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SHORT COMMUNICATION

Constrained-layer Dampers for Attenuation of Structural Vibration

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ABSTRACT

In a constrained-layer damping system, a thin layer of a viscoelastic material is applied over the vibrating substrate and covered with a stiff constraining layer of a metal or a fibre-reinforced plastic. Several viscoelastic materials based on elastomeric blends of copoly (acrylonitrile-butadiene) and polyvinyl chloride were developed. These materials were characterised for hardness, tensile properties, ozone resistance, and electrical and dynamic mechanical properties. Two polymer compositions were used to fabricate 1 mm sheets. The sheets were fixed on an aluminium substrate with a rigid epoxy glue. A fibre-reinforced plastic sheet of 300 μ was fixed on the viscoelastic layer by a rigid epoxy glue. The experimental setup for the measurement of vibration response has been elaborated. The study was carried out with and without the constrained-layer damping system. The vibration attenuation achieved was to a minimum of 5-7 dB at 200-500 Hz and to a maximum of 9-16 dB at 3000 - 4000 Hz for the selected constrained-layer damping system.

Keywords: Constrained-layer damping system, CLD system, viscoelastic material, structural vibration, fibre-reinforced plastic, vibration attenuation, epoxy glue, free-layer damping system

1. INTRODUCTION

The vibrations in structures and machines cause component fatigue and human discomfort, if not properly controlled. For ship structures, vibrations due to the mounted machinery, propellers, etc, are likely to be transmitted into the seawater through the hull vibration, and these can be detected by a passive sonar. The elimination of vibrations in a ship structure, is thus an important acoustic stealth measure. The common methods of controlling unwanted vibrations are: (i) proper design to reduce the excitation at source, (ii) changing of mass and/or stiffness to avoid resonance, and (iii) using damping materials[1-3]. The conventional approaches for the control of vibrations avoid resonance due to coincidence of excitation frequency, and any natural frequency of a system. This is not practical if vibrations occur over a wide range of frequencies, eg, in the case of turbo engines or diesel generators, where the frequencies vary from very small to over 5000 Hz.

The intensity of mounted machinery vibrations to some extent can be reduced by shock mounts.

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* Now transferred to NPOL, Kochi.

However, residual vibrations of the base, in some cases, can be considerably high enough for generating radiated noise. In the case of ship structure, the vibrations of the hull plates due to machinery cause radiation of noise into the seawater, and this acoustic signal can be picked up by an efficient passive sonar. Thus, the reduction of ship structural vibrations and associated noise is of immense importance to acoustic stealth design of ships/submarines.

The availability of a wide range of polymeric materials, which are essentially viscoelastic in nature, with high damping capabilities has made it possible to control the structural vibrations. The polymers are commonly used in two basically different configurations to dissipate the mechanical energy of vibrations as heat[4,5]. The first configuration is the free-layer damping (FLD), where the energy is dissipated due to direct strains, ie, alternate extension and compression of the viscoelastic layer. The second configuration is the constrained-layer damping (CLD), where the shear strains in the viscoelastic layer cause damping of vibrations. Generally, the constrained-layer damping system is used for very stiff structures. The constrained-layer damping application uses a three-layered sandwich system, that is formed by laminating the base plate to a viscoelastic layer and then adding a constraining layer, such as metal or fibre-reinforced plastic.

A schematic diagram of a constrained-layer damping system is shown in Fig. 1. Some of the applications of constrained-layer damping are in aircraft and missile substructures, machinery supports, mounting platforms of electronic equipment, and bridges and buildings. Though constrained-layer damping treatment provides better damping compared to free-layer damping, the latter is more convenient to apply and retain damping over a wider temperature range[6-9]. This paper discusses the development of a polymeric material for use in a constrained-layer damping system.

2. EXPERIMENTAL PROCEDURE

The base polymer used was a blend (50:50 or 30:70) of polyvinyl chloride (PVC) and acrylonitrile-butadiene rubber (NBR). Different compounding ingredients, such as filler (up to 20 phr) and sulphur curatives (2-4 phr) were mixed into the polymer using a two-roll mill and sheets were molded in a compression molding press at 150 °C. Two polymer compositions, EAP1 and EAP2 were prepared which differ in their filler compositions. The polymers were characterised for hardness, tensile, and electrical properties. The dynamic mechanical properties of the polymer were studied using a dynamic mechanical thermal analyser over a temperature range –50 °C to +100 °C at various frequencies.

To study the vibration damping behaviour of the polymer, a constrained-layer damping system was constructed using a base plate of aluminium and the constraining layer of a fibre-reinforced

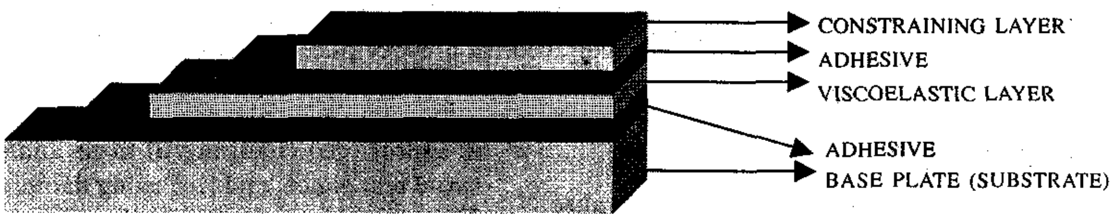

Figure 1. Schematic diagram of a constrained-layer damping system

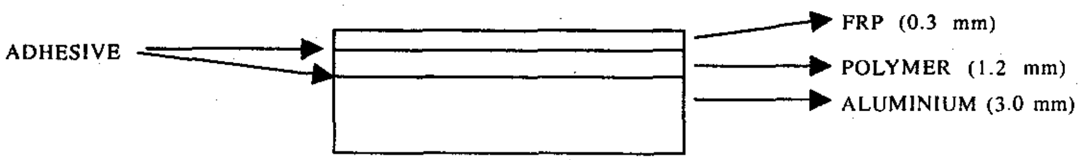

Figure 2. Construction of a constrained-layer damping system

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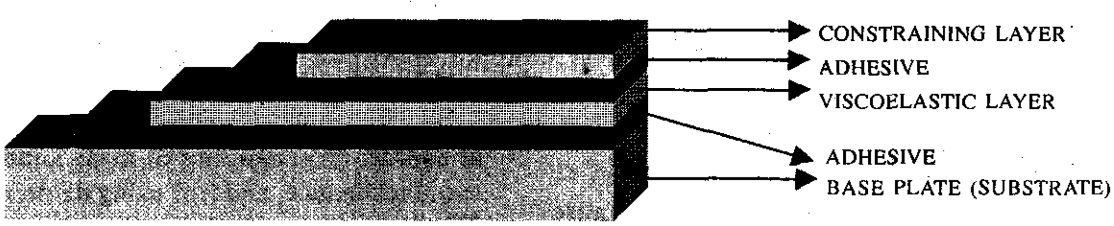

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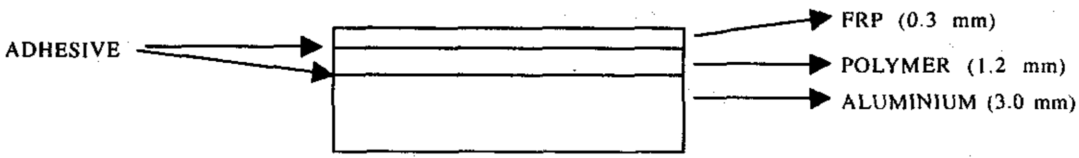

Figure 2. Construction of a constrained-layer damping system

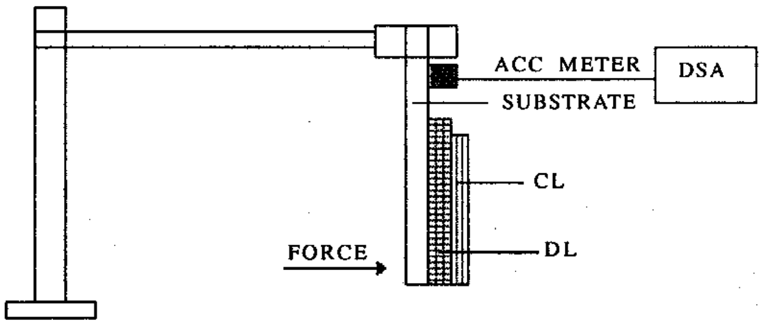

Figure 3. Experimental setup for measurement of vibration response

plastic sheet. The three pieces were fixed together as shown in Fig. 2, using a rigid epoxy adhesive.

The experimental setup to measure the vibration response is shown in Fig. 3. An electrodynamic shaker at the free-end excited the aluminium substrate and the vibration was picked up at the other end by an accelerometer and was recorded by a dynamic signal analyser (DSA).

3. RESULTS & DISCUSSION

The physical properties of the polymer compositions EAP1 and EAP2 are shown in Table 1. These polymers have good physical properties and ozone resistance, suggesting their possible use in stringent conditions. The difference in the mechanical properties and resistivity of the two polymer compositions is attributed to the type and amount of filler used in the blends.

Table 1. Physical properties of polymer for CLD application

Property	Polymer composition	
	EAP1	EAP2
Density (g/cc)	1.16	1.16
Hardness (Shore A)	56	55
Tensile strength (MPa)	9.4	7.3
Elongation at break (%)	405	350
Ozone resistance (100 pphm/48 h/20 % strain/40 °C)	No cracks	No cracks
Abrasion resistance index	100	100
Volume resistivity (ohm-cm) (RT/500V)	5.05×10^{10}	4.35×10^{10}

The dynamic mechanical properties of the polymer compositions EAP1 and EAP2 are shown in Fig. 4, where the loss factor is plotted against the frequency. The master curve is drawn using the William-Landel-Ferry equation of time-temperature superpositioning at a reference temperature of 25 °C. Such curves are useful in vibration damping applications since these provide an estimation of damping capability at low and high frequencies not measurable using instruments.

The loss factor (0.55–1.00) is in the frequency range 100-1000 Hz. It goes through a maximum in the vicinity of the glass transition temperature. The combination of high storage modulus (10-20 MPa) and high loss factor (0.40-0.55) at 1 Hz/25 °C indicates that the polymer is suitable for constrained-layer damping applications. It gives a good compliance to the material for producing maximum shearing–the mechanism of energy dissipation–on flexing of the system due to incoming vibrations[10].

The vibration attenuation of the two polymer compositions in the constrained-layer damping mode against a bare aluminium plate is shown in Figs 5 and 6. It is evident that both the polymer compositions EAP1 and EAP2 exhibit good damping properties in the frequency range 300 Hz and above. However, EAP2 shows better damping at lower frequencies as compared to EAP1, which is due to higher loss factor of EAP2 in lower frequencies, while the dynamic moduli of both the polymer compositions are almost the same.

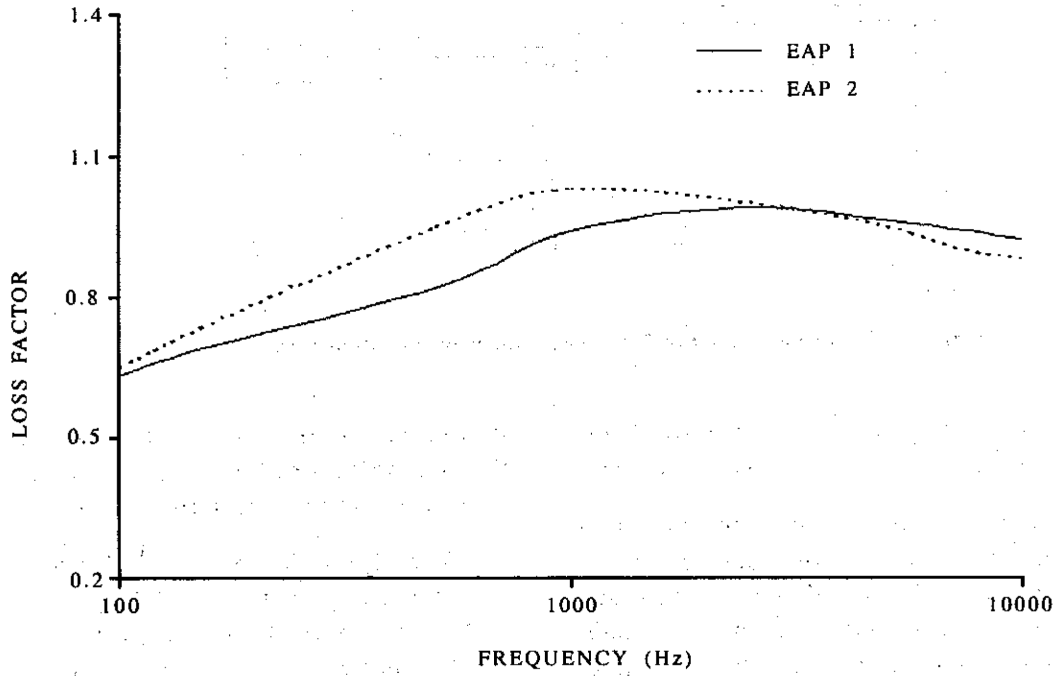

Figure 4. Dynamic mechanical properties of the two polymer compositions EAP1 and EAP2

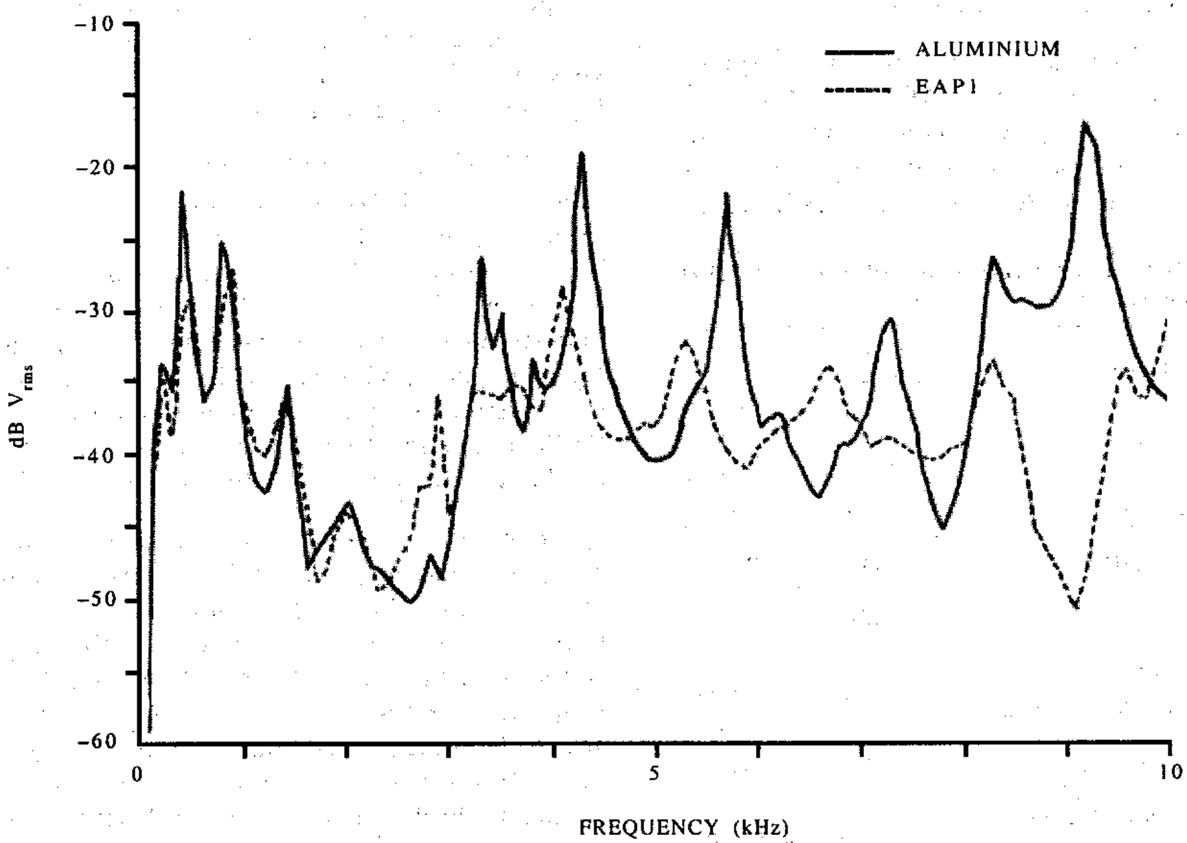

Figure 5. Plot of CLD acceleration data of a bare aluminium plate and a CLD system containing EAP1 as the damping layer

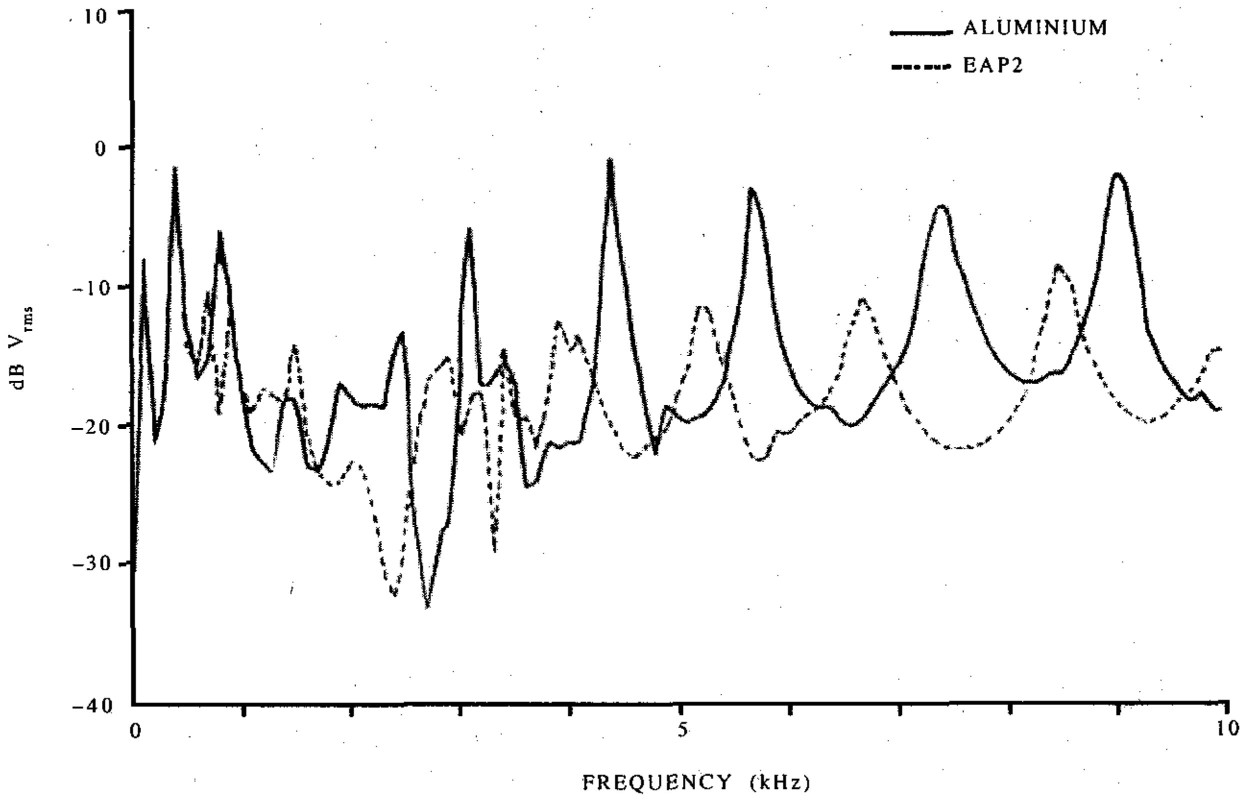

Figure 6. Plot of CLD acceleration data of a bare aluminium plate and a CLD system containing EAP2 as the damping layer

4. CONCLUSION

The two polymer compositions based on polyvinyl chloride and acrylonitrile-butadiene rubber were prepared for use as the damping layers in constrained-layer damping applications. The experimental setup to measure the vibration response of the constrained-layer damping system has been elaborated. Both the polymer compositions show excellent physical properties. The damping properties of the polymer compositions as measured on DMTA and the vibration response as measured on the new experimental setup are satisfactory. The polymer composition EAP2 is found to be better for constrained-layer damping application with the chosen experimental configuration.

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