EFFECT OF CENOSPHERE FILLER ON DAMPING PROPERTIES OF BAMBOO-EPOXY LAMINATED COMPOSITES

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ABSTRACT

This paper deals with evaluation of damping properties of natural fibre composites consisting of bamboo fibre as reinforcement, epoxy as matrix and cenosphere as particulate filler. Hand lay-up technique is used to fabricate the composites with varying number of layers and different weight percentage of cenosphere filler. The prepared specimens are subjected to free vibration test (FVT) to investigate the damping ratio and natural frequency. Damping of the bamboo-epoxy composites is analysed experimentally using cantilever beam test set up by impulse technique. The investigation reveals that the number of layers and cenosphere filler content influences the natural frequency and the damping ratio.

Keywords: Polymer composites, Bamboo fibre, Cenosphere filler, Natural frequency, Damping ratio

1. INTRODUCTION

Natural fibre reinforced composite materials have significant potential for various engineering applications due to their intrinsic sustainability, low cost, eco-friendly nature and good mechanical properties [1-2]. It can be reinforced in different polymer matrices [3-18] and the potential of various natural fibre reinforced composites for non-conventional applications have been reported [8, 19]. But the hydrophilic nature of natural fibre leads to the weak interfacial bonding between fibre and matrix during the fabrication of composites. Hence, the composites suffer from reduced mechanical properties and dimensional instability. In order to overcome this problem, there are numbers of techniques developed to improve the mechanical properties of natural fibre based polymer composites [20-21].

Adding of filler in the natural fibre reinforced composite during their fabrication is one of the techniques to improve the mechanical properties as well as reduce the cost of the composite. Biswas et al. [22] have reported that incorporation of different ceramic filler modifies the mechanical properties and improves the wear resistance property of the bamboo reinforced composite. Incorporation of ceramic filler in the fibre reinforced composite is now gaining wide acceptability among researchers. Apart from ceramic fillers, some industrial by-products which contain metal oxides have also been used as filler material in composite [23-24]. Cenosphere is one of the industrial by-product produce during burning of pulverized coal in thermal power plants. It is a ceramic rich material with hollow microstructure which is being used as particulate filler in polymer composite. There are several instances of investigation on cenosphere incorporated in neat polymer [25-26] and fibre reinforced composite [27]. The amount of fibre/filler content is an important factor for design of composites to control the mechanical properties. Natural fibre improves the mechanical properties of composites, making their use feasible. Mechanical properties of different natural fibre reinforced com-

Table 1: Comparisons of mechanical properties of various natural fibre composites

Sl No.	Fibre/filler	Matrix	W_f/V_f (%)	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (KJ-m^2)	Reference
1	Bamboo	Epoxy	33	83.20	108.92	3.76	[3]
2	Bamboo+ Cenosphere	Epoxy	33	93	126	17.12	
3	Jute	Polyester	35.7	74.59	81.54	-	[4]
4	Hemp	PLA	30	39.29	76.31	-	[5]
5	Lantana Camera	Epoxy	30	19.08	55.49	-	[6]
7	Bagassae	Epoxy	30	-	22	-	[7]
8	Banana	Polyester		29.5	60.4	-	[8]
9	Sansevieria	Polyester	35	75	-	152(J/m)	[9]
10	Elephant Grass	Polyester		72	-	258(J/m)	[10]
11	Rice husk	HDPE	30	19		3.95	[11]
12	Ramie	PP/ PP-g-MA (3 wt %)	30	66	-	4.7	[12]
13	Kenaf	LDPE/ PEG (7 wt %)	30	11.5	-	41	[13]
14	Date palm trunk	HDPE/ PP-g-MA (2 wt %)	33	18	-	-	[14]
15	Date palm leaf	LDPE	28	6.8	-	-	[15]
16	Abaca	PP	30	42	64.5	-	[16]
17	Cellolose	PP	30	65	100	-	
18	Abaca	PLA	30	65	122	-	
19	Cellolose	PLA	30	90	130	-	
20	Wood Floure	Mater Bi-Grade	30	7	-	63(J/m)	[17]
21	Bamboo/ Glass	Epoxy	25/5 20/10 15/15	45.45 47.22 51	44.21 51.51 51.2	48 52.16 61.5	[18]

posites as a function of fibre/filler loading can be seen in Table 1. From this table we observe that the mechanical properties of bamboo-epoxy composite are quite better as compared to other natural fibre. It is also observed that incorporation of cenosphere filler improves the mechanical properties.

One of the structural vibration damping solutions is to develop a composite which have high damping capacity with good mechanical properties. The damping capacity of a material is basically evaluation of energy dissipated in material during vibration. The energy dissipation in fibre reinforced composite depends on the damping at the fibre–matrix interface, the damping due to damage and the viscoelastic nature of matrix and fibre materials. And for laminated composites, damping depends on the layer orientations, layer properties and interlaminar effects. Berthelot et al. [28] give an extensive analysis of the damping of unidirectional fibre composites as function of frequency and fibre orientation. Chandra et al. [29] give a brief review on status of research on damping in fibre-reinforced composite materials and structures. They discuss various studies related to improve damping models for thick laminates and optimization for damping in fibre reinforced composites/structures. Yan et al. [30] has studied the damping properties of alkali treated flax and linen fibre reinforced composites. Lingaraju et al. [31] attempt to improve the damping ratio of glass fibre reinforced epoxy with particle reinforced hybrid nano-clay particles. The influence of fly ash filler weight fraction on damping ratio and natural frequency of jute-epoxy sandwiches with fly ash reinforced functionally gradient (FG) flexible, compliant rubber core has been studied by Doddamani et al. [32]. Though substantial research has taken place to study the fibre reinforced composite with and without filler, but the effect of cenosphere filler on the damping properties of bio-fibre reinforced composites has not yet been reported. Therefore, the objective of this paper is to study the effect of cenospher as a filler material on the damping properties of natural fibre composite. The composite, in the present work, consists of bamboo fibre as natural fibre reinforcement and cenosphere as filler material in the epoxy matrix.

2. EXPERIMENTAL DETAILS

2.1. Materials

In present study bamboo fibre is used as reinforcement which is procured from local sources. Fig. 1 shows a plain weave of bamboo fibre mat. The matrix system consists of a medium viscosity epoxy resin Diglycidyl Ether of Bisphenol – A (DGEBA) and a room temperature curing hardener Triethylene Tetra-amine (TETA) are purchased from ATUL India Pvt Ltd. The cenosphere is used as filler materials. The properties of these constituents are given in Table 2.

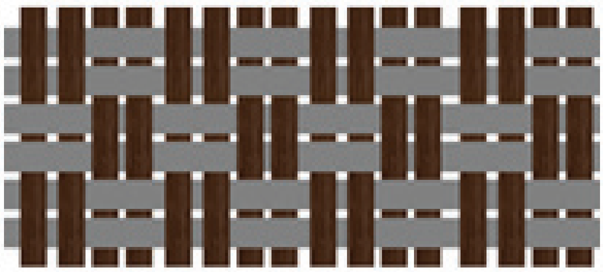

Fig. 1: Schematic diagram of woven bamboo mat

Table 2: Constituents of composite materials and their characteristics

Raw materials	Grade	Characteristics
Bamboo fibre	-	Weave type, Density = 0.95 gm/cc, Width = 4.5 mm, Thickness = 1.5 mm
Epoxy	LAPOX L-12	Viscosity = 9000-12000 mPa.s, Density = 1.1gm/cc
Hardener	K-6	Refractive index at 25^{0}C = 1.4940-1.5000
Cenosphere	CS 300	Particle density = 0.45–0.80 g/ml, Particle size = 60-94 micron,

2.2. Alkali treatment

Initially, the bamboo mats are cut to desired shape and then cleaned with fresh water. It is dried before dipping into NaOH solution of 5% concentration at room temperature [21]. These mats are then thoroughly washed in distilled water and neutralized with dilute HCl solution. The neutralized mats are dried in an oven.

2.3. Fabrication procedure

The conventional hand lay-up technique is used to fabricate composites having 3, 5, 7 and 9 layers of woven bamboo mats. The epoxy is kept at 110^{0}C in the oven in order to remove air bubbles prior to mixing with hardener in a ratio of 10:1 by weight. The laminae are arranged systematically on mould with epoxy resin. A releasing agent (silicon spray) is used to prevent adhesion between composite and mould which facilitate easy removal of composite from the mould after curing. Composite samples are allowed to cure in mould for 24 hours at room temperature under a load of 30 kg. Then they are removed from the mould for cutting of samples of desired shape. In similar procedure, the resin-filler mixture is used to impregnate the bamboo fibre mat at room temperature with varying weight percentages (0, 1.5, 3, 4.5 and 6%) of filler to fabricate the composites.

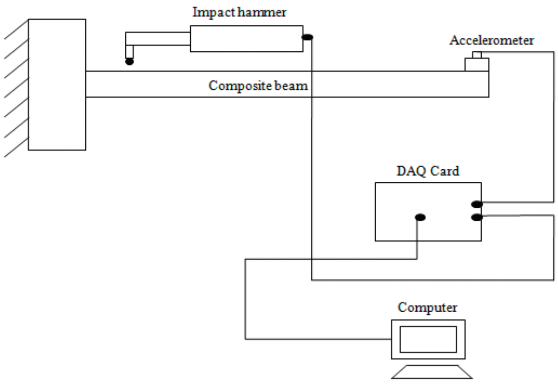

Fig. 2: Schematic diagram of free vibration test set up

2.4. Free Vibration Test

Free vibration test (FVT) is carried out to study the dynamic characteristics of the composite specimens. Fig. 2 shows the schematic diagram of FVT test set up. The length and width of the specimen is 200 mm and 20 mm, respectively. The composite specimens are tested with one end clamped and other end deflected to a displacement. In FVT, the impact hammer [PCB 086C03] excites the composite beam. Impulse excitation is induced at 10 different equidistance points on the beam. The response is obtained at a point near the free end of the beam. The accelerometer [PCB 352C33] is used to measure the vibration response through the Data Acquisition (DAQ) Card [NIPXI 4472]. The accelerometer has been calibrated by the ratio (comparison) calibration method. PC is used for storing the data from accelerometer and impact hammer through DAQ. Fast Fourier Transform (FFT) of the time signal is obtained using Labview 9 software. Five sample specimens are subjected to testing of each composite type and average value is taken to compute damping ratio and natural frequency. The damping factor for the materials is obtained using logarithmic decrement method. The logarithm decrement (δ) is computed from amplitude using following equation [33].

$$\delta = \frac{1}{n} \ln \frac{x_0}{x_n} \tag{1}$$

Where, x_o and x_n are the initial and n^{th} the amplitude of vibration and n is the number of cycles. The damping ratio (ζ) is computed by using the equation (2)

$$\zeta = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} \tag{2}$$

3. RESULTS AND DISCUSSION

The density is one of the important factors determining the properties of the composites which depend on the relative proportion of matrix and reinforcing materials. The density of a fibre reinforced composite can be calculated by using following relation

$$\rho = \frac{1}{\frac{w_f}{\rho_f} + \frac{w_m}{\rho m}} \tag{3}$$

Where, w and ρ represent the weight fraction and density, respectively. The subscript f and m stands for the fibre and matrix of the composite material. For a composite with filler incorporation, the modified density of composite is

$$\rho_c = \frac{1}{\frac{w_f}{\rho_f} + \frac{w_m}{\rho_m} + \frac{w_p}{\rho_p}} \tag{4}$$

Where, the subscript p indicates the particulate filler material. The density and weight fraction of fibre of the composites are given in Table 3. It is found that with the increase in fibre as well as filler content there is a decrease in density for all composite types.

Natural frequency of bamboo-epoxy composites for different number of laminae and varying weight percent of cenosphere are tested. Fig. 3 indicates that increasing in number of lamina increases the natural frequency of the composite. The 7 layered bamboo-epoxy composite has a maximum natural frequency of 55.07 Hz. The increase in natural frequency with increased number of lamina is due to reduced mass

Table 3: Materials combination and properties of the composites

Materials combination	Density (gm/cc)	Young Modulus (MPa)
Bamboo-epoxy composites without cenosphere		
3 layer	1.077	3454.525 (SD=254.62)*
5 layer	1.060	3773.195 (SD=95.06)
7 layer	1.051	3884.775 (SD=65.78)
9 layer	1.035	3215.100 (SD=52.30)
7 layered Bamboo-epoxy composites with cenosphere		
1.5 wt% of cenosphere	1.047	3939.945 (SD=43.12)
3.0 wt% of cenosphere	1.042	4463.223 (SD=166.70)
4.5 wt% of cenosphere	1.038	4127.235 (SD=31.36)
6.0 wt% of cenosphere	1.033	3884.775 (SD=126.16)

*SD- represents Standard Deviation

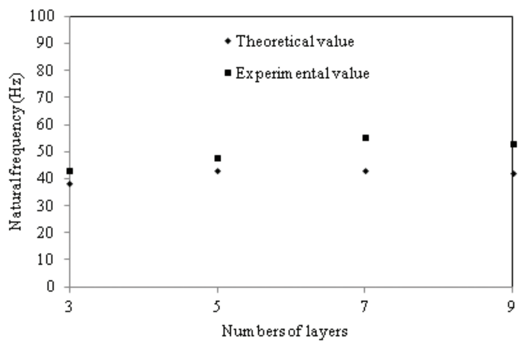

Fig. 3: Natural frequency for bamboo-epoxy composite with varying number of layers

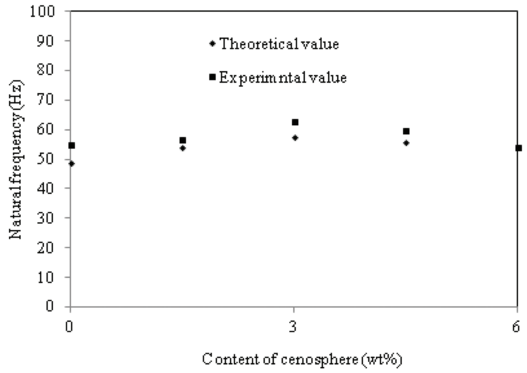

Fig. 4: Natural frequency for bamboo-epoxy composite with varying wt% of cenosphere

as a result of lower density and increased stiffness as shown in Table 3. It is observed that with the increase in number of laminae the Young's modulus increases. But the increase is seen up to the 7 layered bamboo-epoxy composite, beyond which it decreases. The reason may be due to the poor wettability of fibre and fibre matrix adhesion which leads crack initiation and its easy propagation. The results also indicate that cenosphere can increase the modulus by 14.89% for composites with 3 wt% of cenosphere. The modulus of the 7 layered composites is observed to increase with the addition of cenosphere filler. But there is a limitation to addition of filler. The influence of cenosphere filler in 7 layered bamboo-epoxy composite having maximum natural frequency is presented in the Fig. 4. It is observed that the addition of cenosphere filler increases the natural frequency as it increases the modulus of elasticity of the composite. The composite with 3.0 wt% cenosphere has the maximum natural frequency. The decrease in natural frequency beyond the addition of 3.0 wt% of cenosphere is due to agglomeration and weak fibre–matrix interface which in turn lowers the Young's modulus. Cenosphere can increase the natural frequency by 13.92% for composites with 3 wt% of cenosphere. The theoretical values of mode I frequency are obtained by using Euler-Bernoulli Beam theory. The expressions for natural frequency of first mode is given by,

$$w_1 = 1.875^2 \sqrt{\frac{EI}{\rho A L^4}} \quad (5)$$

The theoretical and experimental natural frequencies have good agreement as shown in the Fig. 3 and 4.

The mean values of damping ratio obtained for different composite types with and without filler contents are presented in Table 4. A similar trend is observed as in the case of natural frequency. The 7 layered bamboo-epoxy composite with 3.0 wt% cenosphere has the highest damping ratio due to more energy dissipation through fibre and matrix filler interface. The reason is uniform distribution of cenosphere in the matrix which results in good bonding between the reinforcement and matrix. This provides large interfacial area as well as interlaminar shear strength which increase the energy dissipation at interface [34-35].

Table 4: Damping ratio of different composites with and without cenosphere

Materials combination	**Damping ratio**
Bamboo-epoxy composites without cenosphere	
3 layer	0.0085 (SD=0.00035)*
5 layer	0.0112 (SD=0.00534)
7 layer	0.0168 (SD=0.00266)
9 layer	0.0132 (SD=0.00602)
7 layered Bamboo-epoxy composites with cenosphere	
1.5wt% of cenosphere	0.0267 (SD=0.00264)
3.0wt% of cenosphere	0.0378 (SD=0.00186)
4.5wt% of cenosphere	0.0368 (SD=0.00285)
6.0wt% of cenosphere	0.0319 (SD=0.02031)

*SD- represents Standard Deviation

4. CONCLUSIONS

Bamboo-epoxy laminated composites with varying number of layers and different wt% of cenosphere have been fabricated and their dynamic characteristics are studied. The study reveals that the 7 layered configuration of the composite has highest natural frequency and damping ratio. The addition of cenosphere improves the natural frequency and damping ratio of the composites, but it depends upon the amount of cenosphere. The maximum natural frequency and damping ratio are obtained for 3.0 wt% of cenosphere.

References:

1. **Wang W., Sain M., Coooper P. A.:** Study of moisture absorption in natural fibre plastics composites. *Composite Science Technology,* **66** (2006), 379-86.
2. **Clemons C.:** Wood-plastic composites in the United States: The interfacing of two industries. *Journal of Forest Product,* **52** (2002), 10-18.
3. **Jena H., Pandit M.K., Pradhan A.K.:** Effect of cenosphere on mechanical properties of bamboo–epoxy composites. *Journal of Reinforced Plastics and Composites,* **32** (2013), 794–801.
4. **Sever K., Sarikanat M., Seki Y., Erkan G.,** Erdogan H.U.: The mechanical properties of γ methacryloxypropyltrimethoxy silane-treated jute/polyester composites. *Journal of Reinforced Plastics and Composites,* **44** (2010), 1913-1924.
5. **Hu R., Lim J.K.:** Fabrication and Mechanical properties of completely biodegradable hemp fibre rein-

forced polylactic acid composite. *Journal of Composite Materials,* **41** (2007), 1655-1669.

6. **Deo C. Acharya S.K.:** Effect of moisture absorption on mechanical properties of chopped natural fibre reinforced epoxy composite. *Journal of Reinforced Plastics and Composites,* **29** (2010), 2513-2521.
7. **Acharya S.K., Mishra P., Meher S.K.:** Effect of surface treatment on the mechanical properties of bagasse fibre reinforced polymer composite. *BioResources,* **6** (2011), 3155-3165.
8. **Satyanrayana K.G., Sukumaran K., Kulkarni A., Pillai S.G.K., Rohatagi P.K.:** Fabrication and properties of natural fibre-reinforced polyester composites, *Composites,* **17** (1986), 329-333.
9. **Ramanaiah K., Ratna Prasad A.V., Reddy K.H.C.:** Mechanical, thermophysical and fire properties of sansevieria fibre-reinforced polyester composites. *Materials and Design,* **49** (2013), 986-991.
10. **Ramanaiah K., Ratna Prasad A.V., Reddy K.H.C.:** Thermal and mechanical properties of waste grass broom fibre-reinforced. *Materials and Design,* **40** (2012), 103-108.
11. **Yao F., Wu Q., Lei Y., Xu Y.:** Rice straw fibre-reinforced high-density polyethylene composite: effect of fibre type and loading. *Industrial Crops and Products,* **28** (2008), 63-72.
12. **Feng Y., Hu Y., Zhao G., Yin J., Jiang W.:** Preparation and mechanical properties of high-performance short ramie fibre-reinforced polypropylene composites. *Journal of Applied Polymer Science,* **122** (2011), 1564-1571.
13. **Tajeddin B., Rahman R.A., Abdulah L.C.:** The effect of polyethylene glycol on the characteristics of kenaf cellulose/low-density polyethylene biocomposites. *International Journal of Biological Macromolecules,* **47** (2010), 292-297.
14. **Mahdavi S., Kermanian H., Varshoei A.:** Comparison of mechanical properties of date palm fibre-polyethylene composite. *Bioresources,* **5** (2010), 391-403.
15. **Bendahou A., Kaddami H., Sautereau H., Raihane M., Erchiqui F., Dufresne A.:** Short palm tree fibres polyolefin composites: effect of filler content and coupling agent on physical properties. *Macromolecular Materials and Engineering,* **293** (2008), 140-148.
16. **Bledzki A.K., Jaszkiewicz A., Scherzer D.:** Mechanical properties of PLA composites with man-made cellulose and abaca fibres. *Composites: Part A,* **40** (2009), 404-412.
17. **Samal S.K, Mohanty S., Nayak S.:** Polypropylene–bamboo/glass fibre hybrid composites: fabrication and analysis of mechanical, morphological, thermal, and dynamic mechanical behaviour. *Journal of Reinforced Plastics Composites,* **28** (2008), 2729-2747.
18. **Morreale M., Scaffaro R., Maio A., La Mantia F.P.;** Effect of adding wood flour to the physical properties of a biodegradable polymer. *Composites: Part A,* **39** (2008), 503-513.
19. **Majeed K., Jawaid M., Hassan A., Bakar A.A., Abdul Khalil H.P.S., Salema A.A., Inuwa I.:** Potential materials for food packaging from nanoclay/natural fibres filled hybrid composites. *Materials and Design,* **46** (2013), 391-410.
20. **Xue L., Lope G.T., Panigrahi S.:** Chemical treatments of natural fibre for use in natural fibre-reinforced composites: a review. *Journal of Polymers and Environment,* **15** (2007), 25–33.
21. **Kushwaha P., Kumar R.:** Enhanced mechanical strength of BFRP composite using modified bamboos. *Journal of Reinforced Plastics and Composites,* **28** (2009), 2851-2859.
22. **Biswas S., Satapathy A. and Patnaik A.:** A comparative study on erosion characteristics of red mud filled bamboo–epoxy and glass–epoxy composites. *Materials and Design,* **31** (2010), 1752-1767.
23. **Rothon R.N.: Mineral fillers in thermoplastics:** filler manufacture and characterization. *Advance Polymer Science,* **139** (1999), 67-107.
24. **Patnaik A., Satapathy A., Mahapatra S.S. And Dash R.R.:** Implimentation of Taguchy design for erosion of fibre-reinforced polyester composites system with SiC filler. *Journal of Reinforced Plastics and Composites,* **27** (2008), 1093-1111.
25. **Suresha B., Chandramohan G., Siddaramaiah, Jayaraju T.:** Influence of Cenospheres filler additions on the three-body abrasive wear behaviour of glass fibre-reinforced epoxy composites. *Polymer Composite,* **29** (2008), 307-312.
26. **Deepthi M.V., Sharma M., Sailaja R.R.N., Anantha P., Sampathkumaran P., Seetharamu S.:** Mechanical and thermal characteristics of high density polyethylene–fly ash Cenospheres composites. *Materials and Design,* **31** (2010), 2051-2060.
27. **Das A., Satapathy B.K.:** Structural, thermal, mechanical and dynamic mechanical properties of cenosphere filled polypropylene composites. *Materials and Design,* **32** (2011), 1477-1484.
28. **Berthelot J.M., Sefrani Y.:** Damping analysis of unidirectional glass and kevlar fibre composites. *Composite Science and Technology,* **64,** 1261-1278 (2004).
29. **Chandra R., Singh S.P., Gupta K.:** Damping studies in fibre-reinforced composites-a review. *Composite Structure,* **46** (1999), 41-51.
30. **Yan L.:** Effect of alkali treatment on vibration characteristics and mechanical properties of natural fabric reinforced composites. *Journal of Reinforced Plastics and Composites,* **31** (2012), 887-896.
31. **Lingaraju D., Ramji K., Mohan Rao N.B.R., et al.:** Characterization and prediction of some engineering properties of polymer - Clay/Silica hybrid nanocomposites through ANN and regression models. *Procedia Engineering,* **10** (2011), 9-18.
32. **Doddamani M.R. and Kulkarni S.M.:** Dynamic response of fly ash reinforced functionally graded rubber composite sandwiches - a Taguchi approach. *International Journal of Engineering Science and*

Technology, **3** (2011), 166-182.

33. **Thomson W.T.:** Theory of vibration with applications, 4th ed, London, 1993, 33-35.
34. **Hussain M., Oku Y., Nakahira A. and Niihara K.:** Effects of wet-ball milling on particle dispersion and mechanical properties of particulate epoxy composites. *Materials Letter,* **26** (1996), 177-184.
35. **Chandradass J., Ramesh Kumar M., and Velmurugan R.:** Effect of clay dispersion on mechanical, thermal and vibration properties of glass fibre-reinforced vinyl ester composites. *Journal of Reinforced Plastics and Composites,* **27** (2008), 1858-1601.