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Interphase Effect on Damping in Fiber Reinforced Composites

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Summary

Polymers composite are modeled as fiber, interphase and matrix. Interphase properties are very crucial for bonding between fiber and matrix. Interphase can be strong and weak depending upon its properties. Damping of composite material depends on interphase properties and required damping can be obtained by varying the properties of interphase. In this paper three phase mathematical model has been proposed for the evaluation of damping incorporating the effect of fiber packing. Effect of interphase has been analysed for the longitudinal loss factor, transverse loss factor, transverse shear loss factor and longitudinal shear loss factor. Results obtained by modeling fiber reinforced composite using finite element method are compared with those predicted newly developed model.

keywords: Polymer-matrix-composite; Interphase; damping, fiber packing

Introduction

Study of mechanical behavior of polymer composite is often restricted to a two phase system. However with the development of fiber coating technology the effect of interphase zone generally called interphase is of practical importance for the prediction of overall behavior of the composites. The effect of interphase on mechanical properties of composite may be investigated by studying two extremes, perfect bonding of fiber-interphase - matrix, and debonding. Analysis of interphase is essential for evaluation of damping of fiber reinforced composite.

Many authors have discussed about the effect of hard and soft interphase effect on mechanical performance of composite. Effect of interphase on damping has been discussed by Neilson [1] using rule of mixture to determine loss tangent (tan φ_c^o) for ideal composites. Effect of type of interfacial bonding covering the range from weak to strong is considered in the works of Kubat [2]. Decrease in damping with improvement in the interfacial bonding has been observed by Chinquin et al., [3] and it was verified by dynamic mechanical analysis test. Three phase model using energy balance approach was developed by Vantomme [4] to predict the longitudinal and shear loss factors for composite materials. Finegan and Gibson [5] studied the contribution of interphase to overall damping in fiber reinforced metal

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matrix composite. Further they developed analytical and FEM model [6] to evaluate the loss factor at micromechanical level. Parametric study has been carried out by Chandra et al., [7] for three phase composite which have shown that the change in properties of fiber, matrix and interphase leads to a change in the magnitude of effectiveness of interphase. Vazquez et al., [8] performed the dynamic analysis of unidirectional composite di-epoxy coated fiber and observed different damping behavior for different coating. Improvement in mechanical properties of fiber composite is obtained by saline coupling agent coating on fiber, stiffness and strength of composite materials depends on amount of coating [9]. Effect of interphase on damping of particulate composite has been evaluated [10] and found improvement in damping of composite containing elastic interphase. Effect of gradual interphase on elastic modulus for particulate composite has been studied [11] using the mean field theory and generalized self-consistent method. The effective storage and loss moduli of the composite are also determined through the dynamic correspondence principle.

To the best of knowledge of authors, no previous analytical work has been reported on the effect of viscoelastic interphase on the damping of composite incorporating the effect of fiber packing. In order to consider the effect of fiber packing and interphase, analytical three phase model for the prediction of damping in composite is presented here. Longitudinal (η_{11}) transverse (η_{22}), longitudinal shear (η_{12}) and transverse shear (η_{23}) loss factors are predicted by three phase bridging model and compared with the results available in the literature. The results confirm the effectiveness of the proposed analytical three phase model which considers fiber packing geometry also.

Three Phase Micromechanical Model

Two phase bridging model [12] for unidirectional fiber reinforced composite has been extended to incorporate the effect of interphase. In two phase model elastic stresses in matrix material are correlated with the fiber by bridging matrix. The bridging matrix represents the load sharing capacity of one constituent phase in the composite with respect to the other phase. Accordingly stresses in matrix, interphase and fiber are correlated and relationship derived for elastic modulus are given as in Eq. (1-4).

Constituent material properties used as input for proposed model are taken from Ref. [7]. Concentric cylinder model for unidirectional three phase fiber reinforced composite is taken in the form of representative volume element (RVE). It consists of fiber of radius r_f bounded by interface region of outer radius r_I embedded into matrix of outer radius $r_{m.}$ Further, condition of perfect fiber-interphase-matrix bonding and variable state of stress is assumed within RVE. Expressions for elastic moduli E_{11}, E_{22}, G_{12} and G_{23} are given below.

$$E_{11} = \frac{V_f + V_i a_{11fi} + V_m a_{11fi} a_{11im}}{V_f S_{11f} + V_i S_{11i} a_{11fi} + VmS_{11m} a_{11fi} a_{11im}} \tag{1}$$

$$E_{22} = \frac{\begin{gathered} V_i V_f (a_{11fi} + a_{22fi}) + V_i a_{11fi} a_{22fi} (V_i + V_m a_{22im}) + V_f^{(} V_f + \\ V_m a_{22fi} a_{22im}) + V_m a_{11fi} a_{11im} (V_f + V_i a_{22fi} + V_m a_{22fi} a_{22im}) \end{gathered}}{\begin{aligned} & -V_m a_{11fi} a_{11im} (V_i S_{22i} a_{22fi} + V_m a_{22im} S_{22m} a_{22fi} + V_i a_{12fi} S_{12i} + V_f S_{22f}) \\ & -V_f V_i (S_{12i} a_{12fi} + S_{22i} a_{22fi}) - V_f V_m a_{22im} (S_{12m} a_{12fi} + S_{22m} a_{22fi}) \\ & -V_i a_{11fi} (V_i a_{22fi} S_{22i} + V_m a_{11fi} S_{12m} a_{12im} + V_m a_{22im} S_{12m} a_{12fi} + V_m a_{22im} S_{22m} a_{22fi} \\ & +V_f S_{22f} - V_m a_{11im} S_{12m} a_{12fi} - V_m S_{12i} a_{12im} - V_m a_{12fi} S_{12m} a_{22im}) + V_f V_m \\ & (-S_{12m} a_{11fi} a_{12im} + S_{12f} a_{11fi} a_{12im} + S_{12m} a_{12fi} a_{22im}) \end{aligned}} \tag{2}$$

$$G_{12} = \frac{G_f G_i G_m (V_f + V_i a_{66fi} + V_m \mathrm{a}_{66\mathrm{fi}} \mathrm{a}_{66\mathrm{im}})}{G_f G_m V_i a_{66fi} + G_f G_i V_m a_{66fi} a_{66im} + G_i G_m V_f} \tag{3}$$

$$G_{23} = \frac{V_f + V_i a_{44fi} + V_m a_{44fi} a_{44im}}{V_f S_{44f} + V_i S_{44i} a_{44fi} + V_m S_{44m} a_{44fi} a_{44im}} \tag{4}$$

Subscript f, I and m are fiber, interphase and matrix respectively.

Using the four elastic moduli $E_{11,}E_{22,}G_{12}$, and G_{23} of unidirectional fiber composite and further applying the viscoelastic correspondence principle in which E_f, E_I, E_m become complex with the loss modulus associated as the imaginary part. As the result composite moduli in complex form are obtained which represent the storage moduli and loss moduli component by real and imaginary parts respectively, loss factors η_{11}, η_{22}, η_{12} and η_{23} are predicted.

Results and discussion

Fig. 1 shows the variation of longitudinal loss factor (η_{11}) with respect to hard and soft interphase thickness from 0.02 to 0.1. Longitudinal loss factor (η_{11}) increases with the increase of hard interphase thickness as bond between fiber and matrix increases. For soft interphase loss factor decreases with increase of interphase thickness marginally. Results obtained by this method is almost equal to the result of FEM. Results are in very good agreement with Vantomme results for soft interphase. Fiber packing factor has no effect on longitudinal loss factor.

Fig. 2 depicts the interphase thickness effect on longitudinal shear loss factor (η_{12}) that increases with the increase of soft interphase phase thickness and decreases for hard interphase. Effect of fiber packing factor is significant and it decrease with the decrease of longitudinal fiber packing factor (α). For hard interphase withα=0.8, three phase bridging model results are very close to FEM results hence it can be concluded that it is for square packing. Results of loss factor (η_{12}) is

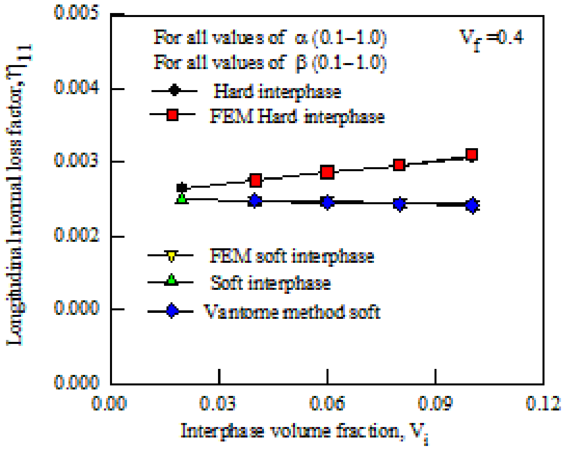

Fig. 1. Effect of interphase volume fraction on η_{11}

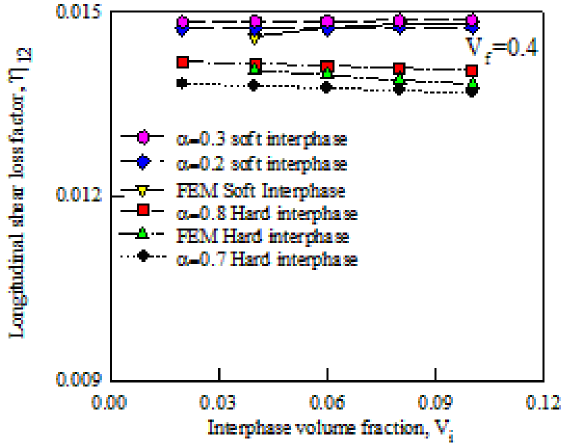

Fig. 2. Effect of interphase volume fraction on η_{12}

in very good agreement at (α) =0.2 and compared well with FEM results obtained for soft interphase.

Figs. (3-4) illustrate that transverse normal loss factor and transverse shear loss factor decrease with the increase of interphase thickness for hard interphase and increase for soft interphase. Proposed model results of η_{22} for soft interphase when (β)=0.3 and for hard interphase (β)=0.5 are in good agreement with FEM results.

Conclusions

A mathematical model for three phase fiber reinforced composites have been developed using the concept of bridging model. Loss factors have been predicted and study of effect of fiber packing and interphase thickness has been carried out.

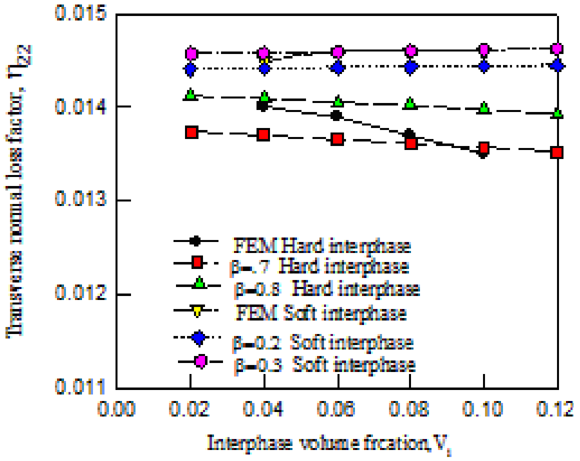

Fig. 3. Effect of interphase volume fraction on η_{22}.

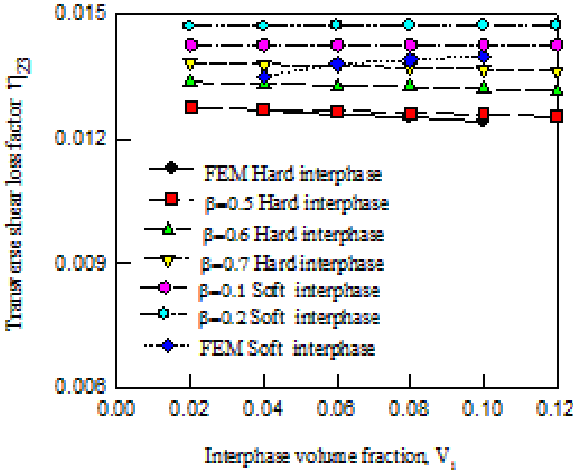

Fig. 4. Effect of interphase volume fraction on η_{23}.

Results obtained from the present model are in very good agreement with FEM model results. Fiber packing plays a significant role in the prediction of loss factors of overall composite. Interphase properties are very important for damping evaluation of composite materials.

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