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Study on damping capacity and dynamic Young's modulus of aluminium matrix composite reinforced with SiC particles

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Abstract

The development of high damping materials for noise reduction and attenuation of vibration on structural applications, such as automotive and aerospace industries, has been investigated. This experimental study is concerned with the damping capacity (tan delta) and dynamic Young's modulus (|E*|) of Silicon carbide (SiC) reinforced aluminium (Al) matrix composite. AlSi-SiC$_p$ composite was produced by hot pressing technique. Damping capacity and dynamic Young's modulus of composite and unreinforced AlSi alloy were studied using a dynamic mechanical analyser (DMA), over a temperature range of room temperature-400ºC (during heating and cooling phases), at 1 and 20 Hz. AlSi-SiC$_p$ composite showed higher damping capacity and dynamic Young's modulus than the AlSi unreinforced alloy. Furthermore, damping capacity was found to increase with temperature, while modulus decreases. The possible damping mechanisms are presented and discussed.

Keywords: Aluminium; SiC$_p$; metal matrix composites (MMCs); damping capacity; dynamic Young's modulus.

1. Introduction

High damping materials have been developed to suppress vibrations and consequently noise reduction for structural applications (where good mechanical properties and high damping capacity are required). The damping capacity of a material is its ability to dissipate elastic strain energy under cyclic loading [1-3] through mechanical vibration conversion to heat energy (usually).

Aluminium (Al) alloys are very attractive materials for automotive, aerospace and other structural applications due to their light weight and specific mechanical properties [1,4,5]. Although, these alloys exhibit low damping capacity [6], some authors [6,7] had reported that the addition of reinforcements can improve this property. In fact, aluminium-metal matrix composites (AMMCs) have been proved to be a promising damping material [1,4,8,9].

Among the most widely reinforcements used, aluminium alloys have been reinforced with ceramics such as silicon carbide (SiC) and alumina (Al_2O_3), aiming to improve their mechanical properties (e.g., modulus and strength) [6]. Wang C. and co-worker [9] studied the damping capacity of an aluminium alloy (Al6061) reinforced by SiC particles. They reported that the composite presented a superior damping capacity compared to the unreinforced alloy. Therefore, aluminium composites reinforced by SiC$_p$ can provide an advantageous compromise between strength and damping capacity [5].

It has been reported that the damping capacity of AMCs is influenced by several factors [3,5]. Rohagti *et al.* [5] reported that the damping capacity of

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AMMCs is influenced by volume fraction, size, shape and nature of particles, processing technique, porosity, and interfacial bond. The damping capacity has been also showed dependent of frequency, cyclic strain amplitude and temperature [3]. In addition, Zhang and co-workers' studies [1], regarding ceramic reinforced Al alloys, showed that, at low temperatures, matrix dislocation damping and the intrinsic damping of the reinforcing material are the main mechanisms while, at high temperatures, the grain boundary sliding, interface sliding and particulate/matrix interface are described as dominant mechanisms.

This work aims to study the damping capacity and dynamic Young's modulus of an AlSi-SiC$_p$ composite processed by hot pressing process, during heating and cooling phases, to the authors´ knowledge never done before.

2. Experimental Procedure

2.1. AlSi-SiC$_p$ composite fabrication

Silicon carbide particle-reinforced aluminium-silicon composite was produced from aluminium-silicon (AlSi) spherical powder (chemical composition as in Table 1), with maximum particle diameter of 45 µm, and silicon carbide particles (SiC$_p$) with 38.8 µm.

Table 1. Chemical composition of AlSi alloy.

Element	Al	Si	Fe	Cu
(wt.%)	88.352	11.5	0.145	0.003

Scanning electron microscopy (SEM) images of AlSi powder and SiC particles are presented in Figs. 1 a) and b). The AlSi-SiC$_p$ composite containing 8.6 vol.% of SiC$_p$ was produced by a pressure-assisted sintering process (hot pressing).

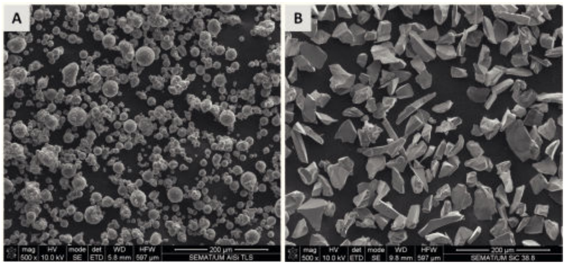

Fig. 1. SEM images of: AlSi powder (a) and SiC particles (b).

AlSi powder and SiC particles were mechanically mixed in a blender for 20 min. The obtained mixture was then divided and placed inside graphite moulds, with 8 mm width and 43 mm length. AlSi-SiC$_p$ samples were sintered by hot pressing, in vacuum (10^{-2} mbar), using a high frequency induction furnace (schematically represented in a previous work [10]). The mould was placed inside a vacuum chamber, where the sample was compressed at 1 MPa and then heated up to 500ºC, with a heating rate of 25ºC/min. At this temperature, the pressure on the sample was raised to 35 MPa (while the heating proceeds at 25ºC/min till 550ºC) and maintained for 15 min. During cooling, the samples were maintained inside the mould, in vacuum, till room temperature. The obtained samples had average dimensions of: 3.4x8x42 mm. For comparison, unreinforced AlSi samples were also produced using the same process.

2.2. Microstructural characterization

Microstructure observations were carried out using Scanning Electron Microscopy (SEM) equipped with Energy Dispersive Spectrometer (EDS). The spatial distribution of SiC particles on the AlSi matrix and interfacial reaction between matrix and reinforcement were obtained by SEM.

2.3. Dynamic mechanical analysis (DMA)

Dynamic Young's modulus (|E*|) and damping capacity (tan delta) were measured on a dynamic mechanical analyser (DMA Q800, TA Instruments), with dimensions of 3x2x17.5 mm using single cantilever testing mode. DMA tests were performed at 1 and 20 Hz; temperature ranged from room temperature to 400ºC (during heating with a heating rate of 10ºC/min and cooling phases) and using constant strain amplitude (2×10^{-5}). These temperatures were chosen based on working temperature range of engine pistons [11] (possible application for this composite). A nitrogen atmosphere was used for the high temperature tests. In this study, damping capacity was evaluated by means of tan delta (tan ф) or loss tangent.

3. Results and Discussion

3.1. Microstructural characterization of AlSi-SiCp composite

The microstructures of AlSi-SiC$_p$ composite and unreinforced AlSi matrix alloy are shown in Fig. 2. SEM image (Fig. 2 b)) revealed a uniform distribution of SiC particles in the AlSi matrix. Furthermore, no significant porosity was found. It can be seen from Fig. 2 c) that there is no considerable interface reaction between SiC particles and AlSi matrix as reported also by G. Miranda *et al.* [12].

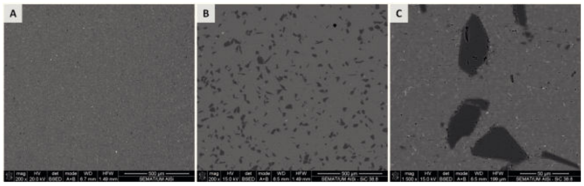

Fig. 2. SEM images of: unreinforced AlSi (a), AlSi-SiC$_p$ composite (b) and zoom view of the composite (c).

3.2. Damping capacity

The DMA tan delta curves for unreinforced AlSi alloy and AlSi-SiC$_p$ composite, as a function of temperature, during heating and cooling, are shown in Figs. 3 a) and b), respectively. The tested frequencies are 1 and 20 Hz for temperature sweep test. Increasing the temperature, the damping capacity of all specimens is increased over the studied temperature. This observation is in line with other study regarding aluminium alloys reinforced with SiC particles [13]. Moreover, a tendency is found for all damping curves: a slight increase till ≈250ºC (where a damping peak is observed) followed by an expressive increase with increasing temperature.

From Fig. 3, it can be seen that damping capacity is influenced by tested frequency. Results showed that an increase on frequency leads to a decrease on damping capacity. Similar behaviour was reported by C.S. Kang *et al.* [13]. A frequency increase corresponds to a higher number of loading cycles per second. Consequently, the contact between particles becomes lower and not uniform and the particles have no time to dissipate the heat energy which results on damping capacity reduction [14].

Additionally, the tan delta curves (Figs. 3 a) and b)) display a hysteresis between heating (increasing temperature) and cooling (decreasing temperature). This behaviour has been described as result of stresses which are presented at the reinforcement-matrix interface and are generated due to the differences in coefficient of thermal expansion (CTE) between the SiC$_p$ (4.0×10^{-6} K^{-1}) [15] and the AlSi matrix (24.0×10^{-6} K^{-1}) [15]. According to A. Vicent *et al.* [16], the stresses can be relaxed by dislocation generation and movement in a ductile matrix as AlSi alloy. The high dislocations density has been reported as one of the contributions to damping [17]. The energy dissipated by dislocation movement increases when increasing temperature, till a certain value and then decreases slightly. After this point, the damping capacity increases again, due to the contribution of other damping mechanisms [2].

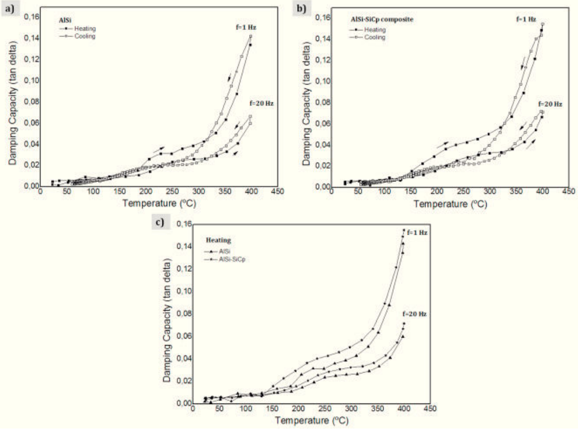

Fig. 3. Tan delta curves of: unreinforced AlSi alloy (a), AlSi-SiCp composite (b) and AlSi-SiC$_p$ compared to AlSi 8 (c), in the condition of increasing temperature, at 1 and 20 Hz.

Fig. 3 c) shows the damping capacity of composite and unreinforced alloy, at 1 and 20 Hz, during heating phase. From Fig. 3 c), it can be observed that the composite shows higher damping capacity than the unreinforced alloy over the frequencies and temperature range tested in this work. The improved damping capacity of composite is a result of balance of several damping mechanisms generated from addition of SiC$_p$. Besides the above mentioned matrix dislocation damping, the intrinsic damping (matrix, reinforcement and interface, if it is formed) is also reported as another contribution to damping, at low temperatures. On the other hand, grain boundary sliding and interface sliding have been described as the possible dominant mechanisms for damping, at higher temperatures [2,4].

The interface between the matrix and reinforcement also influences the damping capacity of composite [1]. As stated above, no substantial interface was formed between AlSi/SiC$_p$, meaning that this kind of possible contribution to damping can be neglected. However, with temperature increasing, the AlSi matrix may become softer than SiC particles, leading to movements at the AlSi/SiC interface (interface sliding) [7]. At higher temperatures, grain boundaries also gain viscous behaviour and the viscous flow movement leading to dissipation of the thermal energy and consequently improvement on damping capacity.

3.3. Dynamic Young's modulus

The dynamic Young's modulus as a function of temperature for AlSi-SiC$_p$ composite and unreinforced AlSi alloy is shown in Fig. 4. The results showed that modulus is clearly influenced by temperature. Increasing the temperature, the dynamic Young's modulus of composite and unreinforced alloy is decreased over the temperature range (Fig. 4). This observation is in line with other study regarding aluminium alloys reinforced with SiC, when produced by powder metallurgy [13]. According to D.S. Prasad *et al.* [14], this behaviour can be attributed to the decrease of the dynamic stiffness with temperature. As observed in tan delta curves, also the modulus curves display a hysteresis between heating and cooling phases, although less pronounced compared with tan delta curves.

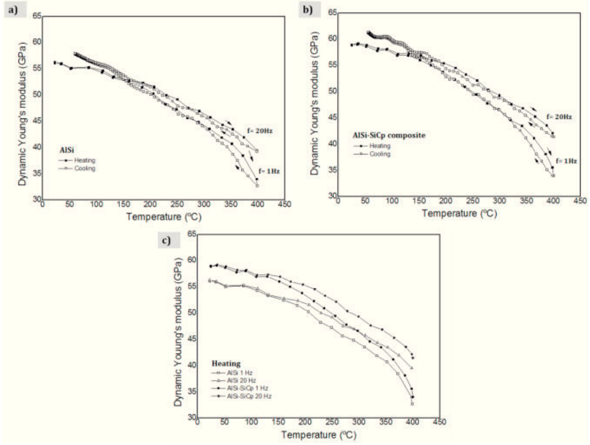

Fig. 4. Dynamic Young´s modulus obtained at 1 and 20 Hz, for: unreinforced AlSi (a), AlSi-SiC$_p$ composite (b) and comparison between AlSi and AlSi-SiC$_p$ composite (c).

Regarding frequency, no expressive influence of frequency on |E*| was found, when compared with the frequency influence on damping capacity.

Fig. 4 c) shows that the composite exhibits higher modulus than the unreinforced alloy, for 1 and 20 Hz tested frequencies, meaning that the modulus can be improved with addition of the SiC particles.

The improved |E*| is a result from the higher dislocations density generated due to the large difference between CTE values of AlSi matrix and SiC$_p$ which also acts as strengthening mechanism. Under loading, the dislocation movements create pinning points for dislocations (Orowan strengthening) around reinforcement particles which contribute to the material hardening, once more energy is required to overcome following dislocations [10]. Furthermore, the addition of reinforcement particles inhibits the process of the grain growth, leading to microstructures with improved mechanical properties [18,19].

Therefore, the dynamic Young's modulus and damping capacity results from the balance of several mechanisms that simultaneously occur in the matrix due to the SiC particles addition and also the temperature increase. The increase on dislocation density seems to be the major cause of the improvement on the dynamic Young's modulus of composite compared with that of the unreinforced alloy, while the interface sliding and grain boundary sliding mechanisms (thermal induced) seem to be the main contributions to the damping capacity of these composites.

4. Conclusions

From the present study, the following conclusions can be drawn:

– It is shown that, by reinforcing AlSi with SiC particles, the damping capacity and the dynamic Young's modulus are improved, when compared with the unreinforced, for all tested frequencies. The damping capacity improvement is attributed to contribution of the dislocations density (at lower temperature) and the interface sliding and grain boundary sliding which are the possible dominant mechanisms at higher temperatures;

– Damping capacity and dynamic Young's modulus showed to be dependent on tested temperature. It was observed that damping capacity increases with increasing temperature, while the dynamic Young's modulus decreases to higher temperatures;

– Regarding frequency, a reduction on damping capacity was found with increasing frequency.

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