system.

Effect of cyanate loading on storage modulus of cyanate/epoxy/glass fibre composite with increasing temperature: Figure 7 shows the response of the storage modulus of the composite of EP, 20, 40 and 60 EPCY for five different temperature. From the Fig. 7, it is observed that the storage modulus increases with increasing in percentage of cyanate loading.

For the neat epoxy/glass fibre composite the storage modulus is 3.8 N mm^{-2} and for 60 EPCY is 15.93 N mm^{-2} at 30°C. The increase in storage modulus of cyanate modified system with increase in cyanate loading may be attributed to the symmetrical triazine ring which offers better damping characteristic to the epoxy system. For the 60 EPCY composite the storage modulus is 15.93 N mm^{-2} at 30°C-10.59 N mm^{-2} at 250°C. The decrease in storage modulus with increase in temperature may be attributed to the softening of polymer

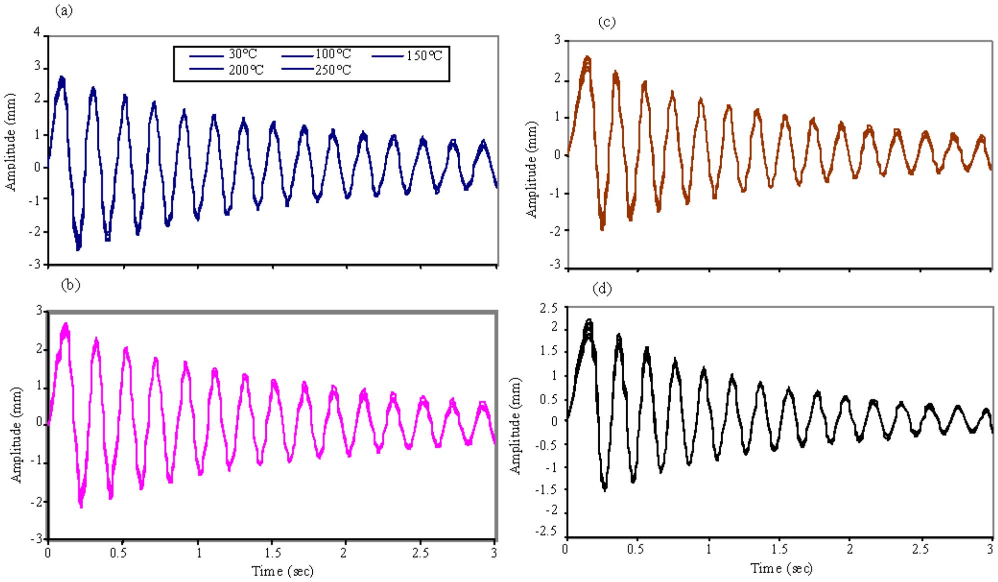

Fig. 5: Vibration damping curves from composite laminate specimen studied under varied temperature (30, 100, 150, 200, 250°C): (a) neat epoxy (b) 20 EPCY (c) 40 EPCY (d) 60 EPCY

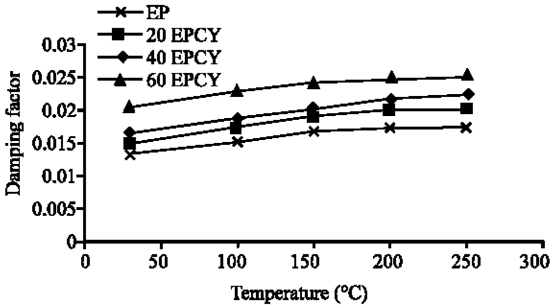

Fig. 6: The variation in damping factor of EP and cyanate modified EP with temperature and cyanate loading

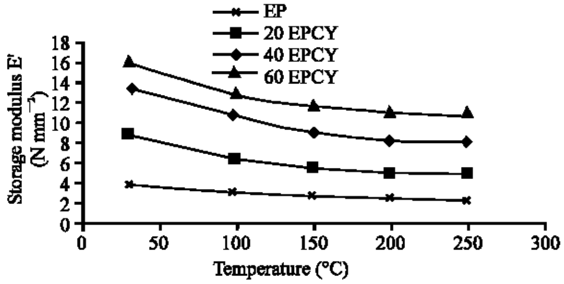

Fig. 7: The variation in storage modulus of EP and cyanate modified EP with temperature and cyanate loading

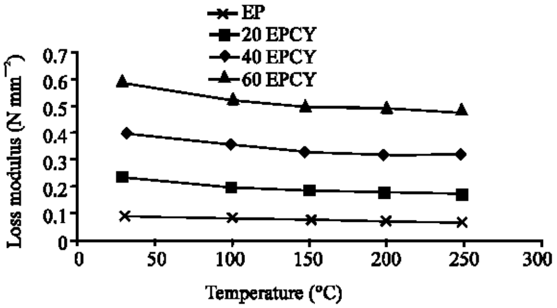

Fig. 8: The variation in loss modulus of EP and cyanate modified EP with temperature and cyanate loading

system. The same decreasing trend in storage modulus is observed in the case of cyanate modified epoxy/glass fibre composites. But the cyanate modified epoxy/glass fibre systems have higher storage modulus than the neat EP system.

Effect of cyanate loading on loss modulus of cyanate/epoxy/glass fibre composite with increasing temperature: The influence of temperature on the loss modulus of neat epoxy and cyanate modified epoxy system are shown in Fig. 8. From the Fig. 8, it is seen that the loss modulus increases with increase in cyanate content.

Effect of cyanate loading on stiffness of cyanate/epoxy/glass fibre composite with increasing temperature: The stiffness of the composite increases with increase in cyanate content as shown in Fig. 9. From the Fig. 9, it is seen that the stiffness decrease with

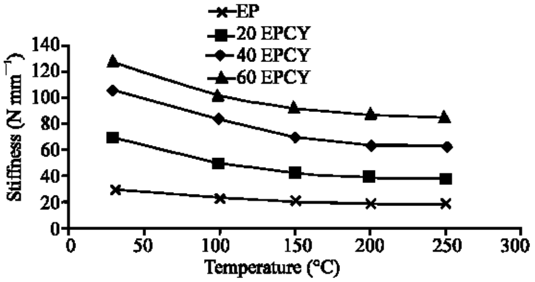

Fig. 9: The variation in stiffness of EP and cyanate modified EP with temperature and cyanate loading

increase in temperature. The neat epoxy system has a stiffness of 29.4 N mm^{-1} and 17.4 N mm^{-2} at 30 and 250°C. A similar increasing trend is observed for 20, 40 and 60 EPCY systems. The stiffness of 20, 40 and 60 EPCY systems at 250°C are found to increase by 2.14 times, 3.57 and 4.84 times, respectively when compared with EP system.

CONCLUSION

Mechanical and Damping properties of cyanate modified epoxy/glass fibre composites is investigated under varied temperature. The effect of temperature and cyanate loading on the natural frequency, damping factor, stiffness, storage modulus and loss modulus are analyzed. It is observed that the natural frequency, damping factor, stiffness, storage modulus and loss modulus are increased in cyanate loading when compared to neat epoxy-glass fibre composite. If temperature is increased in cyanate loading epoxy-glass fibre composite natural frequency, stiffness, storage modulus and loss modulus are reduced but damping factor and amplitude increased. From the results of the present study, it is obvious that the cyanate modified epoxy composite can be used for engineering and aerospace applications to provide better performance.

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