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Effect of Heat Treatment on Damping Properties of Nanoclay Particulate Reinforced MMCs

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Abstract*: *The thermo-mechanical behaviour of Aluminium alloy reinforced with nanoclay particulate was investigated by resonant-bar method. The aging response was detected in specimens, damping and DSC observation. The damping capacity of composite increased with increasing reinforcement of nanoclay and showed a peak in damping capacity during aging. These results indicate that the aging and precipitation kinetics in the matrix alloy are significantly accelerated due to the presence of reinforcement. The damping mechanisms, intrinsic damping, interface damping, dislocation damping and grain boundary damping are discussed.

Index Terms: *Nanoclay, damping properties, heat treatment.*

I. Introduction

High damping capacity and lightweight metals have potential applications in weight-critical structures such as aerospace and automobile applications. The quantity $(E/\rho)^{1/2}$, where E and ρ are the elastic modulus and density respectively, represents the velocity of the elastic waves in the structures which implies that higher specific stiffness results in a higher natural frequency and high damping capacity for the component[269]. One potential means of obtaining a lightweight high damping metal is through incorporation of ceramic particulates into the matrix as in Metal Matrix Composites (MMCs).

Aluminium composite fulfils the requirement of advanced aerospace materials with improved properties including elastic modulus, coefficient of thermal expansion (CTE), damping capacity, wear resistance and increased-temperature performance[1-3].

The damping capacity of a material refers to its ability to convert mechanical vibration energy into thermal energy. Passive damping is a critically important material property from the viewpoint of vibration suppression in aerospace and submarine structures[4]. With the advent of MMCs technology it is possible to modify the damping behaviour of metals and alloys by combining them with non-metallic phases. Ceramic reinforced metals/alloys may combine the ductility and toughness of the matrix with high strength and high modulus characteristics of the ceramic particles while often retaining the same level of damping capacity[5,6]. The dynamic modulus or the stiffness of a material undergoing dynamic loading is useful in the studies of inter-atomic potentials, creep behaviour and thermal expansion[7]. Measurement of dynamic modulus in MMCs often provides a more flexible and accurate alternative to standard static testing techniques.

II. General Theory

Mechanical loss angle (ϕ), loss tangent (tanϕ), internal friction (Q^{-1}), logarithmic decrement (δ), etc are usually used to describe the damping capacity. In the present study the damping capacity describes internal friction

Internal friction (Q^{-1})

Measurement of successive strain amplitude from the oscilloscope will then yield the logarithmic decrement δ as follows[8]

$$\delta = \ln (A_n/A_{n+1}) \qquad (1)$$

where A_n and A_{n+1} are the amplitudes of successive cycles in free decay, The relationship between δ, internal friction factor Q^{-1}, and damping ratio ξ is given by

$$\xi = \delta/2\pi \qquad (2)$$

$$Q^{-1} = 2\xi = \delta/\pi \qquad (3)$$

Mechanical Loss (ϕ)

The phase logϕ of the strain response behind the stress excitation known as the mechanical loss angle, the tangent of which is the measure of fractional loss of mechanical energy per oscillation cycle[9].

$$\tan\phi = \frac{\delta}{\pi} = Q^{-1} = \frac{\ln (A_i/A_{i+1})}{\pi} \qquad (4)$$

This research work reports on a study of the damping behaviour of nanoclay particulate-reinforced Al alloy MMCs processed by liquid metallurgy technique. Resonant-bar techniques were used to find out damping capacity (internal frication) loss as a function of temperature. The effects of nanoclay particulate content and aging time on the composite were investigated. The damping mechanism of composites was also discussed.

III. Experimental Studies

In the present work Aluminium alloy was used as matrix, because of its excellent casting

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properties and reasonable strength. This alloy is best suited for mass production of lightweight metal castings. Table 1 shows the chemical composition of Al alloy.

Table 1 Chemical composition of Al alloy

Mg.	Si	Fe	Cu	Ti	Cr	Al
0.92	0.76	0.28	0.22	0.10	0.0	0.04

The nanoclay was used as the reinforcement. Its content in the composite was varied from 2 to 6 % in steps of 2% by weight. Liquid metallurgy technique was used to fabricate the composite material in which the preheated nanoclay particles to 773 K were introduced into the molten metal pool through a vortex created in the melt using an alumina-coated stainless steel stirrer. The coating of alumina on the stirrer is essential to prevent the migration of ferrous ions from the stirrer material into the molten metal. The stirrer was rotated at 550 rpm and the depth of immersion of the stirrer was about two-thirds the depth of the molten metal. The liquid melt was degassed using pure Nitrogen for about 3 to 4 min before the nano clay particles were added to it. The resulting mixture was tilt poured into preheated permanent moulds to obtain castings. Specimens were machined and polished to a size of 2 x 10 x 150 mm^3. Specimen surfaces were polished with 1μm diamond paste. Specimens were subjected to solution heat treatment for 10 h at 532°C, quenching in 80°C water, and artificial aging at 175°C for as-quench, 1, 3, and 5 hours. Five samples of each specimen were tested under same conditions to verify the reproducibility of the data. The specimens (as cast condition) were subjected to the following heat treatments:

1. Solution treatment for 24 hours at 796 K
2. Quenching in water (Ice cooled) at 273 K
3. Stabilizing at room temperature for 48 hrs
4. Aging at 593 K for different intervals of time ranging 1, 2 and 3 hrs.

In the present study the flexural resonant bar damping system and the internal friction, were used to measure the damping properties of Al MMCs. The resonant bar damping system is shown in the Fig. 1. A simple free cantilever plate can be excited into fundamental mode of flexural vibration by an exciting steel ball. After the exciting steel ball hits the specimen, the amplitude of vibration gradually decreases

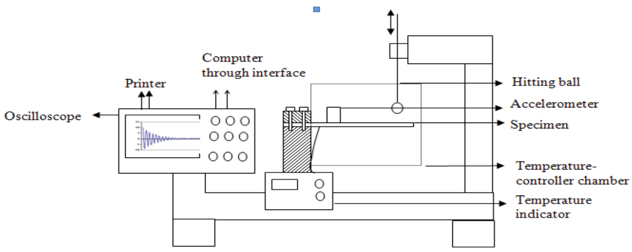

Fig. 1 Sketch of the resonant bar damping system

with time as the vibration energy is dissipated. These decayed amplitudes and frequency of vibration are transferred to oscilloscope and computer by an accelerometer attached on specimen's end. The specimen temperature was measured by a thermometer and controlled by a temperature controlled chamber. The tests were conducted between room temperature and 300 °C at the interval of 50°C.

IV. Results

Effect of temperature

The damping capacity (δ) of matrix alloy and composites with different nanoclay contents as a function of temperature is shown in the Figure 2 for as-quenched, 1, 2 and 3 hour aged conditions. It is observed that at as-quenched and 1, 2, and 3-hour aging condition, the overall variation of damping capacity with temperature may be categorized into three different stages. The first stage which is from 30-150 °C shows that the damping capacity almost remains constant with temperature. During second stage i.e from 150- 250°C, there is a rapid increase in damping capacity and attains peak value at 250°C. The final stage which is from 250-350°C shows that the damping capacity decreases with temperature. Marginal difference is observed in the duration of initial stage of the damping capacity changes between the materials except the fact that the damping capacity of the composites is greater than that of the matrix alloy. However, the middle stage for the composites is found to be higher than that for the base alloy. The stages are similar at all duration of aging except that the damping capacities of both the matrix alloy and the MMCs vary. In all cases, it can be seen that damping capacity increases as nanoclay content increases.

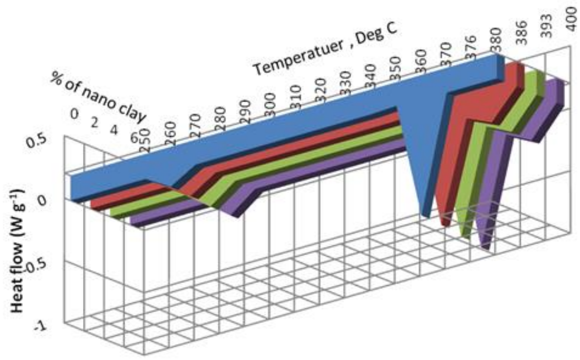

Fig. 4 DSC thermogrms of Al and Al/nanoclay reinforced MMCs for three aged condition at 153°C.

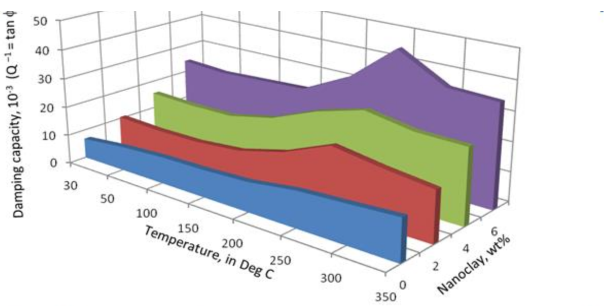

Fig. 2 Damping capacity of Al6061/nanoclay composites with wt.% of reinforcement with temperature for a) as-quenched, b) 1,

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Effect of duration of ageing

The dependence of damping capacity on ageing time in the base alloy and composites are shown in the Fig. 3 at an ageing temperature of 175°C. The plot indicate that the damping capacity initially increases with the increase in ageing time reaching a peak value (1 hour) after which it decreases with the increase in aging time.

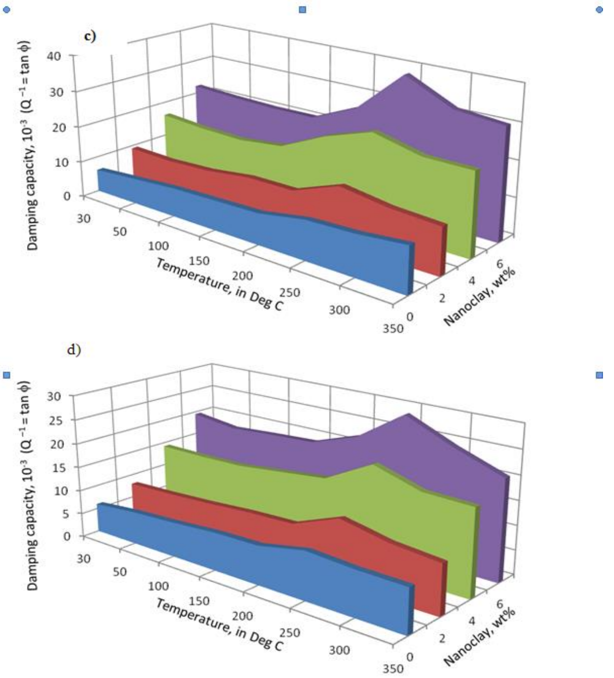

Fig. 2 Damping capacity of Al6061/nanoclay composites with wt.% of reinforcement with temperature for, c) 2, and d) 3 hours aged conditions

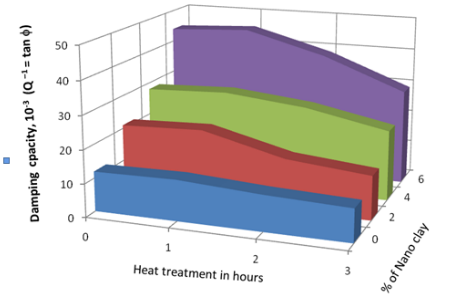

Fig. 3 Damping capacity of Al6061/nanoclay composites with wt.% of reinforcement with aged conditions

The addition of reinforcement has resulted in an increase in the damping capacity of the samples. This suggests an increase in the thermal mismatch induced dislocation density in the composite matrices, which contribute appreciably to the increase in damping capacity. This suggests that during quenching, the dislocation density and the precipitation of metastable phases contribute to overall matrix damping capacity. But after over aged, the influence of the dislocations become less pronounced.

The composites show an endothermic reaction between 370 and 380 °C owing to Guinier-Preston (GP) zone dissolution as shown in the Fig. 4.

V. Discussion

Effect of microstructure

The composite microstructure is physically differentiated into three zones; the un-deformable reinforcement; the plastic region around the reinforcement with high density of dislocations and the elastic region with fine sub-grain size.[10] Each zone contributes to damping capacity in their own way. First zone unmemorable reinforcement nanoclay particulate is a relatively higher damping capacity material at both room and elevated temperature. The damping capacity depends on the specific stiffness (E/ρ- E Elastic modulus and ρ density) of the material[11]. The nanoclay has higher stiffness and lower density than the matrix alloy, which contributed greatly on damping properties.

Secondly, the specific stress relaxation mechanism is the dislocation generation and motions the matrix, near the metal-ceramic interfaces. During cooling, the metal matrix contracts more than the ceramic particulates, and dislocation are punched out from the reinforcement at soon as the thermal stresses overcome the matrix flow stress. This dislocation activity has been also reported in TEM[12]. In other hand, dislocation densities are believed to be one type of defect, which plays a significant role in contributing to the overall damping response. Weak interface bonding between reinforcement and matrix and high dislocation density may contribute to the improvement damping behaviour. The dislocation becomes sources of damping because of internal friction to the motion of the dislocations under cyclic loading; hence, it has been proposed that the damping capacity is proportion to the dislocation density.

Lastly, the damping capacity of the composites is increasing with the increase in addition of the nanoclay particulate. The addition of nanoclay particulate modified the microstructure of the grains of the Al matrix. The grain size of the composites is smaller than that of the matrix alloy. Shamul et al.[13] have been reported grain boundary sliding exhibits viscous like properties, which convert mechanical energy produced under cyclic shear stress into thermal energy, as a result of internal friction. Chu et al.[14] reported the fine-grained structure thus offer a more significant contribution in the dissipation of elastic strain energy than the larger grain size The energy absorbed in grain boundaries is directly proportional to the grain boundary area per unit volume. The grain size of the composites produced fine-grained structures, which offer a significant contribution in the dissipation of elastic strain energy.

Effect of aging

During cooling the dislocation activity increases, resulting in high damping. At low temperatures there is a hardening of the plastic zones, which results in a low damping level during the subsequent heating. When temperature rises, there is a progressive recovery of the dislocation structure, and the process can restart in the next thermal cycle.

The aging response appears weak n damping capacity.

As for the composites, the plentiful grain boundaries, the nanoclay particulate and matrix interface, and grain boundaries accelerate heterogeneous nucleation and homogenous precipitation is largely inhibited.
The aging response suggests that the heterogeneous nucleation of coarse precipitate along grain boundaries and the interface between the reinforcement and the matrix might play an important role on the large contribution to damping capacity. The precipitate along grain boundaries and inteface might increase the damping capacity the damping capacity by increasing the friction between viscous flow and precipitates and thus the energy dissipation of viscous flow.[15]
The reduced damping capacity in the MMCs based on interfacial reaction and degradation of the reinforcement at high temperature[16].

The Snoek[17] theory states that the precipitates may contribute to an internal friction peak there is a relaxation at semi coherent or incoherent face. These contain dislocations and an elastic strain can be produced by their movement. This impels that coherent precipitates could not give rise to internal friction peaks.

Chawla et al[18] have performed DSC analysis on aluminium reinforced with SiC particles. They observed that at lower aging temperatures both GP zones and S' precipitates formed but that at higher aging temperatures the GP zone formation decreased.

VI. Conclusion

1. The addition of nanoclay particulate to Al6061 alloy was found to provide higher damping capacity.
2. The damping capacity of composite increased with increasing reinforcement of nanoclay and showed a peak in damping capacity during aging.
3. These results indicate that the aging and precipitation kinetics in the matrix alloy is significantly accelerated due to the presence of reinforcement.
4. The temperature dependence study of damping for all the samples showed an increase in damping capacity with increase in temperature.
5. Dislocations produced by CTE mismatch were believed to offer a large contribution at lower temperatures in addition to the intrinsic damping provided by the strong matrix alloy.
6. Particulate-matrix interface effect seemed to be more significant at higher temperatures due to softening of the matrix.
7. It is observed that whereas all these mechanisms become prominent only over a certain temperature range, the contribution due to thermoelastic damping is significant throughout.

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