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EFFECTS OF SILICON CARBIDE (SIC) REINFORCED PARTICULATE ON THE DAMPING BEHAVIOUR OF ZA-27 ALLOY COMPOSITE MATERIAL

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ABSTRACT

The effects of SiC particulates on the resultant damping behaviour of ZA-27 metal matrix composites (MMCs) was investigated. The MMCs were processed by stir casting method and the damping characterization was conducted on a dynamic mechanical analyser. The damping capacity as well as the dynamic modulus was measured at a frequency of 1 H_z and over a 25-400^{0}C temperature range. The micro structural analysis were performed using Scanning electron Microscopy. The damping capacity of the ZA-27/SiC with three different volume fractions of reinforcement, were compared with that of ZA-27 alloy. It was shown that the damping capacity of ZA-27/SiC could be significantly improved by the addition of SiC Particulates through Stir casting method. Finally the damping mechanisms were discussed on the basis of data obtained from characterisation of microstructure and damping capacity.

Key Words: Damping Capacity, ZA-27 Alloy Composite Material

I INTRODUCTION

Structural materials that exhibit high damping capacities are desirable for mechanical vibration suppression and acoustic noise attenuation. Mechanical vibrations often affect the proper functioning of equipment. For instance, fatigue failure is common in structures exposed to uncontrolled vibrations [1, 2]. There are also health concerns to humans from the excessive noise being transmitted from such sources [1, 2]. Damping capacity, a material's ability to absorb and dissipate mechanical vibrations, is usually low in structural metals. As a result, vibration attenuation is normally achieved by using external devices to absorb and transmit vibrations from structures. Metal matrix compositing technology, however, offers the possibility of enhancing damping characteristics of structural metals by incorporating high damping materials as reinforcements.

Particulate reinforced metal matrix composites (PMMC) are currently being used as structural components in many aerospace and automotive applications. The increasing demand for PMMCs is due to unique mechanical properties achieved in the metal when ceramic particulates are used as reinforcement phases. PMMCs combine the ductility and toughness of the metal matrix with the high strength and stiffness of the ceramic reinforcement to achieve properties unattainable in either of the starting materials. PMMCs often have high strength to weight ratios, an important consideration in weight sensitive applications. Other distinctive properties of PMMCs can include good thermal stability and excellent wear resistance. Dispersing small particulates(less than 1μm) in a metal increases its strength typically by Orowan type strengthening mechanisms. Traditionally, high modulus ceramic particulates such as silicon carbide (SiC) and alumina (Al_2O_3) have been used as reinforcements purposely for stiffness enhancement, plus strengthening. It is, however, known that other property benefits can be achieved by carefully controlling the matrix properties, the reinforcement properties, and the interface formed between them. For example, although bulk Al_2O_3 and SiC by themselves exhibit low damping capacities available data on PMMCs using Al_2O_3[3] and SiC[4, 5] as reinforcements show slight improvements in damping behaviour when compared to the unreinforced metal.

Zinc-based alloys containing 8%−27% aluminum,1%−3% copper and a marginal quality of magnesium are potential substitute for bronzes, aluminium alloys, cast irons and steels for a variety of engineering applications[6−7]. In spite of a number of merits, such as good cast ability, high mechanical properties and excellent wear resistance, the alloys suffer from porosity, especially for ZA27 alloy, due to its wide range of solidification temperature [8].

In recent years, a new forming technology, squeeze casting, has been developed. Squeeze casting is also known as liquid metal forging, squeeze forming, extrusion casting and pressure crystallization. It is a casting process in which liquid metal solidifies under the direct action of pressure. The major advantages of squeeze casting are: 1) produced parts are free of gas porosity or shrinkage porosity; 2) feeders or risers are not required and therefore less metal wastage occurs; 3) alloy fluidity (castability) is not critical in squeeze casting as both common casting alloys and wrought alloys can be squeeze cast to net shape with the aid of pressure; and 4) squeeze castings can have enhanced mechanical properties as wrought products [9−11].

Wei et al. [12] observed the effects of macroscopic graphite particulates on the damping behaviour of Zn–Al eutectoid alloy. This study proposed that the damping capacities of Zn–Al alloys could be improved by proper heat treatment. The physical and mechanical properties such as hardness, ductility, strength and dimensional shrinkage of the supersaturated ZA-27 alloy during the aging were studied extensively, but the damping capacity variation during the process is less studied. Considering the above Zr-based glassy particulate filled ZA-27 alloy composite can be an alternative to ZA-27 alloy with superior properties and reduced weight to make it priority material in structural applications such as aerospace, submarine, and machinery [13]. However, with increasing reinforcement content the composites attained improved strength, bringing about further improvement in the property [14] such as higher hardness, superior elastic modulus [15], greater dynamic modulus, better damping capacity [16] and less coefficient-of-thermal expansion [14] of the matrix alloy material. The erosive wear behaviour of metal matrix composite and polymer matrix composites are commonly studied by experimentally and theoretical models [17] but very few of researchers have studied computational simulations such as finite element analysis [18].

In view of the above analysis, in the present work SiC is taken as a reinforcing material and ZA-27 is used as a base material for study of damping behaviour.

II. EXPERIMENTAL PROCEDURE

2.1 Preparation of the Composites

In the present work, ZA-27 alloy having the chemical composition as per the ASTM B669-82 ingot specification and the chemical composition of the ZA-27 alloy is given in Table 1 used as the base matrix alloy. SiC particles of size 80µm are used as the reinforcement. The percentage of SiC is varied from 0–12wt% in steps of 4% by weight. In this process, the matrix alloy ZA-27 was first super heated above its melting temperature and stirring was initiated to homogenise the temperature. The addition of SiC into the molten ZA-27 alloy above its liquidus temperature at 500°C was carried out by using a mechanical stainless steel stirrer coated with aluminite. The stirrer was rotated at a speed of 450 rpm in order to get uniform mixing of SiC particulate in the matrix material for 2 to 3mins. The molten metal was then poured into permanent moulds for casting and the temperature was then lowered gradually. Solidified metal pieces were cut into the rectangular size of 25×3×0.7 mm which is required for DMA testing.

2.2 Damping Test Equipment

The damping capacity was measured using a Dynamic Mechanical Analyser (DMA), TRITEC 2000B which was used to measure the mechanical properties of wide range of materials as shown in table 3. Dynamic Mechanical Analysis (DMA) was conducted in a nitrogen atmosphere at a fixed frequency of 1 $H_{z,}$ heating rate of 5^0C/min, a temperature range of 25-400^0C on a rectangular samples with approximate dimensions of 25×3×0.7 mm using a Tritech2000B instrument in single cantilever mode.

2.3 Dynamic Mechanical Properties

Jinhai et al [19] studied that the damping capacity of a material is an evaluation of the energy dissipated in the material during mechanical vibration. High damping materials posses the ability to dissipate mechanical vibration energy, however in metals these properties are often incompatible due to the dependence of microscopic mechanism involved in strengthening and damping.

There is a need to develop a material which posses good mechanical properties and high damping. MMCs are the best suited material for this because MMC processing allows the possibility of tailoring the resultant damping properties by selecting high damping reinforcements and MMC processing modifies the microstructure of metals and alloys, thus introducing energy dissipation sources, hard and high strength reinforcements will improve the mechanical properties of the composites.[20-21].The damping behaviour of MMCs can be attributed to thermal mismatch-induced dislocation damping, interface damping.

Among the various damping mechanisms, defect damping represents a large part of overall damping of crystalline materials under conventional conditions. Defect damping is an intrinsic source and stems from the internal friction exerted on atomic movement in the regions of defects in crystalline metals and alloys. Material damping is extremely sensitive to the presence of defects. Any type of defect will be a source to dissipate energy because of internal friction by the intrinsic movement of the defect under applied cyclic stress. The defects in polycrystalline metals and alloys include point defects,(vacancies, interstititials and substitutionals) , and line defects(dislocations), surface defects(boundaries of various types). Point defects gives rise to damping in the range of low to intermediate levels, line defects gives rise to damping levels in the intermediate to high range, surface defects gives rise to damping levels in the high range [22].Ritchie et al. [23] studied the damp capacity behaviour of ZA-27 wt.% Al alloy (ZA-27,die cast). The high-Zn alloy used in the study exhibited high as-cast strength, hardness and wear resistance as well as high damping capacity. The experimental results obtained by Ritchie et al demonstrated that ZA-27 possesses high damping capacity under service conditions usually at frequencies of 1 H_z to 100 H_z and temperatures from ambient to about 100^0C and the variation of damping with frequency and sample thickness shows that there is a significant component of thermo elastic damping that is consistent with Zener's theory [24]. Ritchie et al concluded that the damping mechanism in ZA-27 alloy was an energy-activated process. The damping mechanism in ZA-27 alloy involved the movement of grain boundaries in the material (super plastic deformation) [23].

Dislocation damping is one mechanism of damping found in ZA-27 alloys. Dislocations exists in all engineering materials, under the applied cyclic loading, the dislocation in materials would attempt to oscillate, which would lead to the dissipation of elastic strain energy, i, e. dislocations could contribute to the internal friction and improve the damping capacity of materials. The internal friction, which results from the dislocation, is independent of vibrating amplitude, so the internal friction is highly sensitive to the change of dislocation loop length. The vacancies and atoms favourably aggregate to dislocation line, and interact with the dislocations, which may impede the motion of dislocations. [25] The grain boundaries and interfaces bear the shear stress when the metals and alloys are under cyclic loading, and the phase interfacial slipping or the grain boundaries interfacial sliding may occur when the magnitude of the shear stress at the interface is sufficient enough to overcome frictional loads, which cause the friction energy loss [26]. Among the materials available as particle reinforcements, SiC and Al_2O_3 particulates when added to the Al matrix, have been shown to increase substantially in specific stiffness and strength.[27-28]. On the other hand, both positive and negative changes in damping capacity with the addition of SiC have been reported [29-30].

III. RESULTS AND DISCUSSIONS

3.1 Thermo-Mechanical Properties of Composites

Dynamic Mechanical Analysis (DMA) of the composites have been carried out to investigate the variation of storage modulus (E'), loss modulus(E") and damping factor (tan δ) as a function of temperature to characterize the thermo-mechanical response of different Wt % reinforcement as shown in Fig.1-3. From the graphs it is observed that while damping capacity increases with increase in temperature, the storage modulus decrease with increase in temperature, whereas both damping capacity and Loss modulus increase with increase in wt.% of reinforcement being more remarkable in the higher temperature range. The graph in Fig.1 shows the variation of storage modulus with temperature. The variation of storage modulus follows $E'_{8\%} > E'_{ZA\text{-}27\ Pure} > E'_{12\%} > E'_{4\%}$ which indicates there is an increase in storage modulus with increase in reinforcement wt.% The storage modulus (E') representing the visco-elastic stiffness of the material has been observed to remain constant without any substantial decay till 75^0C irrespective of the compositions. However, on further increasing the temperature the composites undergo a decay in the magnitude of E’ in the temperature range of 100-125^{0}C irrespective of the reinforcement wt %.At lower temperature regime the trend of storage modulus remained in the order E’$_{8\%}$>E$_{12\%}$>E’$_{4\%}$. However, in the temperature range of 250-390^{0}C the composite with 12% and 8% exhibited same E’ value in magnitude. This indicates at high temperature range the wt% of reinforcement has less effect on the storage modulus of the composites. R.J. Perez,J.Zhang [31] also confirmed same type of results with Al matrix and 10% SiC and concluded that at lower temperatures, the possible dominant damping mechanisms are intrinsic damping of the reinforcing particle, matrix dislocation damping, and particle/matrix interface damping. At high temperatures, on the other hand, grain boundary sliding and interface sliding are likely to be responsible for a large portion of the observed damping.

The damping factor (tan δ) indicates the recoverable energy in terms of mechanical damping or internal friction in terms of visco-elastic system. The variation of tan δ of the composites as a function of temperature shown in Fig.3. The damping capacity of the materials was observed to increase with increase in temperature, as it is already experimented that ZA-27 alloys are ‘high damping metals’ having elevated damping values at ambient and also with increasing temperature [32]. This property has made ZA-27 alloy to be used in many practical application such as engine mounts, bearings and bushes. These results are in accordance with other researchers who have worked on DMA for ZA-27 alloy [32]. A maximum in the tan δ has been observed for the composite with SiC content of 8 wt % indicating enhanced damping performance which is closely followed by the composite with 4 wt% .

IV CONCLUSIONS

The use of SiC particulate as reinforcement to ZA-27 alloy provides a high damping capacity and storage modulus decrease with increase in temperature whereas the Storage modulus increase with increase in wt.% of reinforcement. Fig 3. shows increase of damping capacity with increase in temperature for all cases of SiC particulate in a temperature regime 100-350^{0}C. In damping mechanisms the particulate-matrix interface effect seemed to be more significant at higher temperatures due to softening of the matrix. The use of SiC particulate as reinforcement enhances the damping capacity of the ZA-27 alloy composites even at high temperature.

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LIST OF TABLE:

Table1: Chemical Composition of ZA-27 Alloy in Weight Percent (ASTM B669-82)

Element	Aluminium	Magnesium	Copper	Zinc
Parentage Composition (wt.%)	25-28	0.01-0.02	2.0-2.5	Balance

LIST OF FIGURES:

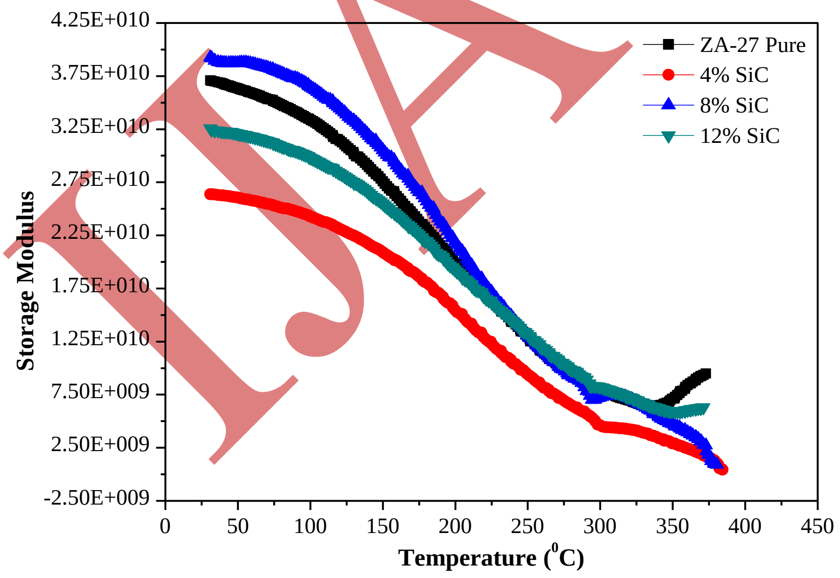

Fig.1: Variation of Storage Modulus E' with Temperature

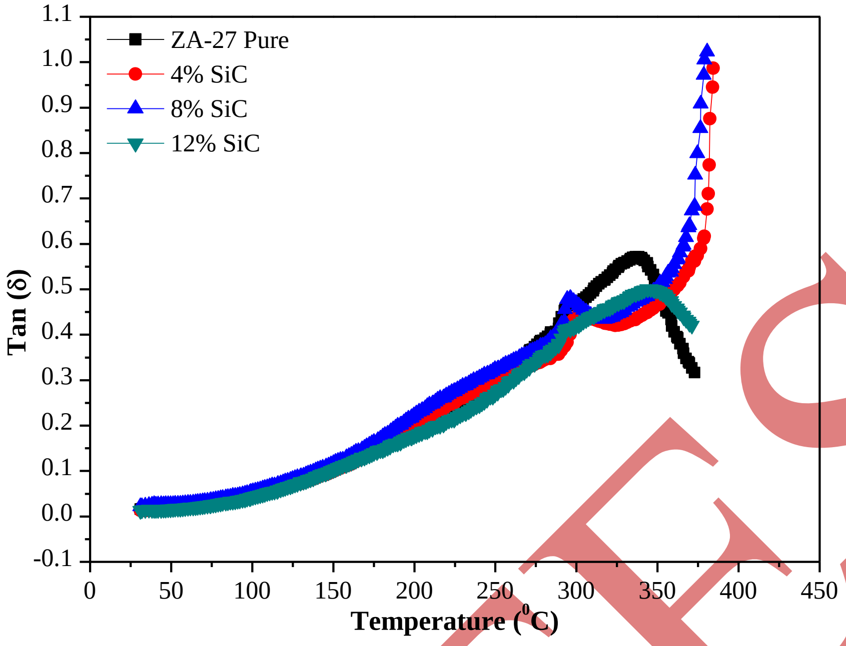

Fig..3: Variation of Damping Capacity Tan (δ) with Temperature.

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