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F.E. Analysis and Experimental Investigation of Effect of Reinforcement Dimensions on Vibration Characteristics of Polypropylene Composite

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***Abstract*—**Composites are being used everywhere nowadays. Their increased utilization necessitates their detailed study before putting them in actual use. Vibration characteristics are one of the important parameters which have to be studied for safe utilization of composites in various field specially related to antivibration applications. Damping behavior directly relates materials ability to absorb shocks and vibrations without getting damaged. Phase Lag gives the measure of damping capacity of any material. Reinforcement types also contribute towards damping behavior. In present work damping behavior of unreinforced material, long glass fiber reinforced and short glass fiber reinforced polypropylene material are examined experimentally. Effect of reinforced fibers dimensions are first studied numerically using F.E. software Ansys. Results of F.E. analysis will provide composite with greater interfacial strength. Increased interfacial strength increases the ability of material to absorb shocks and vibrations without getting fractured, thus absorbing more energy and providing increased damping capacity. Experimental results confirms that presence of reinforced fibers increases the damping capacity and among reinforcements, short fiber reinforced polypropylene shows increased damping capacity then long glass fiber reinforced.

Keywords—*polymer composite, polypropylene, reinforcement, F.E. analysis, damping behavior*

I. INTRODUCTION

High damping capacity materials allows undesirable mechanical vibrations and wave propagation to suppress. Polymer composite materials are being used for many antivibration applications due to their excellent properties of damping behavior, resilience and creep resistance. Especially due to its high specific strength to weight and stiffness to weight ratios composite materials are finding many aerospace applications [1]. Presence of discontinuous fibers makes it theoretically possible to improve damping behavior of composite [2-3]. C. Subramanian [4] invested the effect of reinforced fiber length on the leaf spring performance under dynamic load conditions and confirmed that long fibers can carry three times more load then short fiber composite but the damping behavior of short glass fiber reinforced leaf spring is found to be superior to that of long glass fiber reinforced leaf spring. Rakesh Chandra et al. [5] predicted the damping in three-phase fiber-reinforced composites using finite element analysis and concluded that by optimizing the properties/parameters of interphase (i.e., moduli, loss factors/size and physical state) appropriate level of damping can be achieved in fiber-reinforced composites under different conditions. R.F. Gibson et al. [6] studied the effects of the size of the fiber-matrix interphase on composite damping and described the use of a general purpose strain energy/finite element method for micromechanical modeling of both damping and stiffness in composites. E. J. Lavernia et al. [7] studied the damping behavior of metal matrix composites with discontinuous reinforcements. Experimental damping measurements were carried out on short fiber and long fiber reinforced composites and concluded that short fiber composites shows more damping and increased natural frequency by Amit Kumar Haldar et al. [8]. Excessive vibrations may generate high noise levels, stress fatigue failure, premature wear, and unsafe operating conditions. To avoid these potential problems, there is a need to understand the complete vibration response of these materials. A new simulation model was proposed through measuring the damping factor of fiber reinforced thermoplastic parts and the experimental model analysis of the parts [9]. Hassan et al. [10] investigated the properties of injection molded short and long carbon fiber reinforced polyamide material. Fiber length characteristics were found to be in agreement with the improved tensile strength and tensile modulus of long fiber composites over the short fiber composites, despite the reduction in their fracture strain. Lee et al. [11] conducted flexural and torsional vibration tests to obtain dynamic characteristics of carbon fiber reinforced PEEK. Measured natural frequency and specific damping capacity were compared with finite element results and found to be in good agreement. Present work aims at the finite element analysis of long fiber and short multi fiber to predict the interfacial strength. Composite with high interfacial strength or less interfacial stress will show higher damping capacity, which will be verified experimentally.

II. FINITE ELEMENT MODELING OF LONG SINGLE AND SHORT MULTI FIBER MODEL AND ANALYSIS

The FEA method is used to model composite material on the micro-mechanical level. Consider a fiber–matrix specimen, whose geometry is shown in Fig. 1. The commercial FE software ANSYS is used in the FE simulation. Due to axisymmetry, the specimen can be considered as a 2-D elastic body and 4-node quadrilateral element PLANE42 is used in the analysis.

Following parameters are used in analysis [12]:
1). Fibers are glass fibers with Young's modulus $E_f = 75$ GPa, and Poisson ratio $V_f = 0.2$
2). Matrix is of polypropylene with Young's modulus $E_m = 1.05$ GPa and Poisson ratio $V_m = 0.33$.

Following two cases are considered for F.E. analysis:
1). Tensile interfacial stress distribution along length interface at 20% and 40% volume fraction of single long fiber embedded in matrix as shown in figure 1.
2). Tensile interfacial stress distribution along length interface of short multi fiber model such that volume fraction of fibers remain same as that of single fiber. This model allows to study the effect of fiber dimensions on stress distribution. FEA models of fiber embedded in matrix are shown in figure 1. which are considered to understand the micromechanical behavior of composite. This unit cell domain geometry is defined in terms of the following parameters:

l_f, d_f, r_f: Length, diameter and radius of the fiber

l_m, d_m, r_m: Length, diameter and radius of the matrix.

Fiber aspect ratio: $a_f = L_f / D_f$

Fiber spacing parameter: $X_f = l_m - l_f = X_f \frac{l_f}{a_f}$

The dimensions of the unit cell are hence related to the volume fraction of the fibers in the composite by equation (1) [13]:

$$l_f = \sqrt[3]{4(r_m a_f)^2 v_f l_m} \quad \text{(Eq. 1)}$$

Where v_f= volume fraction of fibers in matrix

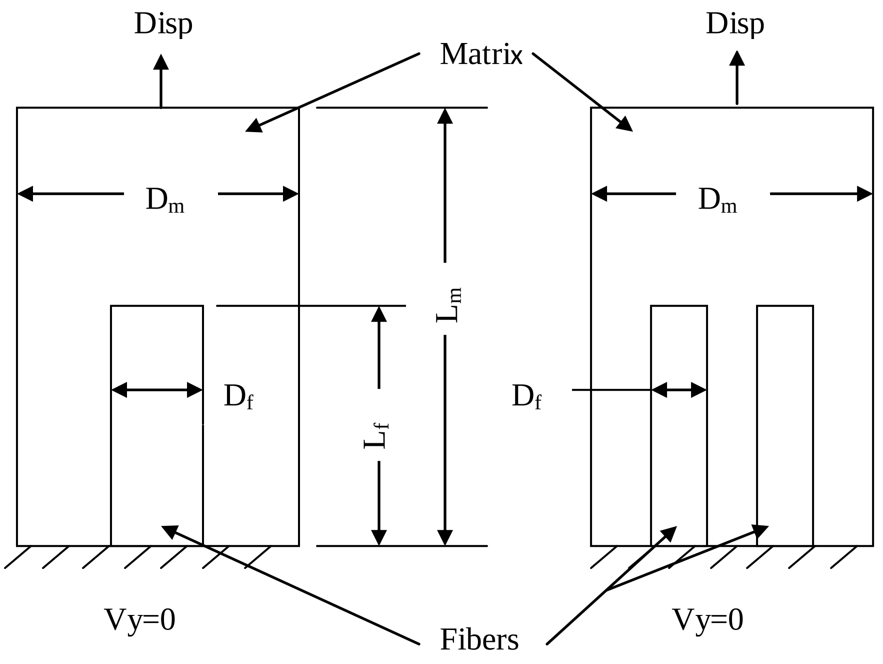

Figure 1: Single long fiber and double short fiber models

Table 1 show the dimensions of models at 20% and 40% of volume fraction of fibers, at fixed aspect ratio of 20, which are obtained by using equation 1.

Type of Composite	Volume Fraction	Matrix Dimensions (µm)		Fiber Dimensions (µm)	
		L_m	D_m	L_f	D_f
Long Single Fiber Model	20%	150	7.5	87.72	4.38
	40%	150	7.5	110.52	5.52
Short Double Fiber Model	20%	150	7.5	69.62	3.48
	40%	150	7.5	87.72	4.38

Table 1: Dimensions of long single fiber and short double fiber model for 20% and 40% volume fraction

2.1 Boundary Conditions

Both composites at same volume fractions are subjected to same boundary conditions of $V_y = 0$ i.e. models have zero displacement in y direction and constant displacement of 1.8 µm is applied on the top of models at $Y=L_m$. F.E analysis results are shown in fig. 5 and fig. 6.

III. TEST MATERIAL FOR VIBRATION ANALYSIS

Unreinforced, long glass fiber and short glass fiber reinforced polypropylene materials were hand molded and subjected to forced vibration to understand the vibration and damping behavior of thermoplastic composites. Test materials were molded into rectangular specimen of size (120 X 12 X 3 mm) as shown in figure 2. Fiber volume was 20% of total volume of composite for both long and short fibers.

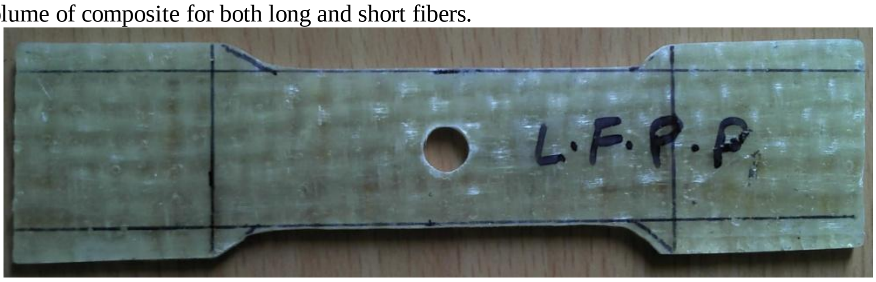

Figure 2: Test specimen

3.1 Experimental Setup for Forced Vibrations

Experimental arrangement for the forced transverse vibrations of the composite specimen is shown in fig.3. Specimen is clamped at one end on a mounting and the force transducer is fixed above the exciter and connected to the cantilever beam. An accelerometer is fixed above the cantilever beam at free end and the signal from the accelerometer and force transducer is fed to the data acquisition and the FFT analysis was made. The power supply is given to the exciter through power oscillator and initial sinusoidal forcing frequency of 20 Hz and voltage of 0.1 V is set through power oscillator. The vibration data is saved in the form of exciting force and resultant acceleration versus time. This procedure is repeated for all the three test materials. From the time domain data, the graph between acceleration versus time and the force magnitude versus time is plotted and superimposed. The schematic of plot is shown in fig. 4 and the phase lag is calculated using following equation (2):

$$\emptyset = \frac{t}{T} \times 360^{\circ} \qquad \text{(Eq. 2)}$$

Where T is time period of one cycle and t is time lag in seconds between exciting force and its response.

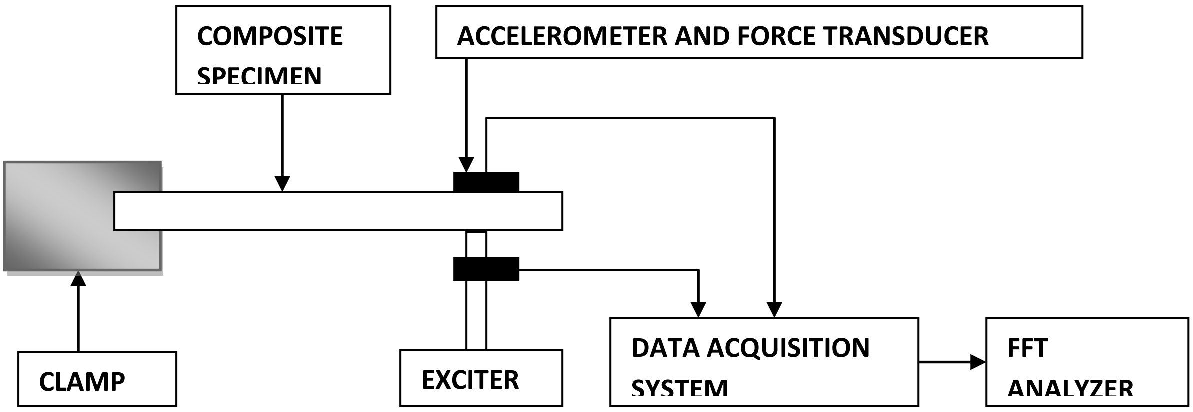

Figure 3: Experimental setup for studying damping behavior

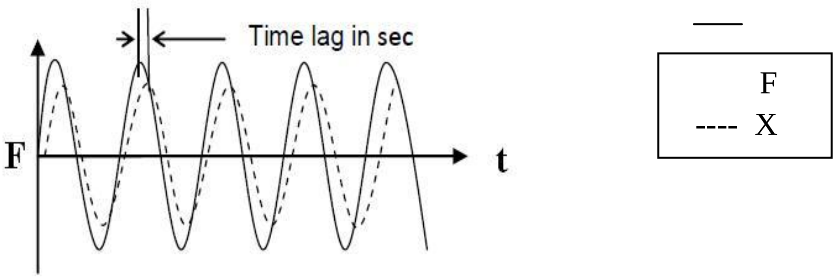

Figure 4: Schematic of excitation force and its response

3.3 Phase Lag

Phase lag angle is a time by which the response lags behind the exciting force. It is a measure of the damping during material deformation. For a homogeneous material, phase lag is directly proportional to the damping, i.e. higher the phase lag angle indicates higher the material damping. Addition of reinforced glass fibers to the base polypropylene increases the phase lag between the exciting force and the corresponding material response. This behavior is due to the presence of fiber matrix interface.

IV. RESULT AND DISCUSSION

4.1 Finite Element Analysis Result

F.E analysis results indicate that maximum stress occurs at the sharp interface (ref. fig. 5) due to stress concentration which is favorable site for cracks to appear. The stress decreases along length interface as distance increases from sharp edge as shown in fig. 5. Increased in volume fraction of fiber shows lower interfacial stress which reduces the chances of cracking and composites shows more strength. Similar results are shown by multi fiber composites because of increased interface area; the stress reduces at particular volume fraction than single long fiber model. Comparisons of stresses for both models are shown in fig. 6.

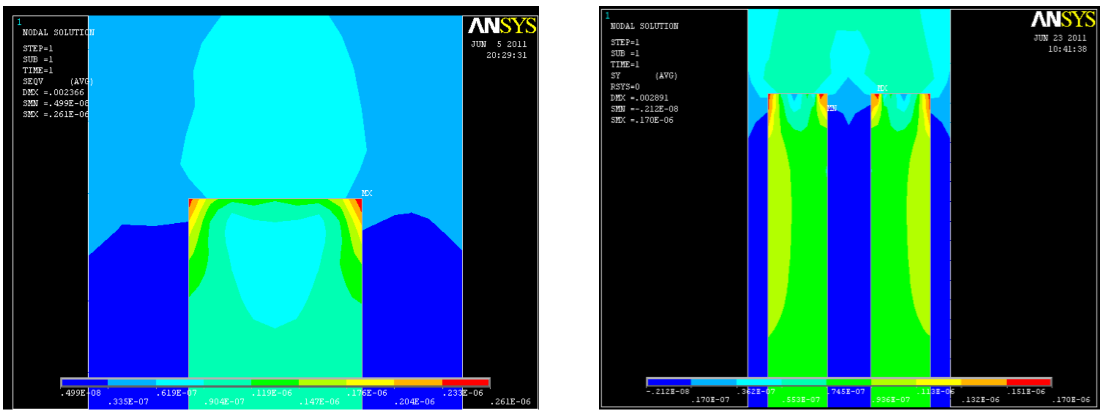

Figure 5: Tensile stress nodal solutions for both long and short fiber models

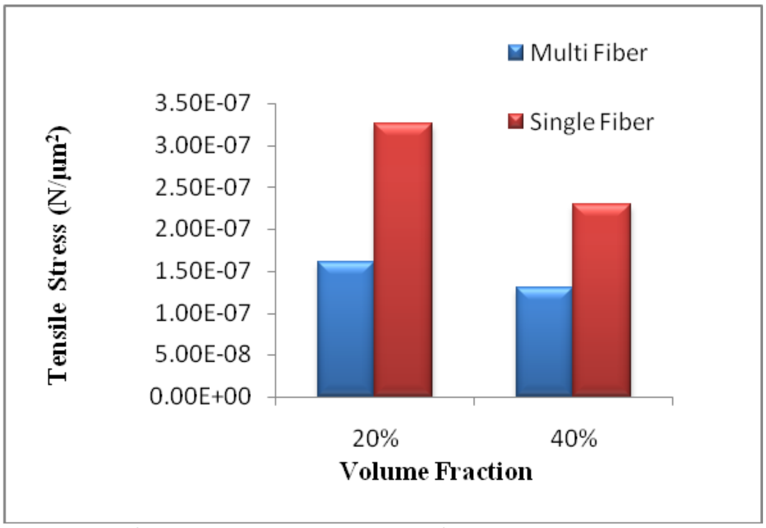

Figure 6: Tensile stress for both long single and double fiber model at 20% and 40% volume fraction

4.2 Damping Behavior

The phase lag obtained from the vibration experiment for all the considered test specimen is shown in fig.7 (a-c). Due to material damping behavior, there is a lag between the excited force and its response in a time scale. Using equation 2, the magnitude of phase lag is obtained. Fig. 8 shows the mean phase lag of all the considered test specimens. Phase lag of unreinforced, long fiber reinforced and short fiber reinforced polypropylene composites obtained from results are 27.61º, 28.24º and 28.36º respectively.

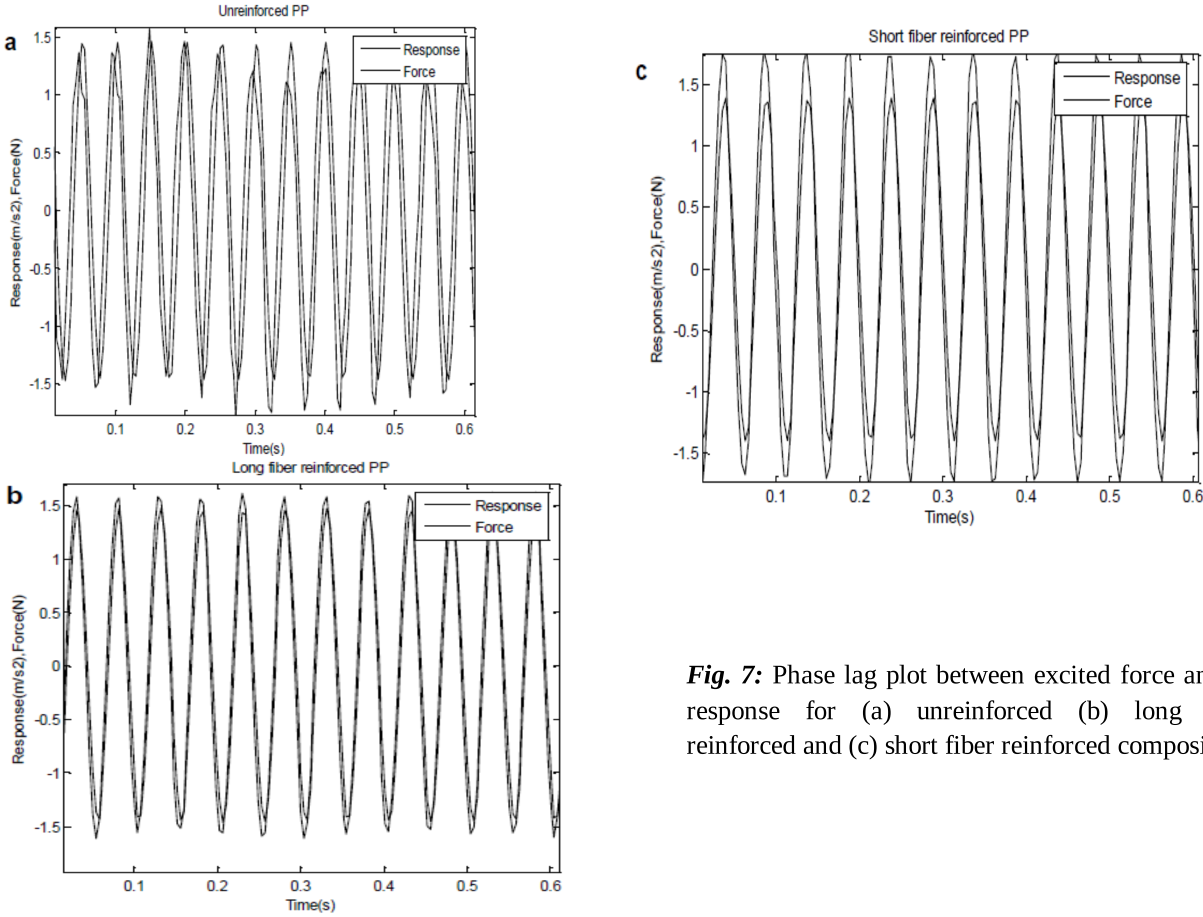

Fig. 7: Phase lag plot between excited force and its response for (a) unreinforced (b) long fiber reinforced and (c) short fiber reinforced composite

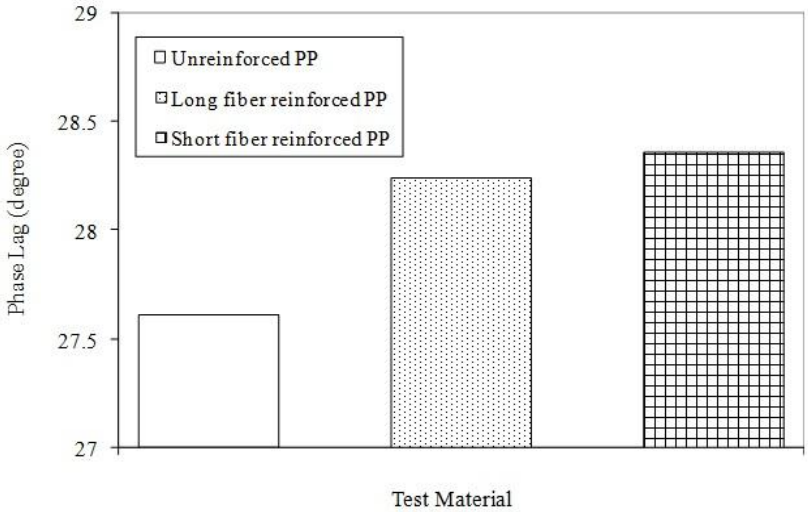

Figure 8: Phase lag between excited force and its response of the test specimens

4.3 Conclusion

Presence of reinforced fibers in the thermoplastic material increases the strength of composite and increase in volume fraction of reinforcement increases the overall strength. Reinforcement alters the damping mechanism and improves the damping behavior. Fiber dimensions in the reinforced thermoplastic material significantly contribute to the fiber matrix interface. Short fiber reinforced material shows superior damping than long fiber reinforced material due to its more density of fiber ends for the same volume fraction. This superior damping of short fibers supports the result of F.E. analysis of greater interfacial strength shown by short fibers composite in comparison to long fiber composite model.

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