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# Optimisation of Damping in Short Fiber Reinforced Aligned Composites: A Review of literature using Micromechanical Analysis

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## Abstract

Vibration damping is becoming increasingly important for improved vibration and noise control, dynamic stability, and fatigue & impact resistance in advanced engineering systems. Specially, there is a strong need for information on methods for improvement of damping in lightweight structural composite materials so that they may be more effectively used in the design of high performance structures and machines. Polymer composites are good candidates in the development of damped structural materials because of their low specific weight and excellent stiffness & damping characteristics. A review is presented on fiber composite materials optimising damping properties and aspect ratios along with experimentally attainable at the micromechanical level.

**Key Word:** Noise Control, Dynamic Stability, Impact Resistance, Polymer, Damping Properties, Aspect Ratio, Micromechanical

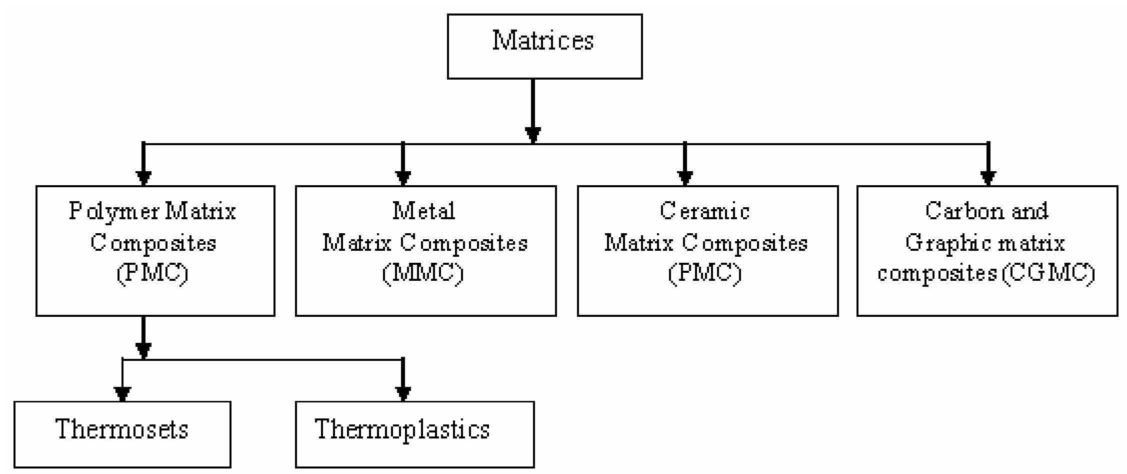
## Introduction

The damping characteristics of composite materials can be affected in two ways- at the macro mechanical level and at the micromechanical level. At the macro mechanical level, the constituent layer properties and orientations, inter-laminar effects, vibration coupling, surface attachments and damping treatments, co-cure damping layers and hybridization of laminae affect the damping capacity of a composite. At the micromechanical level, the improvement of damping can be attained by optimizing the fiber orientation, fiber aspect ratio, fiber spacing, fiber/matrix interphase effects, fiber coatings, fiber and matrix properties, and by using constituent material hybridization concepts.

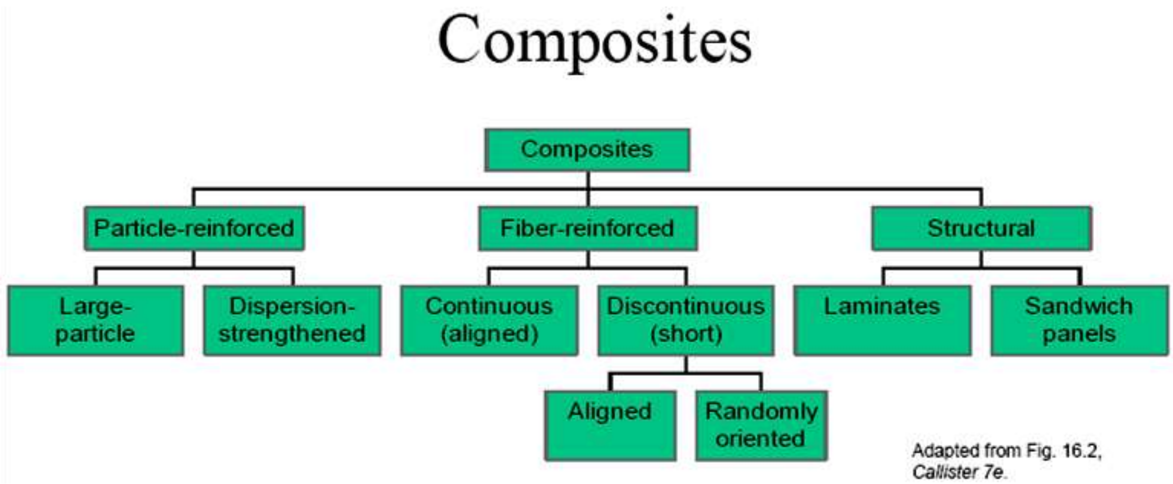
Composites are fibers or particles embedded in a matrix of another material. In matrix-based structural composites, the matrix serves two paramount purposes viz., binding the reinforcement phases in place and deforming to distribute the stresses among the constituent reinforcement materials under an applied force.

Composite materials are commonly classified in following two ways:

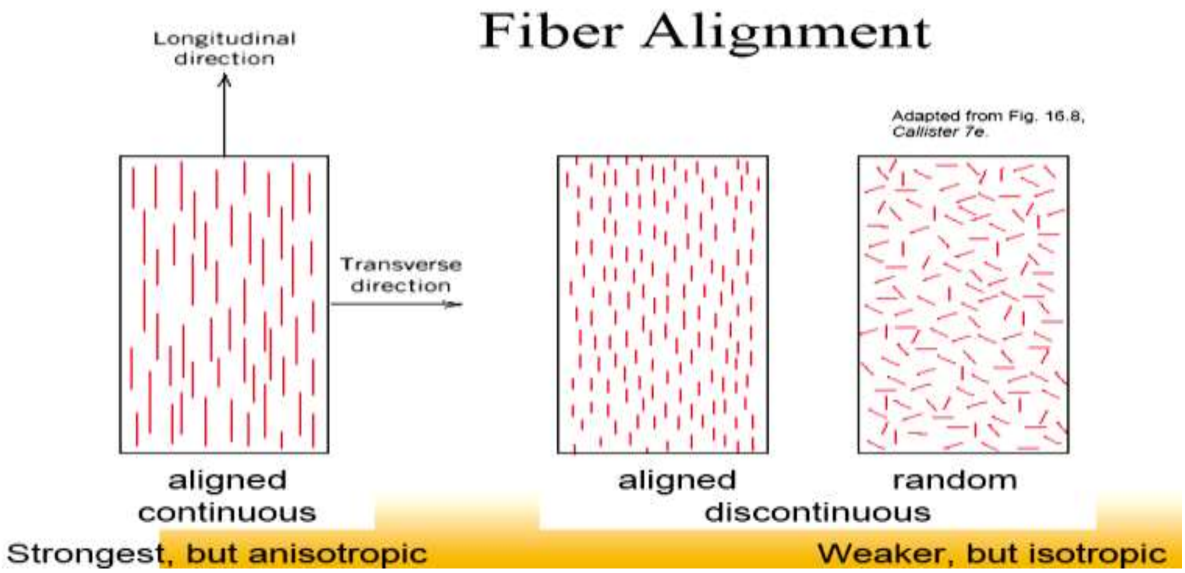
Classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.




The second level of classification refers to the reinforcement form - fiber reinforced composites, laminar composites and particulate composites. Fiber Reinforced composites (FRP) can be further divided as given below.




Fiber Reinforced Composites are composed of fibers embedded in matrix material. Such a composite is considered to be a discontinuous fiber or short fiber composite if its properties vary with fiber length. On the other hand, when the length of the fiber is such that any further increase in length does not further increase the elastic modulus of the composite, the composite is considered to be continuous fiber reinforced. Fibers are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibers must be supported to keep individual fibers from bending and buckling.



Certain sources have been delved into deep. The book by 'Gibson R. F.' titled as "Principles of Composite Material Mechanics" (New York: CRC, 2010) gives an insight about the dynamics of composite materials. The report submitted by Sun C. T. on "Optimization of internal Damping of Fiber Reinforced Composite materials" to Department of Engineering Sciences, University of Florida on Dec'17,1985 gives an idea about the damping phenomenon and the factors affecting that in various types of composite materials.

After going through these two sources, I came to know that the study of discontinuous fiber reinforcement appears to be a viable approach to the problem of improvement of internal damping in fiber-reinforced polymer-composite materials because the presence of shear stress concentrations at the fiber ends of the discontinuous fibers and the resulting shear-stress transfer to the viscoelastic matrix result in increased damping capacity of discontinuous fiber/short fiber composite material.

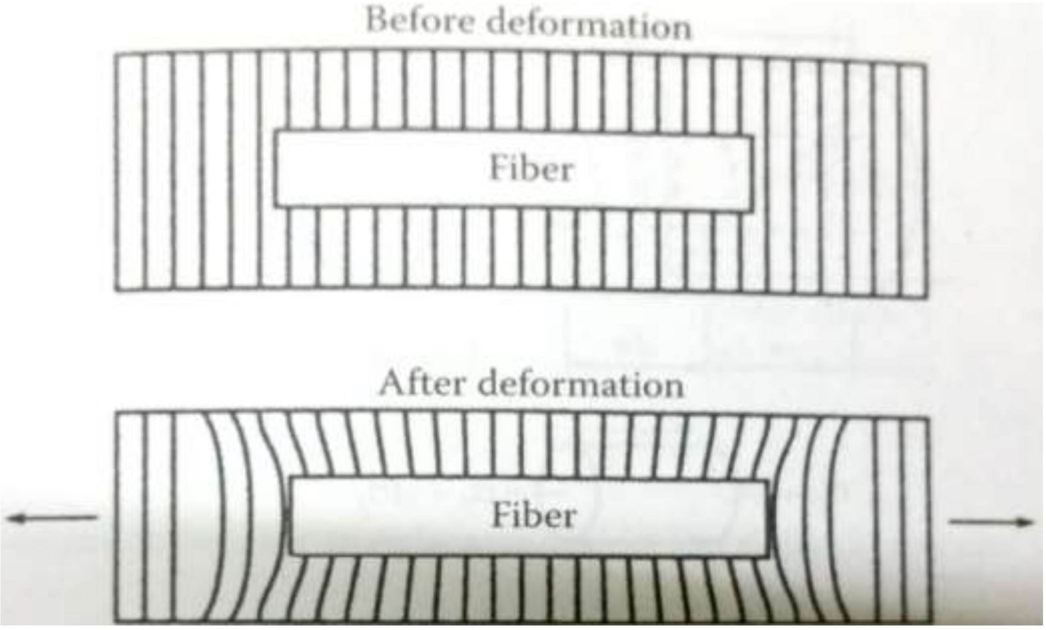



**Fig-1: Shear stress concentrations at the fiber end of discontinuous fiber reinforced composite (Source: Ref-2)**

*After knowing this, I decided to concentrate on the optimisation of damping in discontinuous aligned fiber reinforced composites by micromechanical analysis.*

## Methodology

i. Doing a theoretical micromechanical analysis of discontinuous aligned fiber reinforced composites.
ii. Identifying the factors affecting the damping capacity of discontinuous aligned fiber reinforced composites
iii. To support it with the experimental data available.
iv. Finding out ways to optimise the damping capacity of discontinuous aligned fiber reinforced composites.
v. The goal would be to increase damping without sacrificing the stiffness too much.

### Micromechanical Analysis

Suarez et al.[1], and Gibson et al.[1] showed that the use of discontinuous fiber reinforcement with a stiffness mismatch between fiber and matrix will lead to the improvement of internal damping in fiber-reinforced polymer composite materials by increasing the shear deformation near the fiber ends.

It was also shown experimentally and analytically by Suarez et al.[1] and Gibson et al. [2]. that for unidirectional short fiber composites, damping increases with decreasing fiber aspect ratio.

It has been shown by them that damping in discontinuous aligned fiber composites increases at lower fiber aspect ratios. Experimental research has not been done on damping for fiber aspect ratios (l/d) lower than

[1]Gibson RF, Chaturvedi SK, Sun CT. Complex moduli of aligned discontinuous fiber reinforced polymer composites, Journal of Materials Science 1982;17:3499-3509.

about100 due to difficulties, in fabricating aligned discontinuous fiber composites with such low l/d ratios. Since damping increases at lower fiber aspect ratios, it seems that near optimum damping could be obtained in a whisker or microfiber-reinforced composite. It is known that whiskers are particles with a very low fiber aspect ratio. Investigation of other micromechanical effects for improving damping include studies of the effects of fiber orientation.

**Theoretical Analysis**

In Ref. 1, the case of off-axis fiber orientation was treated analytically. It was predicted that, since the maximum shear stress occurs at an off-axis angle, maximum damping characteristics could be obtained at off axis angles.

*The analysis is carried out by applying the concepts of force balance on short fiber composite model to determine the longitudinal modulus. Then the elementary mechanics approach is used to find the modulus along the loading direction as a function of the mechanical properties of the fiber and the matrix materials. This is followed by applying the elastic-viscoelastic correspondence principle to find out the complex elastic modulus. Then separating the real and imaginary part of the complex modulus, the damping of the composite can be obtained.*

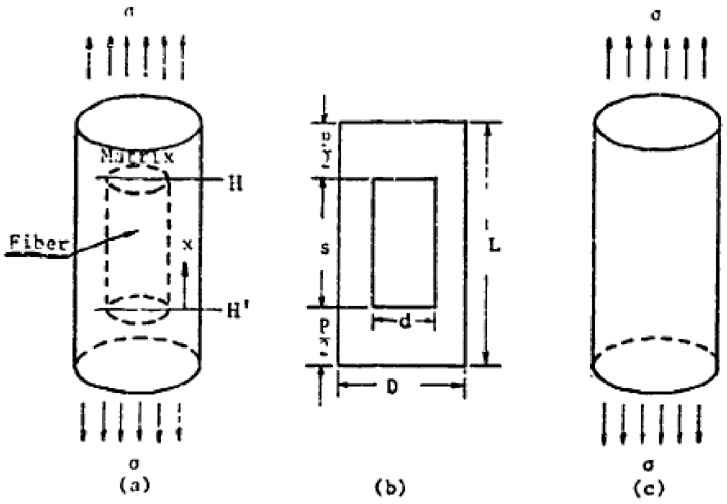



**Fig-2: Short fiber composite model (Source: Ref-16)**

The short fiber composite model is composed of a finite length fiber and the polymer matrix. Figure 2(c) is the homogeneous material equivalent to the composite of figure 2(a). Figure 2(b) is the front middle longitudinal section of view, where, d and l are the diameter and length of the fiber , D and L are the diameter and length of the composite model, p is interpreted as the distance between fiber tips along fiber direction. The ratio p/s is defined as R and is interpreted as the degree of discontinuity.

The theoretical analysis of internal damping and dynamic stiffness for aligned-discontinuous fiber-reinforced composites, mechanics models for the complex moduli, are established in Ref. 4 and Ref.14.

These analytical models were based on the Cox stress distribution. The basic assumptions were:

- **a.** Around fiber is surrounded by a cylindrical matrix under extensional load,
- **b.** Fiber and matrix are isotropic,
- **c.** A perfect bond exists between the fiber and the matrix,
- **d.** There is no load transfer through the ends of the fiber, and
- **e.** The transfer of load from the matrix to the fiber depends upon the difference between the actual displacement at a point on the interface and the displacement that would exist if the fiber were absent.

The expression for elastic stiffness of the discontinuous fiber composite is derived from the average of fiber stress based on Cox's fiber stress distribution (in which the longitudinal fiber stress is a function of position x)

$$\sigma_f = \epsilon_f E_f \left\{1 - \frac{\cosh\left[\beta\left(\frac{s}{2} - x\right)\right]}{\cosh\left(\frac{\beta s}{2}\right)}\right\} \qquad \text{----------- (1)}$$

Where $\epsilon_f$ is the strain in the fiber and

$$\beta s/2 \quad = \frac{2s}{d} \frac{G_m}{E_f \ln\left(\frac{\pi}{4v_f}\right)} \qquad \text{----------- (2)}$$

The average fiber stress is

$\sigma = \frac{1}{s/2} \int_0^{s/2} \sigma_f \, dx$, or

$$\sigma_f = \epsilon_f E_f \left\{1 - \frac{\tanh[\beta s/2]}{\beta s/2}\right\} \qquad \text{----------- (3)}$$

The longitudinal modulus of composite material between sections H and H' can be obtained from rule of mixtures

$$E_C \ = E_f \ \left\{1 - \frac{\tanh\left[\frac{\beta s}{2}\right]}{\frac{\beta s}{2}}\right\} V_f^1 + E_m \, V_m^1 \qquad \text{----------- (4)}$$

Here $V_f^1$ and $V_m^1$ are the fiber volume fraction and matrix volume fraction between sections H and H' respectively. If these are expressed in terms of $V_f$, $V_m$ and R ,

$$E_C \ = E_f \ \left(V_f + V_f R\right)\left[1 - \frac{\tanh(\beta \, s/2)}{\beta \, s/2}\right] + E_m \left(V_m - V_f R\right) \qquad \text{----------- (5)}$$

Here, R is the ratio of P to s.

**Table 1.1 (Source: Ref-16)** shows the values of $\frac{\tanh[\beta s/2]}{\beta s/2}$ of graphite epoxy and Kevlar epoxy with $v_f$ being 0.7 or 0.4. This table indicates that ***the modification term becomes important when fiber volume fraction and fiber aspect ratio, both are small***. On the other hand, when the fiber volume fraction is greater than 0.4 and the fiber aspect ratio is greater than 100, the effect of $\frac{\tanh[\beta l/2]}{\beta l/2}$ could be neglected.

| **Composite** | $\boldsymbol{v_f}$ | **s/d** | $\boldsymbol{\frac{\tanh[\beta s/2]}{\beta s/2}}$ |
|---|---|---|---|
| **Graphite- epoxy** | **0.4** | **5** | **0.725** |
| Graphite- epoxy | 0.7 | 5 | 0.369 |
| **Kevlar-epoxy** | **0.4** | **5** | **0.610** |
| Graphite- epoxy | 0.4 | 25 | 0.180 |
| Graphite- epoxy | 0.7 | 25 | 0.074 |
| Kevlar-epoxy | 0.4 | 25 | 0.135 |
| Graphite- epoxy | 0.4 | 100 | 0.045 |

The longitudinal Young's modulus of the homogeneous material equivalent to short fiber composite model can be calculated using Energy balance.

$$U_a = U_c \qquad \text{----------- (6)}$$

$$U_a = \frac{1}{2}\frac{\sigma^2}{E_M}\frac{P}{L} + \frac{1}{2}\frac{\sigma^2}{E_C}\frac{S}{L} \qquad \& \qquad U_C = \frac{1}{2}\frac{\sigma^2}{E_L} \qquad \text{----------- (7)}$$

Where $E_L$ is the equivalent longitudinal modulus of the homogeneous material. Solving equations (5), (6) and (7), we get

$$E_L = \frac{E_C \ E_m}{(E_C)\left(\frac{R}{1+R}\right) + (E_m)\left(\frac{R}{1+R}\right)} \qquad \text{----------- (8)}$$

For a continuous aligned composite, the off-axis elastic modulus, $E_x$, along the direction of the applied stress is given as a function of the longitudinal modulus, $E_L$, the transverse modulus, $E_T$, the in-planeshear modulus, $G_{LT}$, the major Poisson's ratio, $\nu_{LT}$, and the direction of the applied load $\theta$,as below[2]

$$\frac{1}{E_x} = \frac{1}{E_L}\cos^4\theta + \left(\frac{1}{G_{LT}} - \frac{2\nu_{LT}}{E_L}\right)\sin^2\theta\cos^2\theta + \frac{1}{E_T}\sin^4\theta \qquad \text{----------- (9)}$$

Equation (9) can easily be derived from elementary mechanics. Similar expression can be derived for off-axis aligned short fiber composites, where longitudinal modulus, $E_L$ , is given by equation (8).

The longitudinal modulus $E_L$ is given by eq (4).The transverse modulus, the in-plane shear modulus and the major poisson ratio can be obtained empirically by using the Halpin-Tsai equations and the rule of mixtures.

$$E_T = (E_m)\left(\frac{1+2\eta_1 V_f}{1-\eta_1 V_f}\right) \qquad \text{----------- (10)}$$

$$G_{LT} = (G_m)\left(\frac{1+\eta_2 V_f}{1-\eta_2 V_f}\right) \qquad \text{----------- (11)}$$

$$V_{LT} = v_{fLT} V_f + v_m V_m \qquad \text{----------- (12)}$$

Where,

$$\eta_1 = \frac{\left(\frac{E_{fT}}{E_m}\right)-1}{\left(\frac{E_{fT}}{E_m}\right)+2} \qquad \text{----------- (13)}$$

$$\eta_2 = \frac{\left(\frac{E_{fT}}{E_m}\right)-1}{\left(\frac{E_{fT}}{E_m}\right)+1} \qquad \text{----------- (14)}$$

Equations (1) to (14) are derived for elastic material. The Correspondence principle is used to obtain the corresponding relationships of viscoelastic material. Once the expressions for the complex elastic modulus longitudinal as well as for off axis loads are obtained, by separating the real and imaginary parts, two equations for the storage modulus and loss modulus could be found. This predicts an optimum fiber aspect ratio (ratio of fiber length to fiber diameter) for maximum damping[3].

Using the elastic-viscoelastic correspondence principle, the elastic constants for the composite and for each constituent material can be transformed to complex viscoelastic constants as follows:

$$E_{fL}^* = E_{fL}^{'} + iE_{fL}^{''}$$
$$E_{fT}^* = E_{fT}^{'} + iE_{fL}^{''}$$
$$G_{fLT}^* = G_{fLT}^{'} + iG_{fLT}^{''}$$
$$E_m^* = E_m^{'} + iE_m^{''} \qquad \text{----------- (15)}$$
$$G_m^* = G_m^{'} + iG_m^{''}$$
$$v_m^* = v_m^{'} + iv_m^{''}$$
$$v_{fLT}^* = v_{fLT}^{'}$$
$$E_x^* = E_x^{'} + iE_x^{''} \qquad \text{----------- (16)}$$

[2]Jones, R.M., Mechanics of Composite Materials, Scripta Book Co. (1975)

[3]Gibson RF, Chaturvedi SK, Sun CT. Complex moduli of aligned discontinuous fiber reinforced polymer composites, Journal of Materials Science 1982;17:3499-3509.

Here the prime quantities indicate the storage modulus/ storage poisson ratio and the double prime quantities indicate the loss modulus/loss poisson's ratio. The imaginary part of fiber poisson ratio is set as zero because most fibers are anisotropic materials.

The bulk modulus of epoxy matrix, while considering viscoelastic behaviour, is given as

$$k_m = \frac{E_m' + iE_m''}{3(1-2v_m' - i2v_m'')} \qquad \text{----------- (17)}$$

The complex $v_m$ is obtained from equation (17)

$$v_m' + iv_m'' = \frac{1}{2} + \left(1 - \frac{E_m' + iE_m''}{3k_m}\right) \qquad \text{----------- (18)}$$

Using equation (18) and assuming the bulk modulus of epoxy to be real i.e.

$$k_m = \frac{E_m}{3(1-2v_m)} \qquad \text{----------- (19)}$$

We get,

$$v_m' + iv_m'' = v_m' + i\left[\frac{E_m''}{E_m'}\left(v_m' - \frac{1}{2}\right)\right] \qquad \text{----------- (20)}$$

Similarly, for shear modulus

$$G_m' + iG_m'' = \frac{E_m'}{2(1+v_m')} + i\frac{E_m'}{2(1+v_m')}\frac{9k_m}{(9k_m - E_m)}\frac{E_m''}{E_m'} \qquad \text{----------- (21)}$$

The complex form of $\frac{\beta s}{2}$ is directly taken from ref-16.

$$\frac{\beta' s}{2} + i\frac{\beta'' s}{2} = \frac{\beta s}{2} + \frac{i\beta s}{4}\left(\frac{G_m''}{G_m'} - \frac{E_{fL}''}{E_{fL}'}\right) \qquad \text{----------- (22)}$$

The loss factors of matrix and fiber are treated as material properties and are given as

$$\eta_m = \frac{E_m''}{E_m'} \qquad \text{----------- (23)}$$

$$\eta_f = \frac{E_{fL}''}{E_{fL}'} \qquad \text{----------- (24)}$$

Equations (15), (16) and (22) can be rewritten as,

$$E_{fL}' + iE_{fL}'' = E_{fLT}'(1 + i\eta_f) = E_{fL}^*$$

$$E_{fT}' + iE_{fT}'' = E_{fT}'(1 + i\eta_f) = E_{fT}^*$$

$$G_{fLT}' + iG_{fLT}'' = G_{fLT}'(1 + i\eta_f) = G_{fLT}^*$$

$$E_m' + iE_m'' = E_m'(1 + i\eta_m) = E_m^* \qquad \text{----------- (25)}$$

$$G_m' + iG_m'' = G_m'(1 + i\eta_m) = G_m^*$$

$$v_{fLT}^* = v_{fLT}' = v_{fLT}$$

$$E_x^* = E_x' + iE_x''$$

$$\frac{\beta' s}{2} + \frac{i\beta''}{s} = \frac{\beta s}{2}\left[1 + \frac{i}{2}(\eta_{Gm} - \eta_f)\right] = \frac{\beta^* s}{2}$$

Where $\eta_{Gm}$ is defined as

$$\eta_{Gm} = \frac{9K_m}{9k_m - E_m}\eta_m = \frac{G_m''}{G_m'} \qquad \text{----------- (26)}$$

The equations for complex longitudinal modulus, complex transverse modulus , complex in plane shear modulus and complex major poisson ratio can be rewritten as :

$$E_L^* = \frac{(E_C' + iE_C'')(E_m' + iE_m'')}{(E_C' + iE_C'')\left(\frac{R}{1+R}\right) + (E_m' + iE_m'')\left(\frac{R}{1+R}\right)} \quad \text{----------- (27)}$$

$$E_T^* = (E_m' + iE_m'')\left(\frac{1+2\eta_1^* V_f}{1-\eta_1^* V_f}\right) \quad \text{----------- (28)}$$

$$G_{LT}^* = (G_m' + iG_m'')\left(\frac{1+\eta_2^* V_f}{1-\eta_2^* V_f}\right) \quad \text{----------- (29)}$$

$$V_{LT}^* = \left(v_{fLT}' V_f + v_m' V_m\right) + i\eta_m\left(v_m' - \frac{1}{2}\right)V_m \quad \text{----------- (30)}$$

Where

$$E_C' + iE_C'' = \left(E_{fL}' + iE_{fL}''\right)\left(V_f + V_f R\right)\left[1 - \frac{\tanh(\beta^* s/2)}{\beta^* s/2}\right] + (E_m' + iE_m'')\left(V_m - V_f R\right) \quad \text{--- (31)}$$

$$\tanh(\beta^* s/2) = \tanh(\beta s/2) + i\left(\frac{\beta s}{2}\right)\frac{(\eta_{Gm} - \eta_f)}{2}\left(\frac{1}{\cosh^2(\beta s/2)}\right) \quad \text{----------- (32)}$$

$$\eta_1^* = \frac{\left(E_{fT}' + iE_{fT}''\right)/(E_m' + E_m'') - 1}{\left(E_{fT}' + iE_{fT}''\right)/(E_m' + E_m'') + 1} \quad \text{----------- (33)}$$

$$\eta_2^* = \frac{\left(G_{fLT}' + iG_{fLT}''\right)/(G_m' + G_m'') - 1}{\left(G_{fLT}' + iG_{fLT}''\right)/(G_m' + G_m'') + 1} \quad \text{----------- (34)}$$

Substituting the values of $E_L^*$, $E_T^*$, $G_{LT}^*$ and $V_{LT}^*$ from equations (27) to (30) into equation (9)and substituting $E_x' + iE_x''$ for $E_x'$, we get

$$\frac{1}{E_x' + iE_x''} = \frac{1}{E_L^*}\cos^4\theta + \left(\frac{1}{G_{LT}^*} - \frac{2v_{LT}^*}{E_L^*}\right)\sin^2\theta\cos^2\theta + \frac{1}{E_T^*}\sin^4\theta \quad \text{----------- (35)}$$

Damping Loss factor of the aligned short fiber composite along X direction, is determined by,

$$\eta_x = \frac{E_x''}{E_x'} \quad \text{----------- (36)}$$

Equations (35) and (36) show that the material damping and the stiffness of the aligned short fiber composite are functions of material properties of fiber and matrix, fiber aspect ratio, fiber volume fraction, loading direction and packing geometry of the fiber

$$E_x' = \phi_1[E_f', E_m', V_f, V_m, \left(\frac{l}{d}\right), \eta_f, \eta_m, v_f, v_m, \theta, packing\ array] \quad \text{---------- (37)}$$

$$E_x'' = \phi_2[E_f', E_m', V_f, V_m, \left(\frac{l}{d}\right), \eta_f, \eta_m, v_f, v_m, \theta, packing\ array] \quad \text{-----------(38)}$$

The complete equations are given in Ref. 14.

**Predicted and experimentally obtained data**

Gibson et al. [2], Suarez et al. [3], Sun [14] and Abdin et al. [17] have discussed the predicted and experimentally obtained values of Storage Modulus and Loss factor for short fiber reinforced aligned composites in their works.

Gibson et al. [2] have given following graphs showing the variation of storage modulus and loss factor with the aspect ratio (l/d):

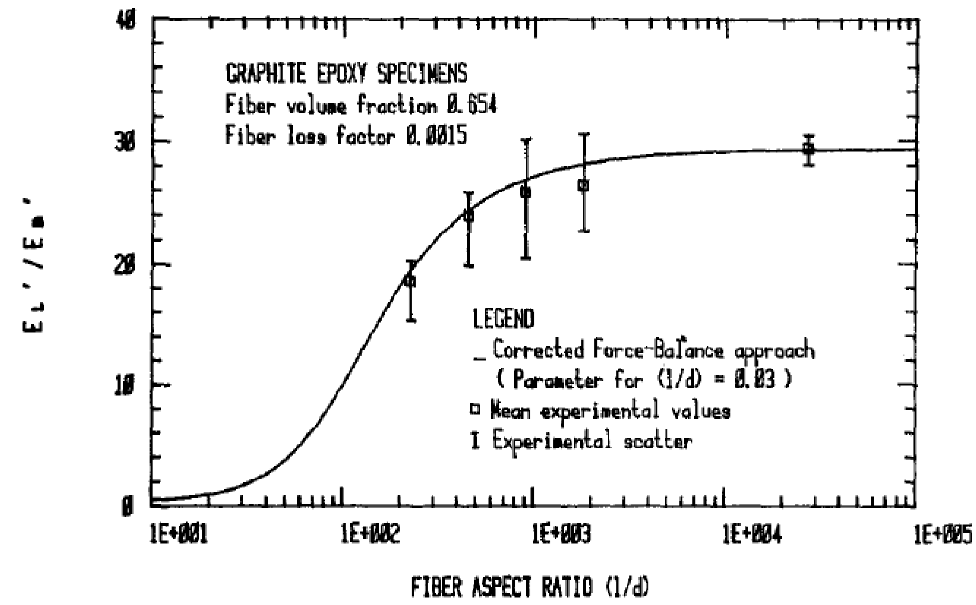



**Fig-3: Predicted and experimentally obtained data for $E_l'/E_m'$ vsfiber aspect ratio for graphite/epoxy with curve fitting (Source: Ref-3)**

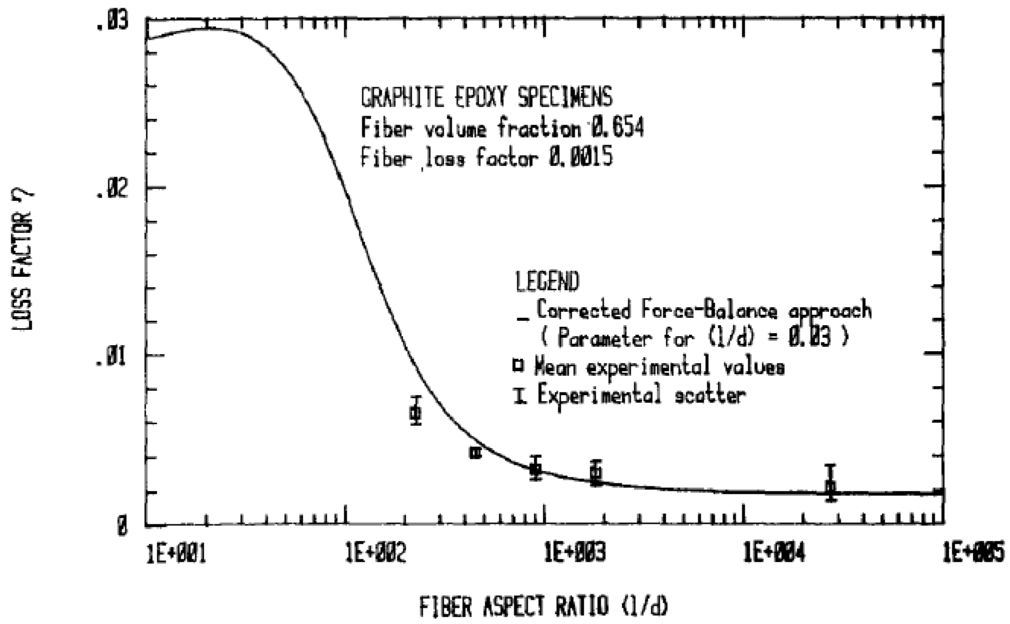



**Fig-4: Predicted and experimentally obtained data for Loss factor vs fiber aspect ratio for graphite/epoxy with curve fitting (Source: Ref-3)**

It is clear that the best damping characteristics are apparently obtained in low- fiber-aspect ratio composites.

Following figures of Ref [3] show the variation of Storage Modulus and Loss factor with fiber direction.

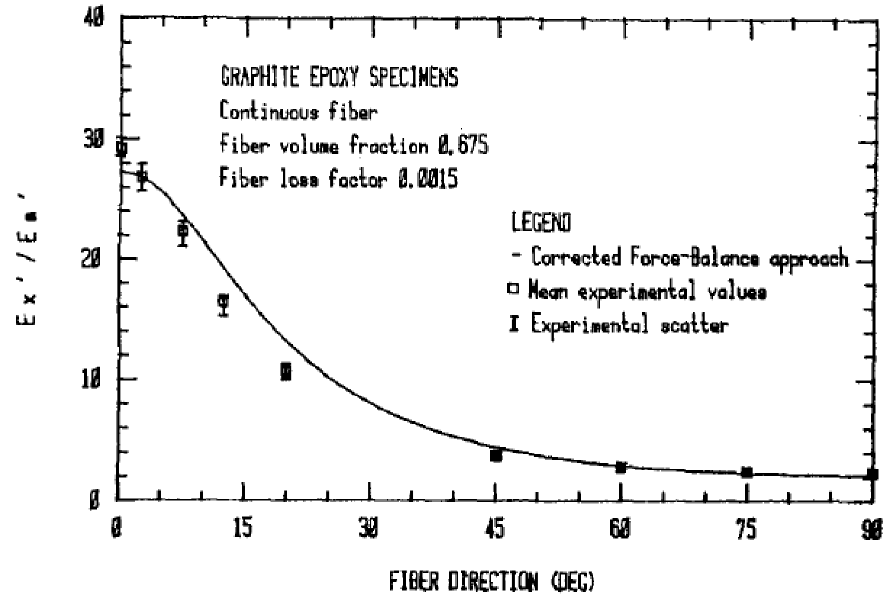



**Fig-4: Predicted and experimentally obtained data for $E_x'/E_m'$ vs fiber direction (Source: Ref-3)**

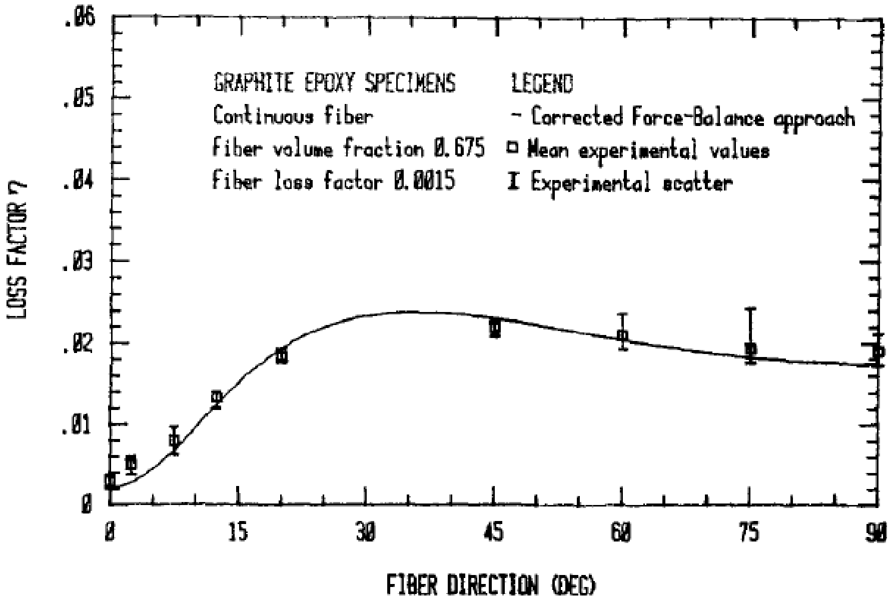



**Fig-5: Predicted and experimentally obtained data for loss factor with fiber direction (Source: Ref-3)**

It is clear that the stiffness (i.e. storage modulus) is maximum at 0 deg and continuously goes down rapidly up to about 30 deg and then more slowly from there to 90 deg. The loss factor increases to a maximum for an optimum fiber direction of approximately 30 deg, then decreases slowly with increasing fiber direction.

Ref(3) shows that the predicted maximum loss factors occur for zero-degree fibers with an aspect ratio near 20, but that when the actual minimum attainable aspect ratios are used, the off- axis fibers give greater damping.

Sun [14] also gives the numerically obtained values for the storage modulus and the loss factor. Following three figures present the non dimensional plots of Storage Modulus, Loss modulus and the Loss factor of graphite epoxy composites as functions of fiber aspect ratio (s/d), with $\theta$ ( the angle between fiber direction and loading direction) as parameter.

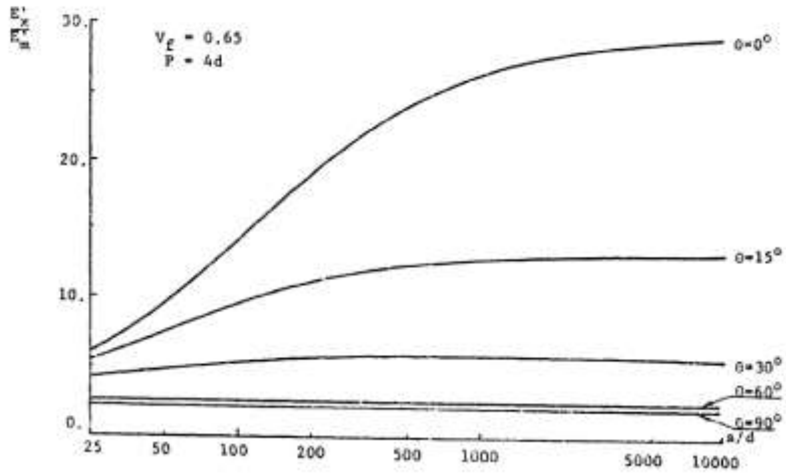



**Fig-6: Plots of $E_x'/E_m'$ vs fiber aspect ratio using $\theta$ as a parameter for Graphite Epoxy Composites (Source: Ref-14)**

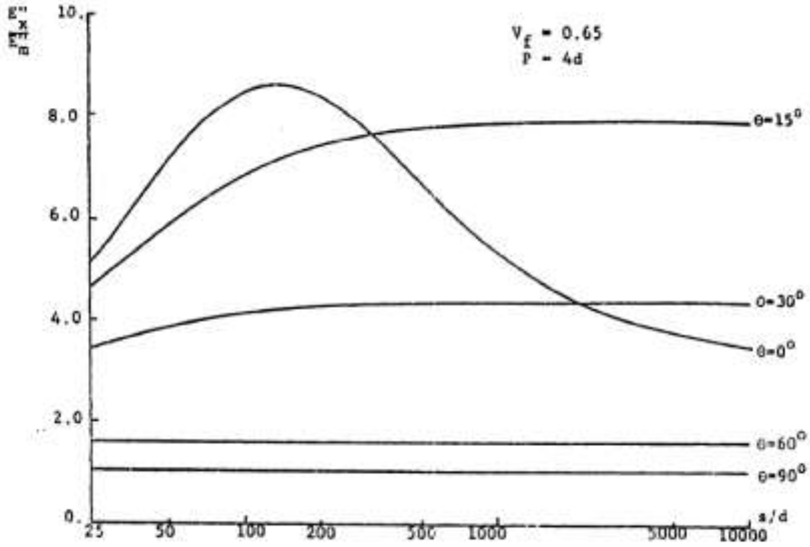



**Fig-7: Plots of $E_x''/E_m''$ vs fiber aspect ratio using $\theta$ as a parameter for Graphite Epoxy Composites (Source: Ref-14)**

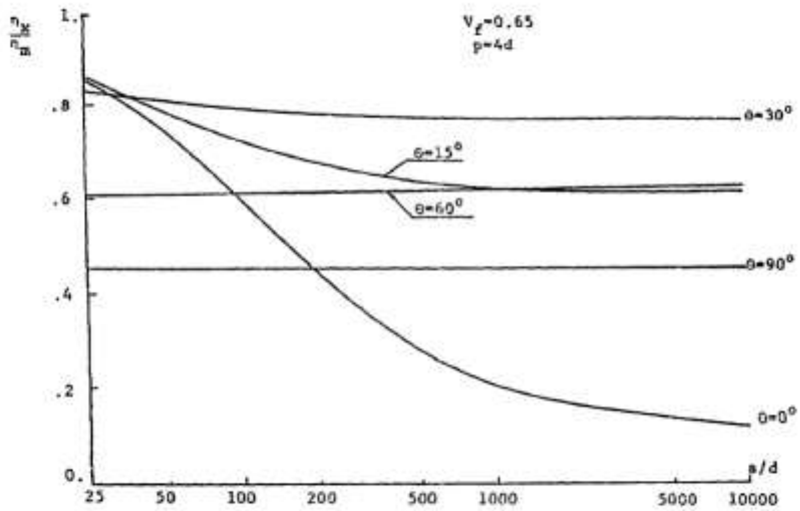



**Fig-8: Plots of $\eta_x/\eta_m$ vs fiber aspect ratio using $\theta$ as a parameter for Graphite Epoxy Composites (Source: Ref-14)**

For small angles, say $\theta < 10 degrees$, the storage modulus sharply increases as fiber aspect ratio increases, the loss modulus reaches its maximum around l/d=130 and then reduces as l/d increases, while

damping apparently decreases as l/d increases. It is recognised that for large angles, the difference in loss moduli have more influence on damping.
Similar results were obtained by Gibson [2],

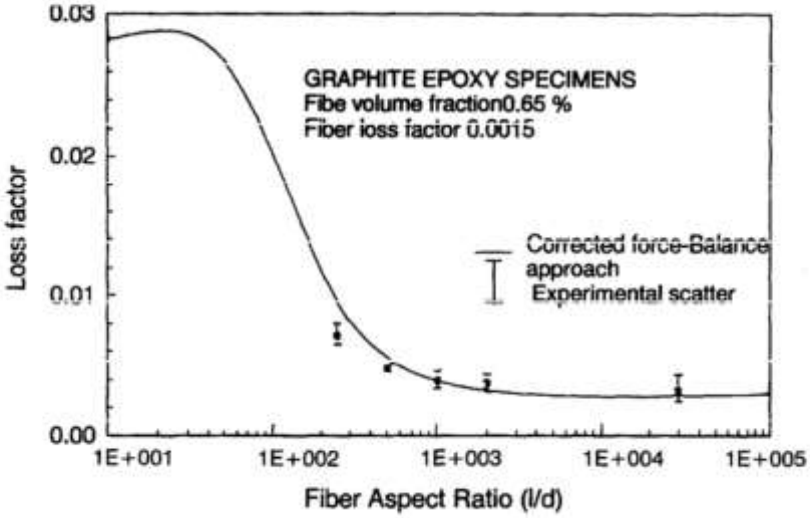



**Fig-9: Plots of Loss factor vs fiber aspect ratio for Graphite Epoxy Composites (Source: Ref-2)**

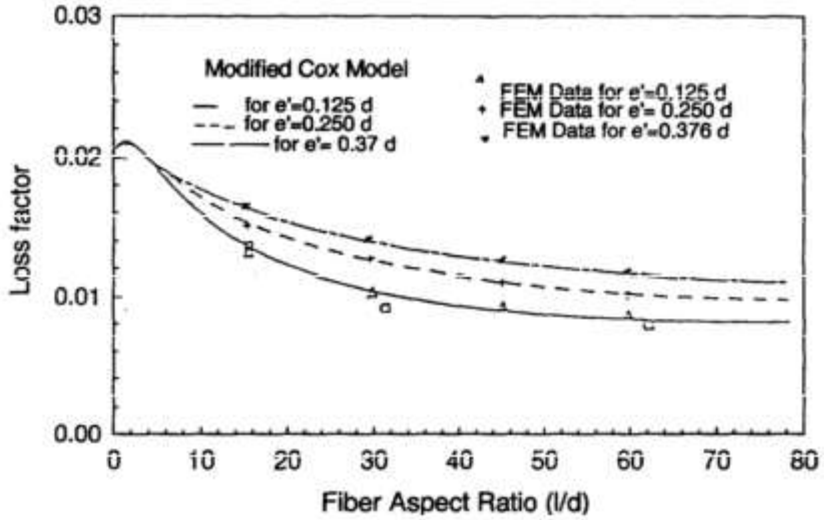



**Fig-9: Plots of Loss factor vs fiber aspect ratio for Graphite Epoxy Composites using FEM data (Source: Ref-2)**

Abdin et al. [17] have also discussed about the predicted values of stiffness and storage modulus for short fiber reinforced aligned composites.

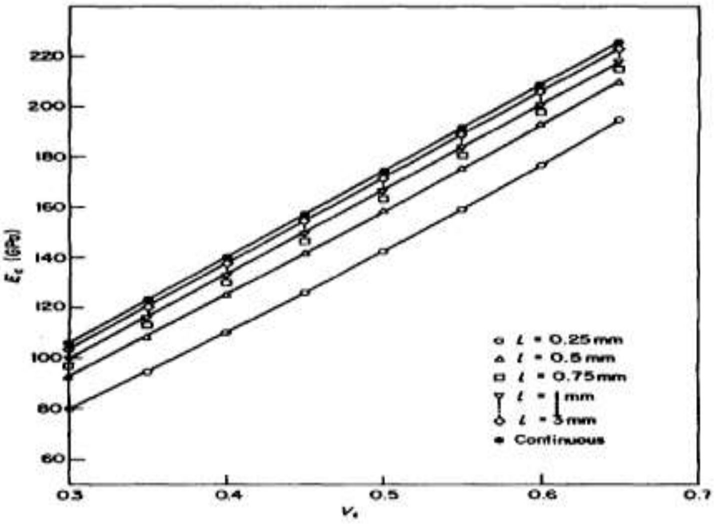



**Fig-10: Variation of modulus of elasticity with fiber volume fraction for aligned short CFRP composites (HM-S/DX21 O) for various fiber lengths (Source:Ref-17)**

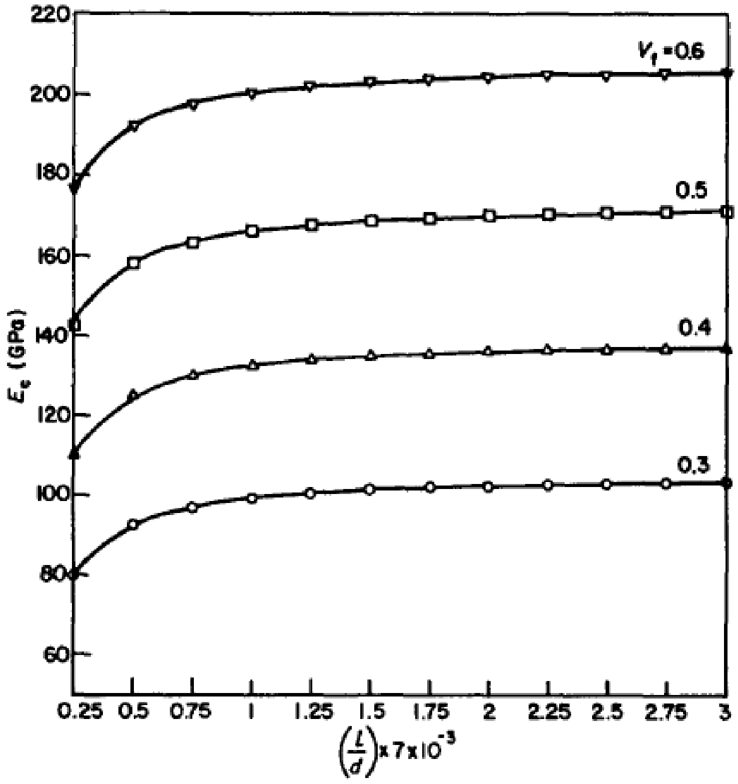



**Fig-11: Variation of modulus of elasticity with fiber aspect ratio for aligned short CFRP composites (HM-S/DX21 O) for various fiber volume fractions (Source:Ref-17)**

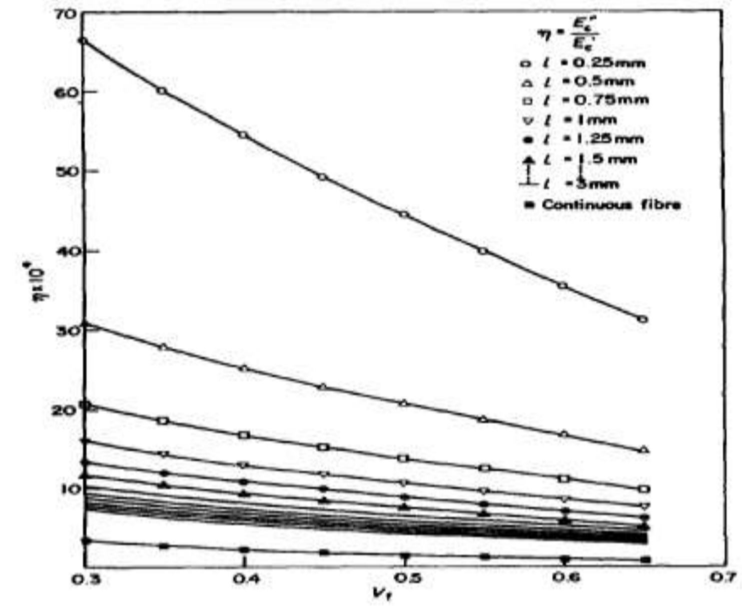



**Fig-12: Variation of material loss factor with fiber volume fraction for aligned short CFRP composites (HM-S/DX21 O) for various fiber lengths (Source: Ref-17)**

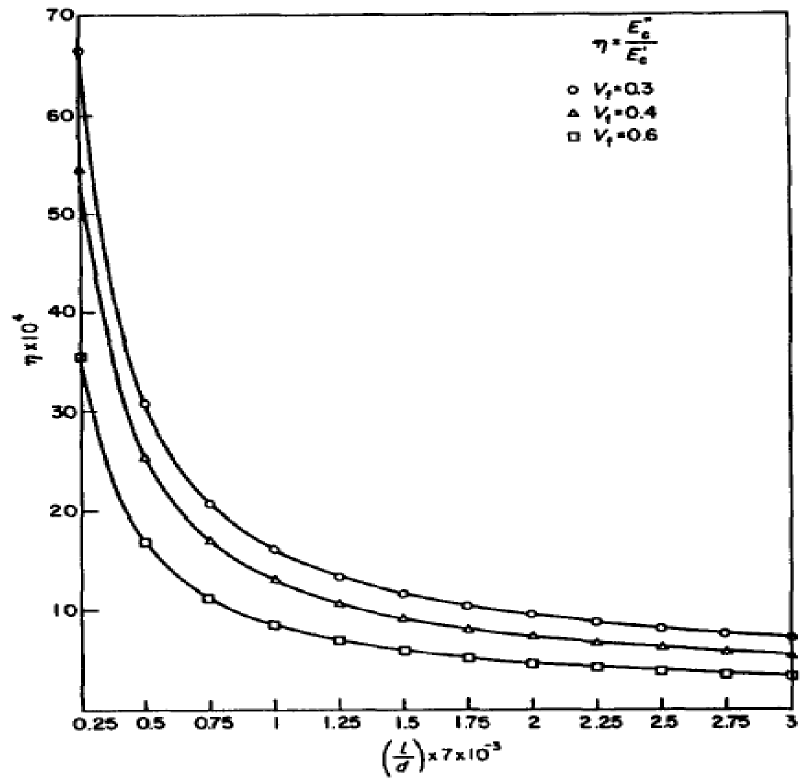



**Fig-13: Variation of material loss factor with fiber aspect ratio for aligned short CFRP composites (HM-S/DX21 O) for various fiber volume fractions (Source: Ref-17)**

It is clearly shown in Figs 4 and 2 that a compromise between stiffness and damping characteristics may be arrived at by control of the fiber aspect ratio.

## Conclusions

**(1)** Analytical predictions show that discontinuous fiber composite materials give maximum damping for fiber aspect ratios less than those experimentally attainable in this research. Experimental data did verify the predicted trend of increased damping as the aspect ratio is reduced

**(2)** High damping could be achieved by small $V_f$, small l/d , while high stiffness could be achieved by high $V_f$ , small $\theta$ and large l/d.

**(3)** For small angles, high l/d gives high stiffness while low l/d brings high damping. For large angles, damping and stiffness are independent of l/d.

**(4)** Reduction of fiber length at a given fiber volume fraction increases the loss factor, the modulus remaining relatively high compare with that of continuously reinforced composites at the same volume fraction.

**(5)** By correct choice of fiber aspect ratio and the volume fraction, damping of aligned short fiber composites can be improved while retaining high modulus of elasticity (stiffness).

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