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Experimental investigation on damping behaviors of Al MMCs reinforced with Cu-coated Al_2O_3 particulates

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Abstract - Nowadays it is commonly considered that high damping and low thermal expansion material which have good mechanical properties are used as structural materials for different applications. The present investigation is based on the effect of thermal residual stresses on the damping behavior of Al/Al_2O_3 metal matrix composites (MMCs). MMCs are processed by compocasting technique with 15 and 20% by weight of Al_2O_3 particle reinforcement. Damping properties have been studied experimentally as a function of temperature over a temperature range from room temperature to 300°C both in the heating and cooling cycle. The damping capacity of both the composites and matrix alloy is found to increase with the increase in temperature during the heating cycle, whereas in the cooling cycle damping behavior exhibited maxima which became more pronounced with the increase in the weight percentage of the reinforcement. The appearance of the maxima may be linked with dislocation generation and motion as a result of plastic deformation of the matrix at the metal/reinforcement interface.

Keywords —MMCs, DMA, Coated particle, Damping behavior.

I. Introduction

Metal matrix composites (MMCs) have proved to be the best choice for such materials due to their low density, reasonably high thermal conductivity, heat treatment capability, processing flexibility, and low cost [1]. The commonly used reinforcements such as SiC, Al_2O_3, and others enhance the mechanical [2] and wear [3] properties rather than the damping capacity. But the damping properties of MMCs play an important role in controlling noise and vibration in a dynamic structure and thus will prolong the service life of structures [4]. Presently many researchers [5-6] designed MMCs for damping enhancement by incorporating particles with a higher proportion that possesses high intrinsic damping capacity into relatively low damping alloys. Furthermore, few researchers showed that the performance of Al alloy matrices reinforced with coated and non-coated SiC_p enhanced damping capacity [7-8]. Although the damping mechanism of particle reinforced aluminum composites has been extensively studied, however very little work has been reported on the effect of particle coatings on the damping capacity of MMCs. The objective of this investigation was to study the effect of Cu-coated Al_2O_3 particles on the damping behavior as a function of temperature.

II. Experimental Procedure

A. Material Preparation

The matrix material used in this study, Al6061 and Al_2O_3 particulates of 30-50 μm were used as the reinforcement. The chemical compositions of both matrix and reinforcement were given in Table 1. Before fabrication of composites, the Cu-coated Al_2O_3 powder particles were prepared by an electroless coating technique, more details of which can be found in [9] Liquid metallurgy technique was used to fabricate the composite materials in which the Al_2O_3 particles were introduced into the molten metal pool through a vortex created in the melt by the use of an alumina-coated stainless steel stirrer. Al_2O_3 content in the composites was 15 and 20 wt. %. Table 1 shows the chemical composition of Al6061 and Al_2O_3.

TABLE I CHEMICAL COMPOSITION OF AL6061 ALLOY

Constituents	Composition in %
Mg	0.92
Si	0.76

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Fe	0.28
Cu	0.22
Ti	0.10
Cr	0.07
Zn	0.06
Mn	0.04
Be	0.003
V	0.01
Al	Bal.

B. Damping Measurement

Specimens were machined and polished to 70mm x 10mm x 2mm dimensions, the specimen surfaces were ground using a series of SiC papers of 100, 200, 400, 600, & 1000 grit and then polished with 3µm diamond paste to obtain a fine finish. The specimens were washed using distilled water and acetone separately and dried. A Dynamic Mechanical Analyzer (DMA model 983, Dupont) used for measuring damping capacity includes sample arms and clamps, flexure pivot, LVDT, electromagnetic driver, and a temperature programmer interfaced with a computer. The specimen was subjected to a flexural sinusoidal strain with constant amplitude and the resultant-bending stress was measured simultaneously. The sample was held between the two end clamps and enclosed in a chamber that provides heating and cooling capability. The electromagnetic driver applies flexural strain to the specimen and the resultant stress on the sample was measured by LVDT. The specimens were displaced by 250 µm peak to peak at the drive clamp corresponding to a maximum strain of $2.6x10^{-4}$. The sample length measured between the clamps was approximately 38 mm. The temperature of the specimen was varied from 25ºC to 500ºC both in the heating and cooling cycles at the rate of 10ºC/min.

III. Results

Fig. 1 and 2 show curves of damping (tan φ) vs. temperature (T) plotted for Al matrix, Al/ uncoated Al_2O_3 and Al/ Cu coated Al_2O_3 MMCs for different frequencies of 0.1, 0.5, and 1.0 Hz. The common observation from the two figures is that the damping is improved with increasing temperature and decreasing frequency. Several interesting trends are observed from the curves that are found to be the characteristic feature of the Al_2O_3 einforced Al composites both coated and uncoated reinforcements. In the heating cycle, from 25-150°C, damping capacity seems to increase marginally with an increase in temperature, from 150-250°C it is found to increase rapidly with an increase in temperature, and from 250-300°C it increases mildly but linearly with increase in temperature. Also, in the heating cycle, for all three types the unreinforced matrix alloy, uncoated composites, and coated composites, maxima (peak) is observed at 300°C. In the cooling cycle, a closer observation of the figure reveals some interesting details on the hysteresis behavior and the maxima (peak) phenomena of the composites exhibited between the heating and cooling curves. In the cooling cycle, different nature of curves is observed. Initially, from 300-250°C the damping capacity marginally decreases, from 250-250°C it increases, and from 250-25°C it steeply decreases with a decrease in temperature. Overall, the damping capacity and the area of the hysteresis curve increase with the increase in reinforcement. Careful observation of the damping capacity data in the 225-250°C range shows a peak. The damping capacity of the composites, as well as the matrix alloy, has been found to increase with the increase in temperature and increase in reinforcement.

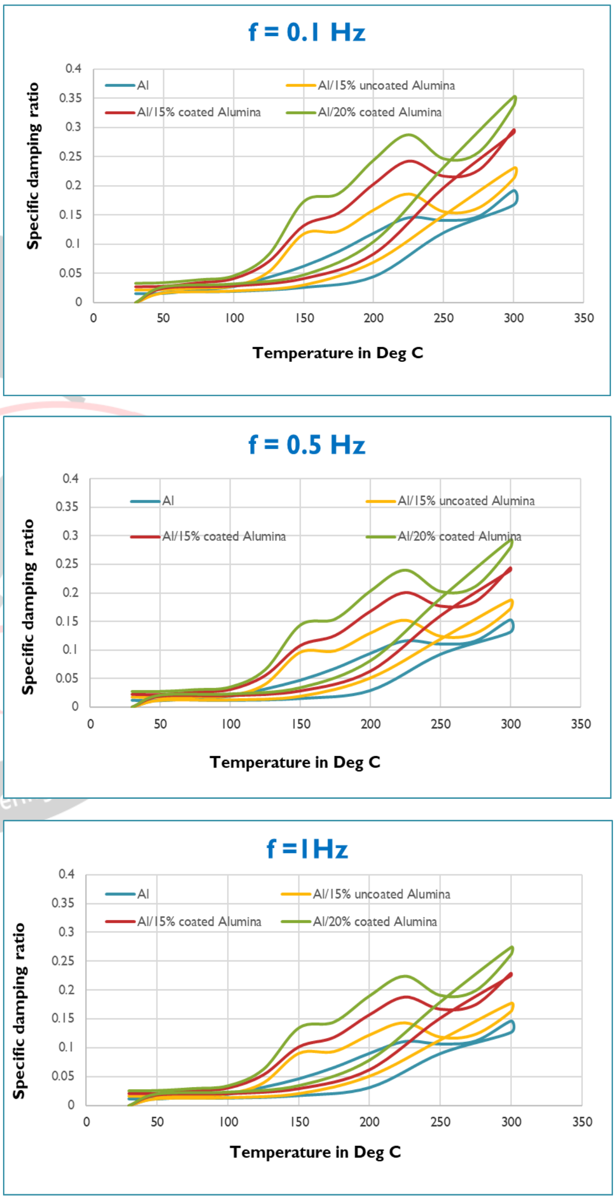

Fig. 1. Damping capacity (tan φ) at a) 0.1 Hz b) 0.5 Hz and c) 1 Hz of Al alloy, Al/ uncoated Al_2O_3 MMCs, and Al/ coated Al_2O_3 MMCs as a function of heating and cooling at 10°C/min

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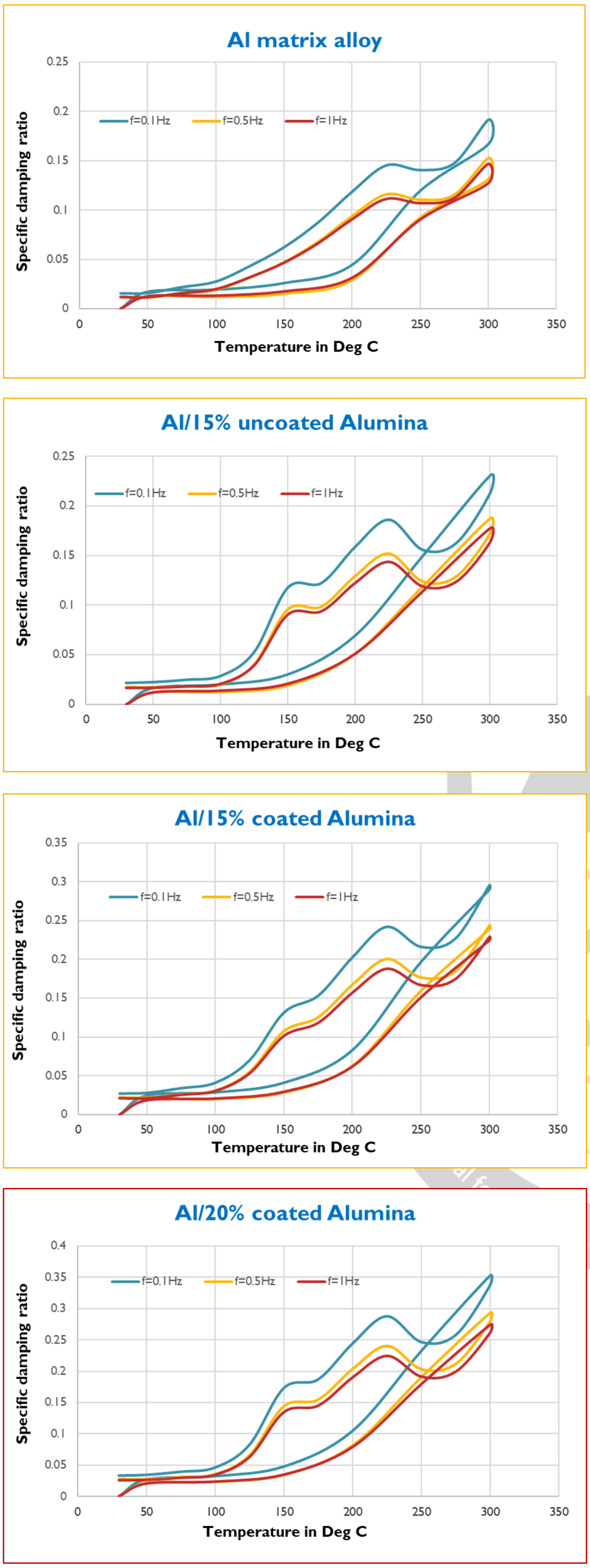

Fig. 2. Damping capacity (tan φ) at a) Al matrix alloy, b) Al/Al_2O_3 uncoated MMCs, and Al/ coated Al_2O_3 MMCs for 0.1 Hz, 0.5 Hz, and 1 Hz of Al alloy, and as a function of heating and cooling at 10 °C/min

IV. Discussion

As expected, the addition of Al_2O_3 particulates to the Al matrix leads to the improvement of modulus due to its high intrinsic modulus, as has been verified from other experiments [10,11]. Al/ uncoated Al_2O_3 and Al/Cu coated Al_2O_3 MMCs composites have been developed with higher stiffness (E) and lower density (ρ). (E/ρ)1/2 also represents the velocity of the elastic waves in the material. Thus, higher specific stiffness results in a higher natural frequency for the components [12], which is one of the reasons for the increase in the damping capacity of the composites. Perez et al. [13] have reported that the dislocation concentration found in Al matrices of ceramic particulate-reinforced MMCs is in the order of 1013 to 1014 cm^{-2}. Kim [14] has reported that if the heat dissipation were taken into account as part of the plastic work, the predicted dislocation densities of the elastoplasticity model would have been in reasonable agreement with the measured dislocation densities of 109 to 1010 cm^{-2}. These dislocations are generated to accommodate the residual strain around the particulate, but the dislocation concentration near the reinforcement-matrix interface is larger and it decreases with an increase in distance from the interface.

The thermal stresses in MMCs have been already studied by internal friction or damping capacity measurement [15]. The existence of the damping maxima is particularly important since this maximum may be related to the thermal stresses, which are generated in the composites. In the absence of thermal stresses, the dislocation can vibrate around its equilibrium position and contribute to the damping. This partly accounts for the observed damping capacity of the base alloy. When the composite specimen is cooled, tensile thermal stresses arise in the matrix due to the particulate distribution and induce a long-range movement of the dislocations, which is superposed on the oscillatory motion imposed by the damping apparatus. This interaction is supposed to be the origin of the observed maxima. The dislocation density in the unreinforced matrix is quite low [16]. Hence, the damping capacity is suggested simply to come from the dynamic hysteresis of the lattice defects [17] such as the vacancy or interstitial due to the reinforcement. The stress-induced ordering process of these leads to an anelastic strain, and the damping mechanism is referred to as the linear reversible anelastic relaxation and it opens up the dynamic hysteresis loop. The dynamic hysteresis loop generally dissipates a smaller quantity of energy while the residual stresses are relaxed from the composite during the heating and cooling cycles [18]. It was found that the damping capacity at 300° C (heating cycle) and 1 Hz for 20 wt.% of Cu coated alumina has increased by 22% compared to 15 wt.% coated alumina, 54% compared to 15 wt.% uncoated alumina, and 2.16 times compared to as-cast Al alloy.

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V. Conclusion

The nature of the damping behaviors of the coated Al_2O_3 particulate reinforced composites was similar to that of the uncoated ones. The damping behaviors of the coated Al_2O_3 particulate reinforced composite were improved strongly compared with that of the uncoated one. The dynamic modulus of both uncoated and coated composites exceed that of Al alloy. There is a strain peak and hysteresis in damping curves of all three types of materials and all three vibration frequencies which could be attributed to the dislocation process. The damping capacity of all three types of material depended on the vibration frequency. When the vibration frequency was lowered; a higher damping capacity was obtained which is due to the thermoelastic damping.

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