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Effect of Moisture on Damping of Fibrous Composites

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Abstract - **In practical applications, the composites absorb moisture from the atmosphere and for marine applications the composites are immersed in water. This absorbed moisture affects the mechanical and dynamic properties of polymer composites. The aim of the present work is to investigate changes in the damping properties (loss factor and storage modulus) of fibrous composites (glass/epoxy and graphite/epoxy) due to moisture absorption. Experiments were conducted on the graphite/epoxy (fibreduxXAS/914C) and glass/epoxy (LY556/HT972) composites with different lay-ups under different conditions, viz., room temperature, immersion in water for 24 hours, immersion in boiling water for 2 hours and immersion in water for 7 days. Tests were repeated after re-drying. The experiments were carried out using Bruel & Kjaer Complex Modulus apparatus. Effect of moisture on loss factor and storage modulus was determined. It is observed that the type of lay-up affects the influence of moisture on damping behaviour to a very large extent.**

Key words: Damping, moisture, loss modulus, storage modulus, composite materials.

1. INTRODUCTION

A vibration is associated with fluctuating stresses and during sufficiently violent motion; these may become large enough to cause failure. Undoubtedly the worst feature of vibration is that it can cause fatigue in metals, in reinforced plastics and in other structural materials. To reduce the undesirable effects due to vibrations high damping is important in minimising the vibration damage and to controlling the noise. In advanced structural composites subjected to dynamic loading, especially in aerospace automobile, transport applications, railway and marine applications, dynamic characteristics are more important for which special damping layers of various viscoelastic materials are widely applied.

For naval applications, fibre-reinforced plastics, combining relatively high stiffness with good damping properties, can provide materials for structures that prevent propagation or transmission of sound under water. Epoxy resins are widely used in advanced composite materials, but their brittle nature makes them liable to impact damage and they have only modest damping properties. Composite materials used in marine applications are inevitably exposed to seawater and are likely to be subjected to a range of temperatures. Conventional epoxy systems absorb water leading to degradation in the matrix-dominated properties. High damping materials allow undesirable mechanical vibration and wave propagation to be passively suppressed. This proves valuable in the control of noise and the enhancement of vehicle and instrument stability.

Damping refers to the internal energy dissipation by a material when it is subjected to cyclic loading or vibrations. The ability of the material to dissipate energy is referred to as its damping capacity. A damping material has to have a high damping capacity. Damping capacity is characterised by means of the loss factor, d defined as the inverse of the quality factor ($d = 1/Q$). Quality factor in turn is defined as the ratio of the resonance frequency to be bandwidth at half power.

A material with a high value of loss factor is better damping material. Damping capacity is closely related to the internal friction of the material. A material with high internal friction has higher damping capacity. Internal friction and therefore damping capacity is strictly a material property.

The increased use of fibre reinforced composites in industry has led to the study of change in properties due to environmental effects. When a composite material is exposed to humid air or high temperatures both the moisture content and the temperature may affect the thermal and mechanical properties of the material. It is important to know their response to environmental service exposure.

2. LITERATURE REVIEW

Changes in loss factor and modulus on a newly developed epoxy composites were investigated by immersing in seawater. The changes in mass, effective young’s modulus, and loss factor at two different temperatures were tested and measured. It was found that the absorbed water led to loss in stiffness and an increase in the loss factor at both the temperatures. It was also found that carbon/epoxy composites not only offered the greater stiffness (greater than the GRP) but also had good damping characteristics [1, 2].

Maymon et al. and Zai et al. found the effects of moisture absorption and elevated temperature on the dynamic flexural behaviour of graphite/epoxy composites and found that the moisture absorption and elevated temperature alter damping differently for each type of lay up. The hot wet environment increases damping for UD laminates while, it decreases damping markedly for ±45° and (02/+452/901/-451)s laminates [3, 4].

The effects of both thermal damage and moisture content on the graphite/epoxy composite material were studied. The results show that the stiffness and natural frequency increases with increased exposure to heat. Damping tends to decrease with increased exposure to heat. An increased length of delamination crack decreases the natural frequency but increases the damping. Eiji et.al have studied the effect of vibration modes on loss factor using half power method. Using a composite beam with a viscoelastic layer, they found that the bending mode provides an accurate loss factor [2, 5, 6].

The resonance apparatus was developed to characterise the damping properties i.e young's modulus and loss factors of polymers. The measurements were made on a high damping material, an epoxy polymer and low damping material, aluminium. From the loss factor vs frequency curves for the epoxy polymer, a glass transition was observed [7, 8].

Sun, et al derived the material damping of a laminated composite analytically. The derivation is based on the classical laminated plate theory in which there are eighteen material constants in the constitutive equations of laminated composites. Numerical results of extensional damping, coupling damping and flexural/bending damping are presented as a function of number of parameters such as fibre aspect ratio (l/d), fibre orientation, and stacking sequence of the laminate. Numerical results for the laminated composites indicate similar trends as observed in the UD composite i.e. damping and stiffness always behave in opposite manners [9].

Theoretically the material damping of short fibre reinforced polymer matrix composites was determined. The major damping mechanism in such a composite is the visco-elastic behaviour of the polymer matrix. Numerical results of the composite storage modulus ‘E^1’, loss modulus ‘E^{11}’ and loss factor ‘d’ are plotted as functions of parameters such as l/d, θ, v_f and are discussed in terms of variations of (l/d), θ and E_f/E_m in detail. The results can be used to optimise the performance of composite structures [10, 11].

Collings and Copley studied the effect of moisture absorption of CFRP composites with three different types of resin systems. They used finite difference model for the prediction of moisture uptake of composites when they have been exposed to steady or non-steady conditioning. Dennis M. Riggs, et al explained the effect of moisture and temperature on graphite / epoxy composites. Browning, et al studied the effect of absorbed moisture on the mechanical properties of a neat epoxy resin and derived graphite epoxy composites. Glass transition temperature and modulus as a function of moisture content and temperature are determined for both the neat resin and composites. Results indicate that the absorbed moisture and temperature effects on neat resin translate directly to matrix dominated properties of the composite and lead to a change in failure mode, while fibre dominated properties show very little environmental sensitivity [12 – 15].

R.V. Silva, et al. have provided a critical review on the damping properties of polymer matrix composites. It has focused on various factors determining the damping, such as matrix, fibre types, fibre architecture, fibre surface modification, and incorporated fillers. It also discussed the role of interfacial region on the improvement of damping, where high shear strain energy is stored at this region [16].

Keeping in view of the research carried out, in the present work it is planned to investigate changes in the damping properties (loss factor and storage modulus) of fibrous composites (glass/epoxy and graphite/epoxy) due to moisture absorption. The lay up sequence in composite laminates is also varied. In practical applications, the composites absorb moisture from the atmosphere and for marine applications the composites are immersed in water. This absorbed moisture affects the mechanical and dynamic properties of polymer composites. For the present study four conditions were selected, viz., room temperature (without moisture), 24 hr. immersion in water, 2 hr. immersion in boiling water, and 7 days immersion in water. Tests were repeated after re-drying also. Moisture content, loss factor and storage modulus were measured under these conditions.

3. EXPERIMENTAL PROCEDURE

The experimental work consists of preparing the laminates. Glass/epoxy (Araldite LY556/HT972) laminates were prepared with five types of lay up sequence [(a) (0/90/90/0) or (0/90)S; (b). (0/90/0/90) or (0/90)AS; (c). (0/0/90/90) or (02/902); (d). (90/0/0/90) or (90/0)S; (e). (0/+45/-45/-45/+45/0) or (0/±45)S]. Graphite/epoxy (Fibredux-XAS/914C) laminates were prepared with 3 lay up sequence [(a). [±45/02/±45/03/±45/0]S; (b). [0/±45/90]2S; (c). [±45/03/±45/03/90/0]S].

The laminates are marked, as per required dimensions of 100 mm x 10 mm. From each laminate, 12 specimens are extracted. The laminates are cut carefully using the band saw, without producing any delamination. After cutting the specimens are finished on the belt sander to get uniform dimensions.

The specimens cut from the laminates are tested using the Complex Modulus apparatus for four different conditions. For each condition, three specimens from each laminate were tested. It is necessary to have at least three specimens of each kind for each test to ensure reproducibility of the results. Moisture content, loss factor (d) and storage modulus (E^1) are determined.

Burn test is carried out for glass/epoxy composites for finding fibre weight fraction (w_f) and fibre volume fraction (v_f). Acid digestion test is carried out on carbon/epoxy composites for finding w_f and v_f. Displacement method is used to find out the density of all the composites.

4. RESULTS AND DISCUSSION

Different types of specimens (3 lay ups of graphite/epoxy and 5 lay ups of glass/epoxy) were tested at room temperature, immersed in water for 24 hrs, two hrs in boiling water and after re-drying, and seven days immersion in water and after re-drying. Percentage moisture absorption was found by measuring weight gain. Loss factor and storage modulus was found using Complex Modulus apparatus. The results are shown in tables 1 to 8.

Table 1. % Moisture Absorption (graphite/epoxy)

Lay-up	24 hr. in water	2 hr. in boiling water	7 days in water
a	0.179	0.230	0.297
b	0.158	0.246	0.440
c	0.104	0.149	0.220

Table 2. Loss factor ‘ d’ (graphite/epoxy)

Lay up	Before immersion	24 hrs. in water	2 hrs. in boiling water	After re-drying	7 days in water	After re-drying
a	0.0127	0.0130	0.0133	0.0128	0.0138	0.0129
b	0.0122	0.0129	0.0133	0.0122	0.0135	0.0124
c	0.0108	0.0111	0.0114	0.0110	0.0118	0.0110

Table 3. Storage Modulus E1 (graphite/epoxy)

Lay up	Before immersion	24 hrs. in water	2 hrs. in boiling water	After re-drying	7 days in water	After re-drying
a	9.834	9.613	8.652	9.647	8.199	9.721
b	23.176	21.393	20.637	22.640	20.431	23.207
c	26.892	26.650	26.243	26.785	26.163	26.806

Table 4. % Moisture Absorption (glass/epoxy)

Lay-up	24 hr. in water	2 hr. in boiling water	7 days in water
a	1.43	2.780	4.496
b	1.49	2.130	5.007
c	1.34	2.736	3.775
d	1.30	2.370	3.294
e	0.90	2.325	2.730

Table 5. Loss factor ‘d’ (glass/epoxy)

Lay up	Before immersion	24 hrs. in water	2 hrs. in boiling water	After re-drying	7 days in water	After re- drying
a	0.0145	0.0183	0.0187	0.0146	0.0192	0.0151
b	0.0189	0.0211	0.0218	0.0190	0.0241	0.0196
c	0.0256	0.0283	0.0288	0.0263	0.0294	0.0260
d	0.0337	0.0370	0.0395	0.0343	0.0399	0.0340
e	0.0099	0.0105	0.0113	0.0103	0.0116	0.0104

Table 6. Storage Modulus E1 (glass/epoxy)

Lay up	Before immersion	24 hrs. in water	2 hrs. in boiling water	After drying	7 days in water	After drying
a	10.680	9.997	9.809	10.642	9.745	10.620
b	6.309	6.285	6.223	6.300	6.190	6.288
c	3.395	2.861	2.630	3.149	2.420	3.372
d	2.270	1.669	1.337	2.137	1.268	2.236
e	10.594	9.932	9.472	10.455	9.268	10.433

Table 7. Fibre content & density of graphite /epoxy Composites

Lay-up	w_f	v_f	ρ (g/cc)
a	0.741	0.65	1.521
b	0.741	0.65	1.521
c	0.741	0.65	1.521

Table 8. Fibre content and density of glass/epoxy Composites

Lay-up	w_f	v_f	ρ (g/cc)
a	0.5332	0.350	1.539
b	0.5132	0.332	1.540
c	0.4804	0.304	1.537
d	0.5167	0.335	1.543
e	0.4816	0.305	1.531

Following observations are made from the above tables:

The moisture absorption is a function time, as time of immersion increases the moisture absorption increases up to the saturation value. As compared to graphite/epoxy composites, glass/epoxy composites absorb more moisture. The glass fibres are hygroscopic in nature and fibre matrix interface is also attacked by water in glass fibre reinforced plastics. For both graphite/epoxy and glass/epoxy, the effect of moisture is to increase the loss factor and decrease the storage modulus. Increase in loss modulus and decrease in storage modulus is higher for higher moisture content as expected. The effect of lay up sequence on changes in loss factor and storage modulus is not very significant in case of graphite/epoxy composites. This is mainly due to the fact that moisture absorption is lower as compared to glass/epoxy and also graphite fibres are less affected by moisture. In glass/epoxy composites for lay up (d)-(90/0)S , where 900 layers are outer layers, the effect on storage modulus is the maximum. For the other lay ups also, there is a significant effect of lay up sequence on loss factor and storage modulus. When the samples were re-dried at 105 ºC for half an hour to remove the absorbed moisture, all the samples regained their room temperature properties, although complete recovery is not achieved.

5. CONCLUSION

The damping of materials is an important parameter for the structure and machinery subjected to the dynamic loading. Most of the conventional metallic materials possess very little or no material damping and some times layers of viscoelastic materials are externally bonded to improve the damping. On the other hand, plastics which are viscoelastic materials have very high inherent material damping, but they have poor mechanical properties for the engineering applications. Fibre reinforced polymer composites provide good mechanical properties as well as inherent material damping. Polymer composites are very much affected by the presence of moisture. Therefore, a study of effect of moisture on damping properties of most commonly used polymer composites viz.- glass/epoxy and graphite/epoxy was undertaken.

Following main observations are made from the study:

Glass/epoxy absorbs more moisture compared to graphite/epoxy under similar conditions.

Loss factor increases with increase in moisture content while storage modulus decreases for both glass/epoxy and graphite/epoxy.

Changes in loss factor and storage modulus are more pronounced for glass/epoxy mainly because of higher moisture absorption.

Lay up sequence governs the moisture effects on loss factor and storage modulus and the effect is more in the case of glass/epoxy laminates.

The moisture effects are maximum for laminates with 900 outer layers.

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