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Factors affecting the damping capacity of cast aluminium-matrix composites

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The damping capacity of stir-cast aluminium-matrix composites containing graphite and silicon carbide particles, were studied using a cantilever beam specimen and an HP 5423A Structural Dynamics Analyser. Damping data were determined in the first mode of vibration. Aluminium-matrix composites containing 5–10 vol% graphite particles and 10 vol% silicon carbide particles were prepared by the stir-casting technique and die cast to obtain standard samples (6 mm × 25 mm100 mm). Graphite particles were found to be more effective in enhancing the damping capacity of composites compared to silicon carbide particles. The damping capacity of composites increased with the volume percentage of graphite within the range studied. However, no notable improvements in damping capacity were observed by dispersion of silicon carbide in aluminium alloy. The results have been analysed in terms of the effect of size, shape, nature and volume fraction of particles on the damping capacity of the aluminium matrix particulate composites and compared with the damping capacity data available in the literature. The effects of frequency, strain amplitude, temperature and processing on damping capacity of the aluminium matrix composites are reviewed.

1. Introduction

The damping capacity of a material is an important consideration in its selection as a structural member, because the resulting stress in dynamic cyclic loading is inversely proportional to the damping capacity. In a structure, a high-damping material may allow undesirable noise and vibration to be passively attenuated. Thus the use of high-damping material may eliminate the need for special energy absorbers or dampers which sometimes are quite massive.

Aluminium alloys are widely used for structural applications because of their light weight, easy fabricability and capacity for providing high strength by alloying and heat treatment. In the recent past, a variety of aluminium-matrix composites has been developed and evaluated for their damping capacity [1–16]. Rohatgi *et al.* have shown that the damping capacity of aluminium alloys increases with the addition of graphite [6] and mica [9] particles and the resulting composites have been found to show specific damping capacity normalized with respect to density to be larger than that of cast iron containing a similar volume per cent of graphite. Studies on damping capacity on aluminium–graphite [6], copper–graphite, [8] and aluminium–mica [9] have indicated that the damping capacity of metal-matrix composites (MMCs) increases with increasing size and amount of graphite or mica. Damping in metal–graphite composite appears to be due to energy losses at the matrix–particle interface from various mechanisms and, in addition, from the absorption of vibrational energy during microplastic deformation of the particle itself. Increase in damping capacity of aluminium-mica composites has been mainly attributed to the flake shape of the mica particles and interface voids.

Studies on reinforced MMCs including continuous graphite fibre/aluminium alloy composites [10–25] have shown that these composites possess excellent damping properties compared to their base alloys. Damping behaviour of these composites results from a combined effect of interfaces, the constituent fibre, and matrix materials. Fibre-reinforced composites with imperfect bonding at the interface have been found to result in higher damping compared to those with well-bonded composites. In these composites, damping at the fibre/matrix interface could also occur owing to the presence of a high dislocation between the fibre and the matrix. Updike and Bhagat [18] reported that graphite fibres enhanced the damping capacity of a composite in the absence of reaction at the aluminium–graphite interface.

Perez *et al.* [5] and Zhang *et al.* [15] studied the damping behaviour of as-received 6061-T6 aluminium alloy and graphite particulate-reinforced 6061 aluminium alloy composite processed by spray atomization and co-deposition. They also studied the damping capacity of the spray-deposited 6061 Al–graphite composite in the extruded condition. Recently, Zhang *et al.* [26] have studied the effect of temperature and frequency on the damping of aluminium–matrix composites.

Bhagat *et al.* [17] measured the damping capacity of mechanically alloyed and hot pressed and extruded 6061 T6 aluminium alloy, Al–Mg alloy and

Al–Cu–15 vol % SiC_p composite and they reported about a 2.42–2.82 times increase in the loss factor of the matrix alloy as a result of 15 vol % dispersion of silicon carbide particles. Wolfenden and Wolla [27] and Armstrong *et al.* [28] studied the effect of strain amplitude on the damping capacity of aluminium–matrix composites. Friend *et al.* [29] studied the effect of frequency on the damping of fibre-reinforced aluminium composite. Hinai *et al.* [25] measured the damping of Al–Ge alloy as a function of heat treatment and mechanical working while Sakai *et al.* [23] have shown higher damping in the Al–Pb system will increasing lead and degree of mechanical working.

The present paper describes the effect of size, shape, nature and volume fraction of graphite and silicon carbide in aluminium alloy on the damping capacity of the resulting composite, based on the experimental results. In addition to the above factors, the effect of temperature, strain amplitude, frequency and processing is also described, based on the basis of the results reported in the literature.

2. Experimental procedure

2.1. Preparation of the composite

The matrix aluminium alloys used for the preparation of composites were 2014 and 319. Synthetic graphite particles of average size 125 μm, supplied by Superior Graphite Co., Chicago, and SiC particles (15 μm) supplied by Norton, were used as dispersoids. Aluminium alloy particulate composites with lower volume percentages of dispersoids up to 10% were made using the vortex method [6]. Aluminium alloy–50 vol % graphite particle composites were also made by the pressure-infiltration technique.

Strip specimens were machined for damping measurement and one of the samples is shown in Fig. 1. Microstructural examination of the matrix, as well as that of the composite, was conducted on polished and etched samples using standard metallographic techniques. Typical microstructures are shown in Figs 2 and 3.

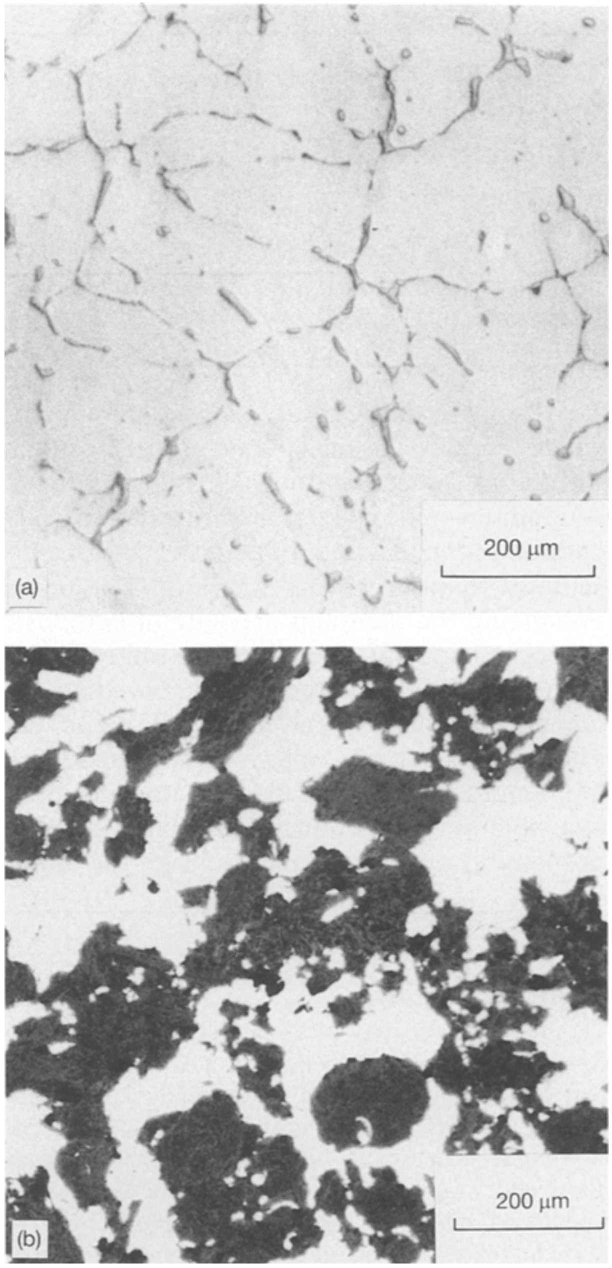

Figure 2 Microstructures of (a) as-cast base alloy (A12014) and (b) A12014–50 vol % granular graphite particle composite.

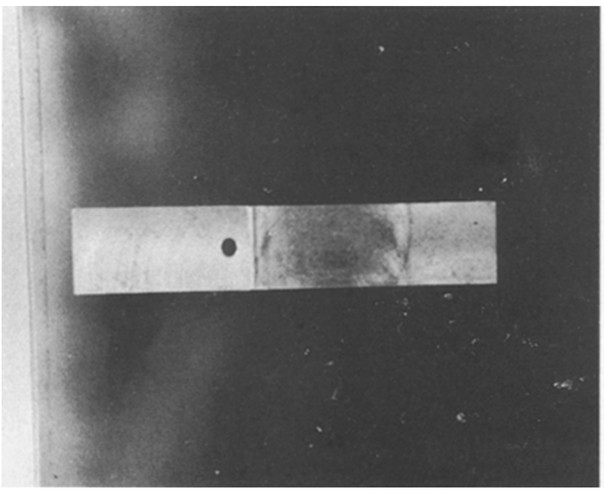
Figure 1 Photograph of a damping capacity test specimen (A319 + 10 vol % graphite, 6 mm × 25 mm × 100 mm).

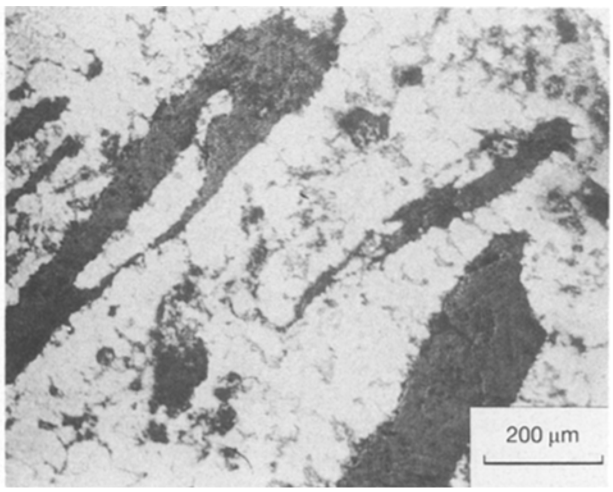

Figure 3 Microstructure of A319–10 vol % flake graphite particle composite.

2.2. Measurement of damping capacity

In order to evaluate the damping capacity of composites as a function of modal frequencies, a half-power bandwidth technique was used. Cantilever beam specimens (100 mm × 25 mm × 6 mm) were used in damping measurements. Test facilities available at Control Data Corporation, Minneapolis, were used in this work. The facilities consisted of an instrumented impact hammer, a signal analyser (FFT) and a data acquisition system. One end of the specimen was clamped and the other end was free to vibrate. An accelerometer was mounted at the free end of the specimen to measure specimen response during motion. Each test specimen was subjected to vibration by impacting with the instrumented hammer, and the resulting signals from the accelerometer mounted on the specimen together with that from the impact hammer force transducer, were fed to the FFT analyser. This analyser was utilized to display the transfer function of the specimen in frequency domains. The transfer function shows the resonant peaks of the system. For the first mode of vibration, the damping factor was computed from the following relationship

$$\text{damping factor } (\varepsilon) = \frac{1}{2}\left[\frac{f_{i+1} - f_i}{f_{ni}}\right] \quad (1)$$

where f_i and f_{i+1} are frequencies associated with half-power points for a resonant frequency of f_{ni}. The other damping parameters can be related to the damping factor by

$$\begin{aligned} 2\varepsilon &= \frac{\delta}{\pi} \\ &= \frac{\psi}{2\pi} \\ &= \eta \\ &= \tan\phi \\ &= Q^{-1} \end{aligned} \quad (2)$$

where ε is the damping factor, ψ the specific damping capacity, δ the logarithmic decrement, ϕ the loss angle, η the loss factor, and Q a quality factor.

3. Results and discussion

Fig. 2a and b show microstructures of cast base aluminium alloy 2014 and 2014–50 vol % graphite composite, respectively. The microstructure of Al319–10 vol % flake graphite composite is shown in Fig. 3. These figures indicate a reasonably uniform distribution of particle dispersoids in the matrix alloy. The microstructure of a pressure-infiltrated sample (Fig. 2b) clearly reveals the much larger volume per cent of graphite particle (50%) as compared to that produced by the vortex method (Fig. 3).

The results of damping capacity measurements on aluminium alloy are shown in Fig. 4. This figure also includes the results reported by other investigators. The data show that most of the aluminium alloys have a specific damping capacity less than 2.0%, regardless of their composition, processing techniques, or test conditions.

The normalized specific damping capacity (e.g. SDC of the composite/SDC of the matrix alloy) of 2014 Al–graphite particle composite containing different volume percentages of granular graphite particles (125 μm) are shown in Fig. 5. The data show that the dispersion of graphite particles results in a very significant increase in the damping capacity of 2014 Al alloy. The increase in damping capacity is directly related to the increase in volume percentage of graphite particles within the range studied. It can be seen from Fig. 5 that the addition of 10 and 50 vol % graphite increases the damping capacity of 2014 Al alloy by 6.4 and 17 times, respectively, which is well above the damping capacity of the base aluminium alloy shown in Fig. 4. Similarly, data in Table I indicate that additions of 5 or 10 vol % 300 μm flake graphite particles results in about an 8-fold increase in the SDC of A319 aluminium alloy; the SDC of A319 (Al–4–5 Si 2–4 Cu) has been assumed to be close to 1.33% measured for A356 and is used for

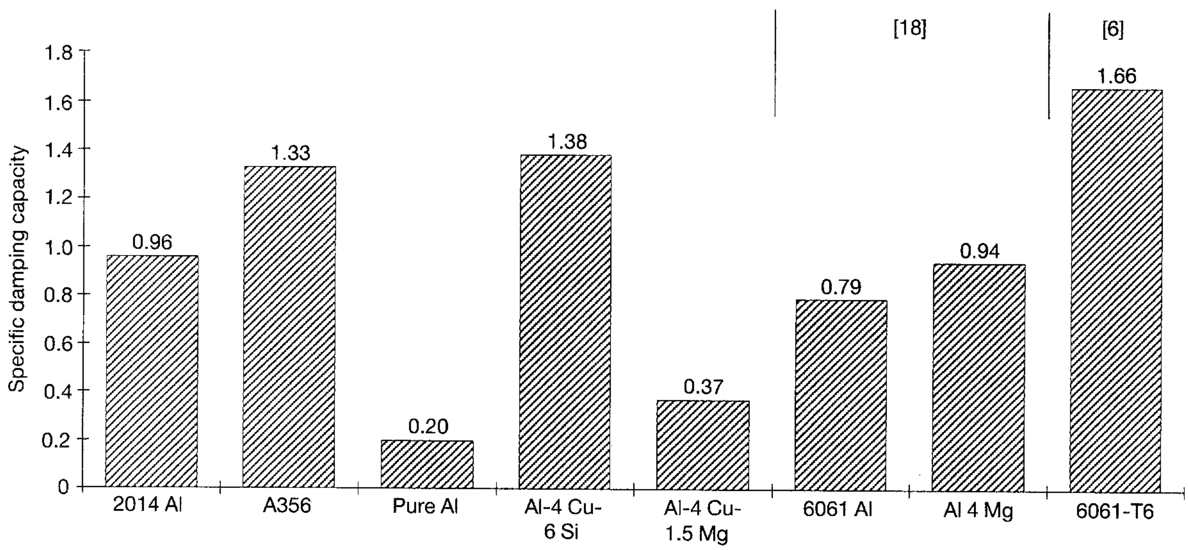

Figure 4 Specific damping capacity (SDC) of aluminium alloys. Base aluminium alloy damping capacity. Silicon heat treatment.

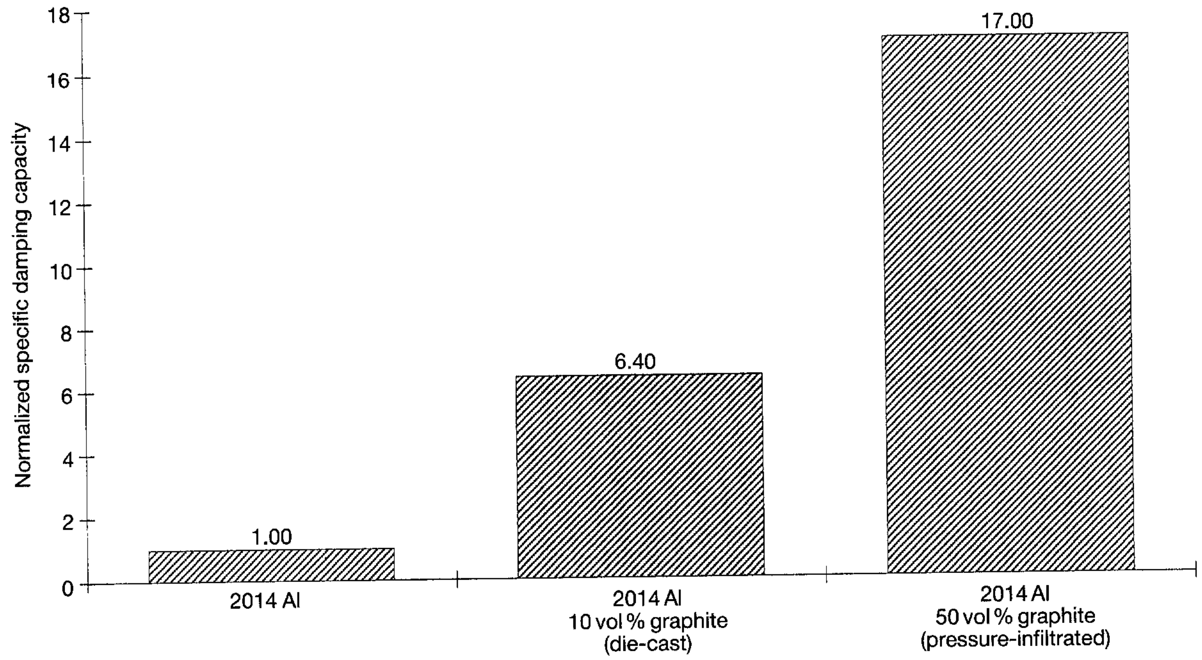

Figure 5 Normalized SDC of 2014 Al–graphite particle composite. Particle size 125 μm, granular.

TABLE I Damping capacity of A319–Graphite particle (300 μm flake) composite

Material	Frequency (Hz)	SDC (%)	Normalized[a] SDC
A-319-5 vol % graphite	1111	11.6	8.7
A-319-10 vol % graphite	510	9.7	7.3

[a]SDC value of 1.33 for A-356 (Table I) was used to calculate the normalized SDC of A-319 (Al–4–5 Si–2–4 Cu)–graphite particle composites.

TABLE II Damping capacity of A356–silicon carbide particle (15 μm) composite

Material	Frequency (Hz)	SDC (%)	Normalized SDC
A-356	450	1.33	1
A-356–10 vol % SiC	450	1.34	1

normalization. The damping capacity of A-319 containing 5 or 10 vol % flake graphite is significantly higher than those for the matrix alloy (Fig. 4). The damping capacity of A356-silicon carbide particle composite is shown in Table II. The data indicate no effect of improving the damping capacity of A356 alloy as a result of dispersions of 10 vol % silicon carbide particles.

The results shown in Table II indicate no increase in the damping capacity of aluminium alloys by the addition of SiC particles, while a very significant increase in damping capacity was obtained by additions of similar, lower or higher volume percentages of graphite particles (Fig. 5). This can be attributed to the nature of silicon carbide particles and their bonding, and not necessarily to their small particle size (15 μm, compared to that of 125 and 300 μm for graphite), because Perez *et al.* [5] have shown that dispersions of 4.5 vol % 7 μm graphite particles resulted in a more than 50% increase in damping capacity of 6061 aluminium alloy.

A higher increase in the damping capacity of graphite-dispersed aluminium alloys compared to that of aluminium–silicon carbide particle composite may be due to the higher intrinsic damping capacity of the graphite particle. Graphite is much softer than silicon carbide and is capable of dissipating energy by shear deformation.

The somewhat higher increase (8 compared to 6 times) in the damping capacity of aluminium alloy containing 300 μm flake graphite particles compared to that containing 125 μm granular graphite, can be due to the combined effects of size and shape of the dispersoid. Zheng *et al.* [15] have reported that the anisotropy of graphite facilitates sliding between graphite basal planes which effectively dissipates elastic strain energy during cyclic loading. It is possible that flake graphite particles have their basal planes more favourably oriented for damping than that for granular graphite particles.

The damping capacity of an aluminium-matrix particulate composite for different combinations of matrices and dispersoid presented in Tables I and II, Fig. 5 (present work) and Figs 6–12 (data from the literature) indicate the dependence of damping capacity on volume per cent, particle size and shape, nature of particles and interface and processing methods.

3.1. Effect of volume per cent

The results of the present work on damping capacity as a function of volume per cent of graphite particles are shown in Fig. 5 This figure indicates that the

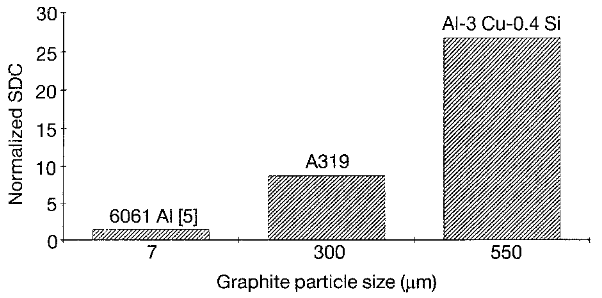

Figure 6 Normalized SDC of aluminium alloys containing flake graphite particles of different sizes. Vol % graphite ≃ 5%.

damping capacity of an aluminium-matrix composite increases with increasing volume per cent of dispersoid. The damping capacity of aluminium alloy 2014 increased from 0.96% to 6.12% as a result of the dispersion of 10 vol % graphite (125 μm) particles. Similar progressive increases in damping capacity with volume per cent dispersoid have been shown by Nath *et al.* [9] and Rohatgi *et al.* [6] in the case of aluminium alloy–mica and aluminium alloy–graphite composites, respectively (Figs 7–11). The addition of 2.55 vol % mica (40 μm) results in an increase in damping capacity of 2014 alloy from 0.37% to 4.24% (Fig. 9). Rohatgi *et al.* [6] have shown an increase in the damping capacity of aluminium alloy from 0.02% to 5.33% (Fig. 7) with the addition of 5 vol % graphite (550 μm) particles. Specific damping capacity to density ratios for graphite aluminium alloy and mica-dispersed aluminium alloy are also shown in Figs 8 and 10. These figures also include the specific damping capacity to density ratio of grey cast iron for comparison. It can be seen from these figures that aluminium alloy composite containing 5 vol % graphite or 2.55 vol % mica particles have a specific damping capacity to density ratio higher than that of some variety of grey cast irons. It should be noted here that grey cast iron may contain about 15 vol % of graphite

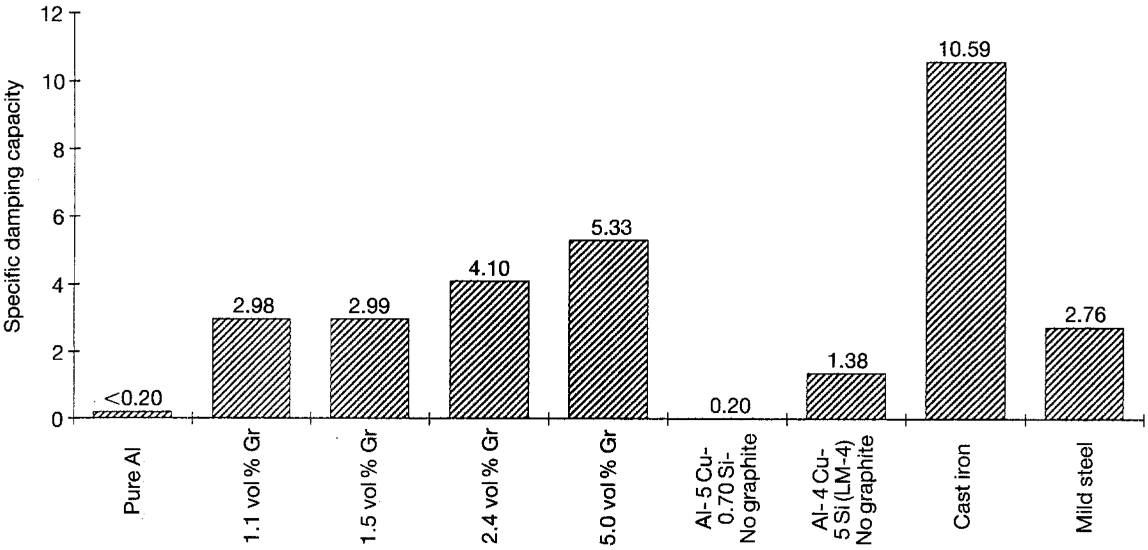

Figure 7 SDC of graphite aluminium alloy (Al–3Cu–0.4Si) composites, cast iron and steel [6].

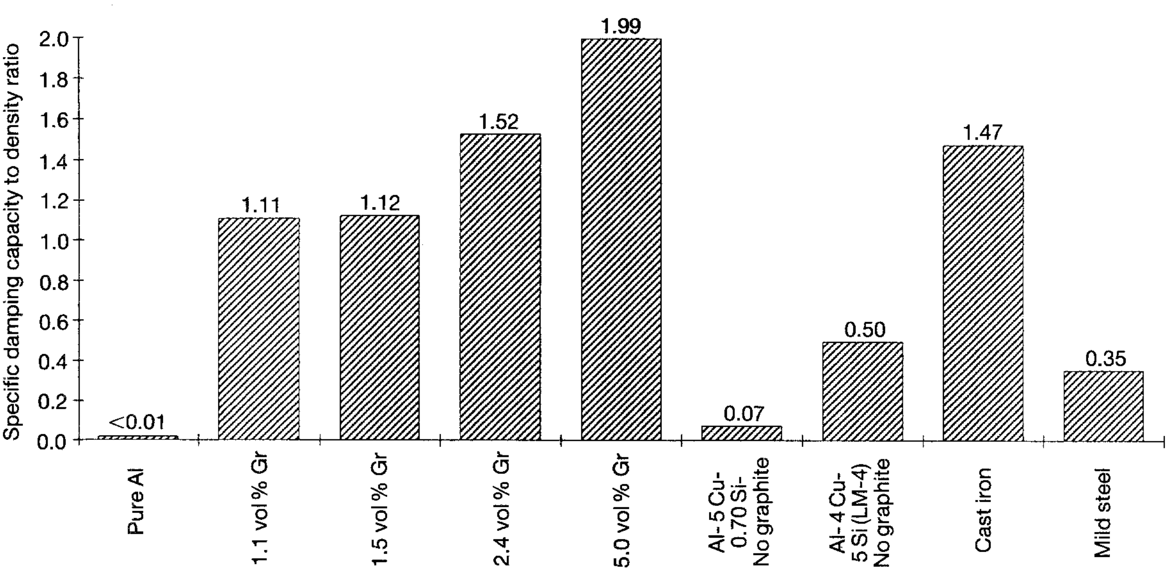

Figure 8 SDC–density ratio of graphitic aluminium alloy (Al–3Cu–0.4Si) composites, cast iron and steel [6].

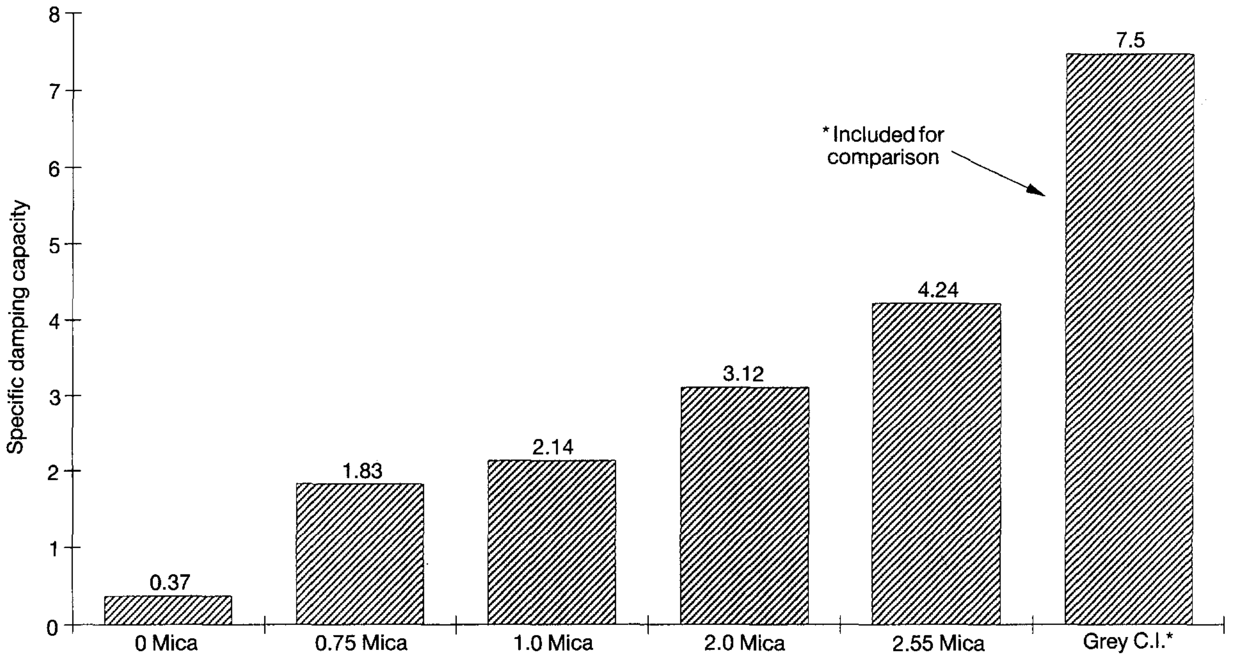

Figure 9 Damping capacity of mica-dispersed aluminium alloys [9].

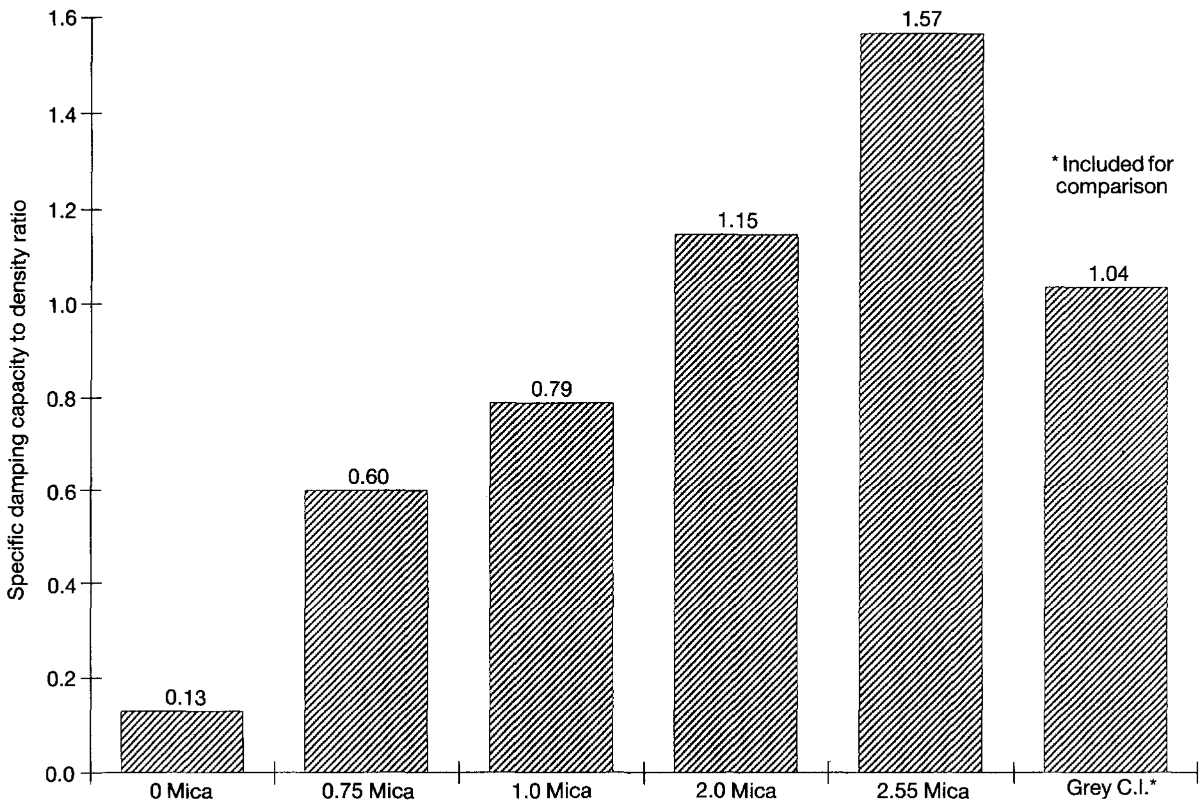

Figure 10 SDC to density ratio of mica-dispersed aluminium alloys (Al–4Cu–1.5 Mg) [9].

as against 5 vol % graphite and 2.55 vol % mica particles present in the aluminium alloy-matrix composites. Thus, cast aluminium-matrix particulate composites have potential for providing lightweight high-damping material. Onuki *et al.* [7] have also shown an increase in aluminium alloy damping capacity (from 0.12% to 3.7%) as a result of increasing volume per cent of graphite (0% to 23%). It has been shown in the earlier work [7] that for the same volume percent of graphite the damping capacity is the same for both aluminium and copper alloys, which indicates, that damping capacity is primarily dependent on the dispersoid, and not so much on the matrix.

3.2. Effect of particle size and shape

The effect of particle size and shape on damping capacity of cast iron is well documented [4]. It has

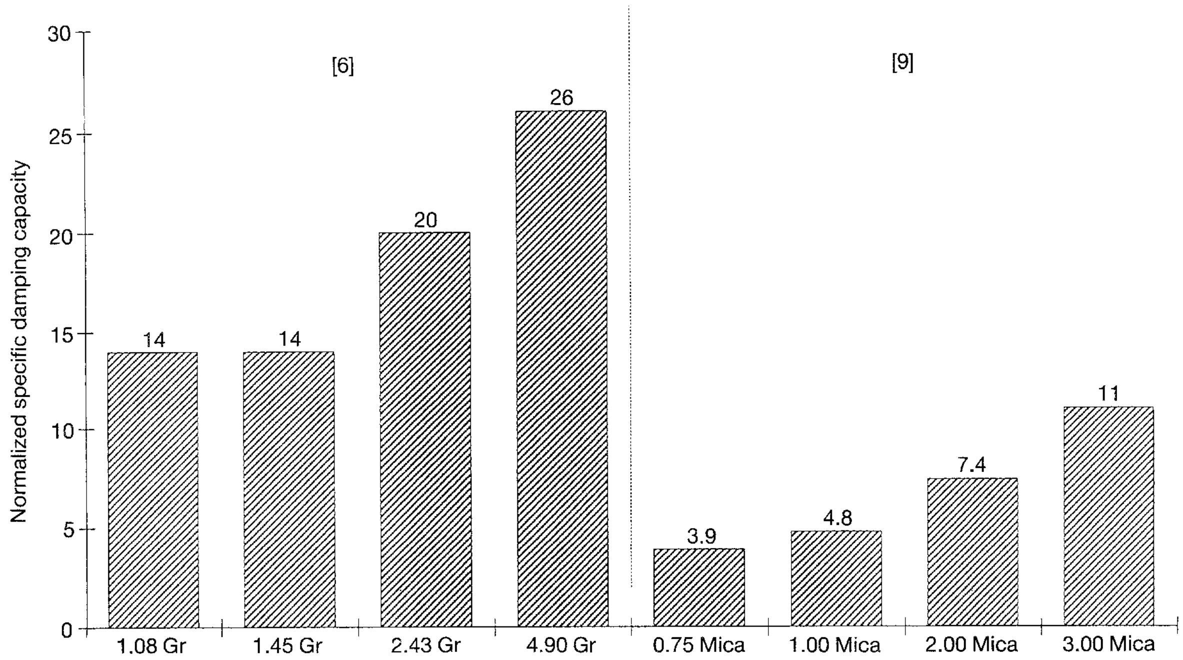

Figure 11 Normalized SDC of aluminium alloy–mica and aluminium alloy–graphite particle composites.

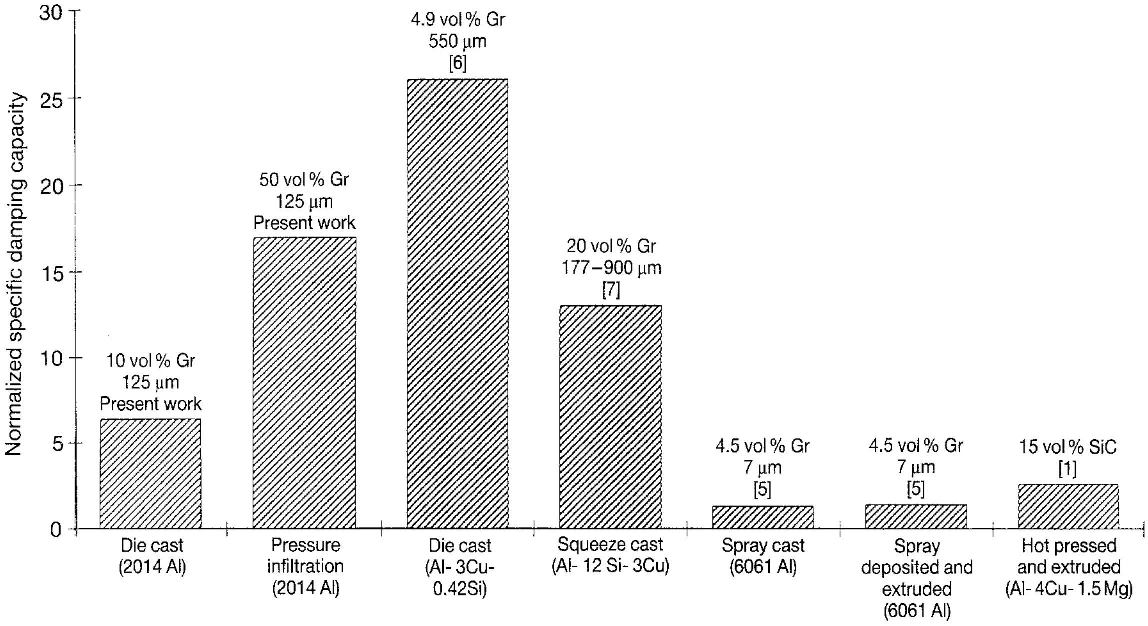

Figure 12 Normalized damping capacity of aluminium–matrix composites processed by different techniques.

been shown that in the case of cast irons, the damping capacity increases with increasing size and volume per cent of graphite. Fig. 6 shows the normalized damping capacity data for aluminium-matrix composite containing different sizes of about 5 vol % graphite particles. It is evident that the normalized specific damping capacity increases with increasing particle size of graphite. A similar influence of graphite particle size on the damping capacity of composites has also been reported by Suwa *et al.* [8]. Wolfenden and Wolla [27] have shown a 2-fold increase in specific damping capacity of aluminium–50 vol % tungsten carbide fibre composite by increasing the size of the fibre from 127 μm to 762 μm. Onuki *et al.* [7] have shown that aluminium-matrix composites containing 16 vol % 200 and 500 μm graphite particles have specific damping capacities of 1.9% and 3.3% respectively. It is also known that the damping capacity of the spheroidal graphite cast iron is lower than the cast iron containing flake-shaped particles. In the present study, the normalized damping capacity of the composite containing 300 μm flake-shaped graphite is considerably higher than damping capacity of the composite containing a similar amount of 125 μm granular graphite and some of this difference can be attributed to the shape effect. Perez *et al.* [5] have also attributed an increase in the damping capacity of extruded aluminium–graphite composite to the change in shape of graphite from ellipsoidal to chain-like as a result of extrusion. Van Aken *et al.* [22] have also shown that cross-rolled aluminium indium alloy with pancake-shaped inclusions of indium, exhibits higher levels of damping than directionally rolled alloy containing fibrous inclusions.

3.3. Effect of processing

It is well known that the processing method affects the structure and properties of a material. The damping capacity of the material is also influenced by the processing technique. Hot working markedly changes the structure and properties of metallic material. Processing of a material has a marked influence on grain size, porosity, and interfacial bonding between matrix and reinforcement. In addition to these, mechanical working of alloy is known to effect a change in shape of the second phase. It is known that spherical inclusions changed to an elliptical shape during rolling of steel. These changes in structure of metal–matrix composites appear to change the damping capacities of composites. Sasaki *et al.* [23] have reported an increase in damping capacity of Al–Pb–Fe alloys with increasing amount of lead and increasing degree of mechanical working. Hunt *et al.* [24] have shown an increase in damping capacity of 2124 aluminium alloy–silicon carbide composite as a result of artificial ageing. Hinai *et al.* [25] reported an increase in the damping capacity of Al–Ge alloy with increasing amount of germanium; they showed that furnace cooling gave a higher damping capacity than water quenching which was considerably increased by cold working. Perez *et al.* [5] have also reported an increase in damping capacity of aluminium–graphite alloys as a result of extrusion.

The variation of damping capacity of aluminium-matrix composites processed by different techniques is shown in Fig. 12. This figure indicates that in spite of the fact that the squeeze-cast composite contains higher volume per cent (20) of graphite as compared to the gravity die-cast composite, which contains only 5 vol% graphite, the former has lower (12.5) normalized damping capacity than the latter (26.7) for nearly similar average particle size. This difference in damping capacity can be accounted for by the improved interfacial bonding and soundness of the material in the squeeze-cast sample which results in a lower damping capacity of the composite. Perez *et al.* [5] have shown a higher damping capacity in 6061 Al–graphite composite processed by spray deposition, compared to that of 6061-T6 alloy. The higher damping capacity of spray-deposited composite was accounted for by the presence of microporosity and fine-grained microstructure in this material. The damping capacity of this material was found to increase further as a result of extrusion and this was explained by change of ellipsoidal shape graphite particles in as-sprayed 6061 Al/Gr MMC to chain-like graphite flakes after extrusion. In spite of reduced porosity, the effect of shape change resulting from extrusion is responsible for the improved damping capacity in extruded material, illustrating the overriding role of particle shape. Relatively small increases in damping in hot-pressed and extruded composite shown by Bhagat *et al.* [17] may be accounted for by the improved interfacial bonding resulting from hot pressing and extrusion.

3.4. Nature of dispersoid and interface

Tables I and II and Figs 4–11 also indicate the dependence of damping capacity of a composite material on dispersoid constituents. Fig. 13 compares the normalized damping capacity (damping capacity of composite/damping capacity of matrix alloy) for composites as a function of volume per cent of second phase. It can be observed from this figure that the normalized damping capacity of a graphite particle-dispersed aluminium alloy is maximum and that of an SiC dispersed alloy is minimum, while mica-dispersed alloy shows a strong dependence. This somewhat lower damping capacity of mica-dispersed aluminium alloy compared to graphite-dispersed aluminium alloy may be related to the 20 times higher shear strength of mica than that of graphite. A similar reason may be responsible for the low damping capacity of SiC–dispersed aluminium alloys. Even in the fibre-reinforced composites, reinforcement of aluminium alloys with SiC fibres results in lower damping capacity than reinforcement with graphite fibre [16].

The higher damping capacity of a composite compared to that of the matrix alloy has been reported to result from (1) dissipation of energy at the matrix/dispersoid interface as well as (2) micro-plastic deformation within the dispersoid, and (3) generation of high dislocation density at the interface owing to thermal mismatch of constituents, and also from (4) the presence of micro-voids at the interface. Thus graphite, being a layered soft material, is capable of dissipitating large amounts of energy by microplastic deformation within the particle. Lead, being a soft and high-damping material is also known to impart high damping to copper alloys [7] as well as to aluminium alloys [23].

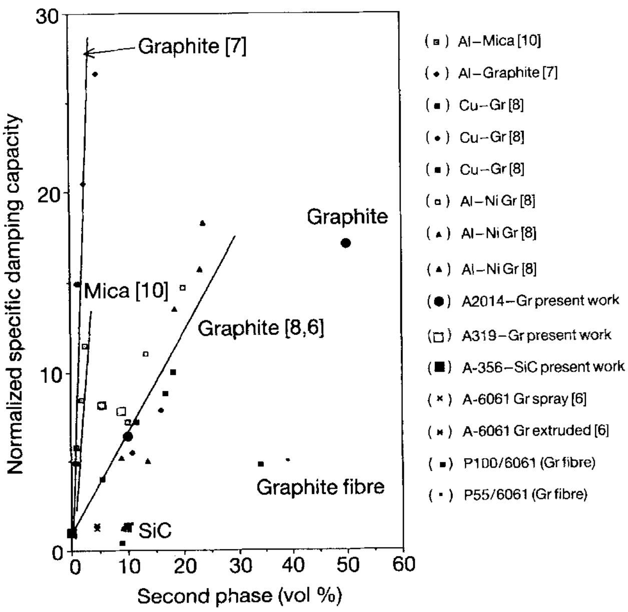

Figure 13 Normalized SDC as a function of vol% second phase.

The thermal expansion mismatch of constituents in composites can result in residual stress and high dislocation density at the interface. Reaction between the constituents at the interface affects the nature of the interface, which is governed by the coefficient of thermal expansion of the particle and the matrix. The higher the difference in coefficient of thermal expansion, the higher will be the residual stresses and dislocation density resulting in higher damping capacity for the composite. The increased damping capacity in aluminium–mica composite has been reported to be due to thermal expansion mismatch (CTE of mica is at least one-tenth of that of aluminium alloy). This thermal expansion mismatch, together with poor wettability of mica with aluminium alloy, have been found to result in interfacial voids which may account for the improved damping capacity of aluminium alloy–mica particle composite. The absence of interfacial reaction and weak interfacial bonding resulting in a higher damping capacity of fibre composites has been reported by Bhagat *et al.* [20]. A limited increase in damping capacity of 6061 alloy by silicon carbide fibre and alumina fibre, and a high increase (5–14 times) in damping by graphite fibre has been reported by Updike *et al.* [21].

3.5. Effect of strain amplitude
The effect of strain amplitude on the damping capacity of Al/Al_2O_3, Al/SiC and Al/W fibre composites has been studied by Wolfenden and Wolla [27]. According to them, the damping capacity of Al/Al_2O_3 and Al/SiC fibre composite shows no amplitude dependence, whereas Al/W fibre composite shows strain-amplitude-dependent damping. It has been shown that the damping capacity of Al–44 vol % tungsten fibre composite increases from 0.23% to 0.38% when strain amplitude changes from 1 μm to 50 μm. This behaviour has been explained by Granato and Luke's [30, 31] theory of dislocation damping. Similarly, Armstrong *et al.* [28] have reported an increase in damping capacity of 6061 Al/P55 graphite fibre composite from 7.5% to 12.3% as a result of an increase in strain amplitude from 200 μm to 300 μm.

3.6. Effect of temperature and frequency
In the case of linear damping, material is generally independent of strain, but depends greatly upon frequency and temperature. Damping resulting from a linear mechanism can increase with frequency up to a certain level and then decrease. In general, at a constant temperature, damping decreases with increasing frequency. At a certain combination of temperature and frequency, a damping peak can occur depending on the mechanism related to applied loading and internal relaxation processes occurring in the material. Bhagat *et al.* [17] have shown a peak damping for SiC particulate-reinforced aluminium alloy composite at a frequency of 1318. A similar trend for fibre-reinforced aluminium matrix composites was also shown [17]. Recently, Sakai *et al.* [23] have shown a decrease in damping capacity of Al–Pb–Fe alloys with increasing frequency. Zhang *et al.* [26] have also shown a decrease in damping capacity with increasing frequency and decreasing temperature in the case of SiC, Al_2O_3 and graphite particle-dispersed aluminium-matrix composites. They have observed a damping peak at a particular combination of temperature and frequency, depending on the type of composite. The difference in damping capacities of these composites is very small in the lower temperature range (50–250 °C) compared to those in the higher temperature range (250–500 °C). Friend *et al.* [29] have shown increased damping capacity of SiC–Al, Borsic–Al, Boron–Al composite compared to that of 6061-Al matrix. The damping capacities of each of these materials were found to increase with increasing frequency: the damping capacity of 6061–Al was lower at 550 °C than that at 460 °C. However, the damping capacities for Boron–Al, Borsic–Al and SiC–Al composite were higher at 550 °C than those at 460 °C. These changes in damping capacities of the material were attributed to the formation of a thermally induced interphase.

3.7. Comparison of the damping capacity of cast particle and fibre-reinforced composites
Fig. 4 shows a plot of normalized specific damping capacity versus volume per cent of dispersed particles, based on data from the present work as well as from the literature. This figure also includes the data for carbon fibre-reinforced composite material P100/6061 and P55/6061. These data show a general tendency for increase in damping capacity of composites with increasing volume per cent of second-phase or fibre. It is clear from this figure that the damping capacity values of the particulate composites are higher compared to that of fibre-reinforced composite.

4. Conclusion
A comparison of the results of damping capacity of aluminium-matrix composites generated by the present authors and those by previous investigators reveals that the damping capacity of MMCs is strongly related to volume fraction, size, shape, nature of particles, the processing technique, porosity, and interfacial bond. Experimental data suggest that large particulate size, poor bonding, flake shape, and soft dispersoids with preferably lamellar structure, enhance the damping capacity of the composites; however, the effect of individual variables needs to be studied more carefully, keeping the other variables constant. Hard and strong particles and processing techniques resulting in better interfacial bonding lead to lower damping capacity in the corresponding composite alloys. A schematic representation of these factors on SDC of metal-matrix composites is shown in Fig. 14. In general, damping capacity increases with temperature and strain amplitude and decreases with frequency. The cast particulate composites are found to have better damping capacity than the fibre-reinforced MMCs, and could be a potential candidate for vibration-insulating application in consumer

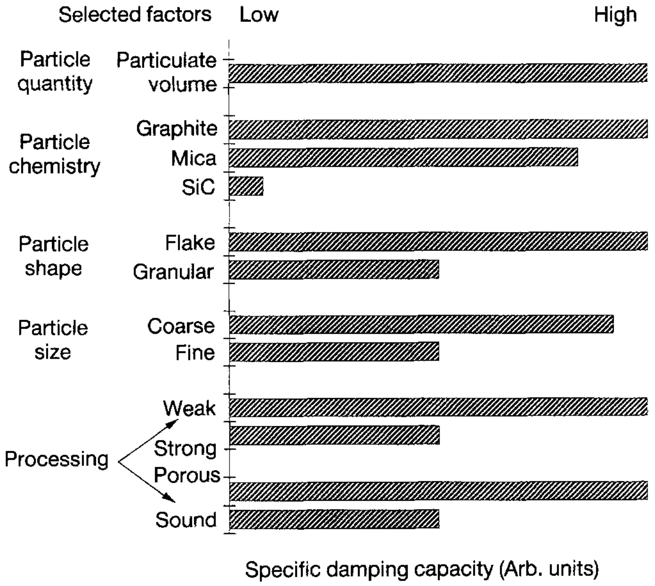

Figure 14 Schematic representation of factors affecting the SDC of metal-matrix composites.

industries whereas the costly fibre-reinforced composite may be economically useful only for applications in advanced aerospace structures.

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