Vibration Analysis of Stir-Cast Mg-Al/Mg2Si Composites with Bismuth Alloying

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Abstract: The vibration characteristics of Mg-Al/Mg2Si composites are crucial for their performance in various applications. This study analyzes the natural frequency and material damping of Mg-Al/Mg2Si composites, focusing on the effects of geometrical structures and varying bismuth content. We used a fast Fourier transform (FFT) analyzer to determine the first three natural frequencies and modal damping, and performed finite element simulations to identify natural frequencies and mode shapes of the composite specimens. Both methods revealed that Mg-Al/Mg2Si composites exhibit specific natural frequencies and modal damping, with increasing bismuth content leading to higher modal damping. These findings provide insights for optimizing the design and application of these composites, guiding the development of Mg-Al/Mg2Si composites with tailored vibration characteristics to enhance their performance in practical applications.

Keywords: Magnesium Alloys, Mg2Si reinforcement, Modal Analysis, Vibration Behaviour

I. INTRODUCTION

Magnesium alloys are having low mechanical properties, due to which its application in aerospace and automobile industries is limited. From the study it is observed that magnesium alloy composite with different particulate reinforcements shows the enhanced mechanical properties. Now a days, it is observed that magnesium alloy composites with Mg2Si particles has shown higher potential due to its low density and higher hardness values, so Mg2Si reinforced Mg metal matrix composites have wide opportunities in automotive aerospace industries [1-2].

The processing of Mg metal matrix composites includes ex-situ and in-situ method [3]. Ex-situ methods include conventional methods such as powder metallurgy, stir casting, squeeze casting etc. In-situ method, reinforcement are synthesized internally in the matrix during composite fabrication. Conventional casting produce large size Mg2Si particles and they are hardened brittle, it will reduce the mechanical as well as tribological properties [4-5]. Modification is a simple and effective technique for refining the microstructure and improving the mechanical, tribological properties [6] of composites. Recently, La, Y, B, Na, Sb, Gd, Sr, P and some other materials have been used to modify Mg2Si in the Al and Mg metal matrix composites for obtaining fine microstructure and improved mechanical properties.

Schaller and May encourt [7] worked on the vibration behavior of the Mg-2 wt% Si alloys reinforced with long carbon fibers exhibited higher damping capacities. Zhu and Peng [8] studied the metal matrix composites of nano-sized dispersoids for the damping properties and found the enhanced damping properties.

Vibration analysis is a non-destructive technique [9-10] which helps early detection of machine problems by measuring/ evaluating vibration. Using the careful analysis of vibration, the vibrational characteristics of the equipment can be carried out which reduces the failure of the system [11-12]. Before, vibration investigation required dialing an instrument through the full range to recognize frequencies at which vibration was noticeable. The most recent age of vibration analyzers [13-15] has a larger number of capacities and robotized capacities than their archetypes had. Numerous units show the full vibration range [16] of three tomahawks at the same time giving a depiction of what is new with a specific machine. Vibration analysis can also be used in determining some of the material properties such as damping [17] factors, natural frequency etc.

The main objective of this work is to carryout modal analysis of Mg-Al/Mg2-Si Alloy for different composition of varying Bismuth. The dynamic behavior of MgAl/Mg2Si is investigated by characterizing its properties under different modes of vibration, both analytically and experimentally. The FFT analyzer in combination with PC is used as the data acquisition unit. The input force and output response is measured by force transducer and accelerometer respectively. Analytical analysis is done using ANSYS software. The modal parameters obtained from the modal analysis can be used to analyze the system behavior under the assumed operating conditions.

2.MATERIALS AND PROCESSING

2.1 Raw Materials

Commercially pure magnesium ingot (99.3% pure), aluminum ingot (99.2% pure), and silicon powder (99.95% purity) were used as the primary materials to prepare the Mg-Al/Mg2Si composites. The magnesium and aluminum ingots were obtained from Jagada Industries, Virudhunagar, and cut into smaller pieces using a power hacksaw to facilitate melting within crucibles. The silicon powder, sourced from Jedee Enterprise, Mumbai, had a particle size of 23 microns.

2.2 Modification Material

Bismuth (Bi) powder, also obtained from Jedee Enterprise, Mumbai, with a particle size of 44 microns, was used to modify the Mg-Al/Mg2Si composites. Bismuth is characterized by its low melting point (271°C) and possesses self-lubricating properties during friction processes.

2.3 Processing of Mg-Al/Mg2Si Composites

The processing of Mg-Al/Mg2Si composites began with commercially pure magnesium ingots and silicon powder as the initial materials. The melting process was conducted in a steel crucible using a 2 kW electric resistance furnace under an argon gas protective atmosphere. Given magnesium's flammability in the presence of oxygen, all processing steps were carried out in an inert gas atmosphere. The furnace was equipped with bottom pouring arrangements and maintained an inert gas atmosphere throughout.

A composition of approximately 88.3 wt.% Mg and 9 wt.% Al was melted and superheated to 760°C. Silicon powder, preheated to 200°C and packed in aluminium foil, was added to the Mg-Al melt (2.7 wt.% Si). The melt was held at 760°C for 10 minutes and stirred at 600 rpm for 7 minutes to ensure complete dissolution of the silicon. Various amounts of bismuth powder (0.7 wt.%, 1.4 wt.%, and 2 wt.%), preheated to 200°C to eliminate moisture and gases, were then added. Finally, the composite melt was poured into preheated steel moulds (dimensions: 3 mm × 5 mm × 120 mm) at 400°C.

3. EXPERIMENTATION

The experimental setup for conducting modal analysis is depicted in Figure 1. The Mg-Al/Mg2Si test specimen is securely fixed, and a designated point at its center is marked for mounting the accelerometer to measure vibration acceleration. Free vibration of the Mg-Al/Mg2Si test specimen is induced at various points, and the response is captured using OROS software for coherence analysis. Once coherence is established, the results are recorded, and the excitation point is adjusted accordingly. A photograph of the experimental setup is presented in Figure 1.

Figure 1. Experimental setup

The response is measured at different points as shown. There are two channels used in this setup. Channel 1 is connected to hammer which is used for exciting the Mg-Al/Mg2Si test specimen for free vibrations. Channel 2 is (shown in Fig 2) connected to the accelerometer which is used for measuring response of the Mg-Al/Mg2Si test specimen.

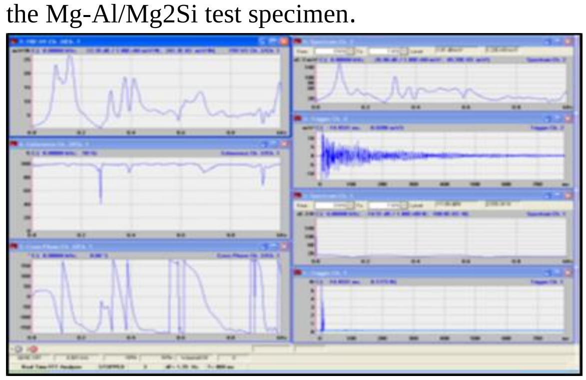

Figure 2: Spectrum and Coherence from FFT Analyzer

4. RESULTS AND DISCUSSION

4.1 Experimental Results

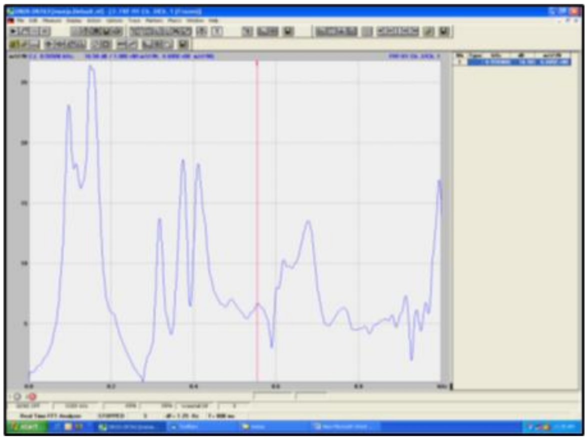

Figure 3: Spectrum Showing Natural Frequency of Mg-Al/Mg2Si + 0.0 wt.% Bi

Table 1: Natural Frequencies Analysis of Mg-Al/Mg2Si Composites

Sl No	Natural Frequencies of (Mg-Al/Mg2Si+0.0 wt.% Bi) in Hz	Natural Frequencies of (Mg-Al/Mg2Si+0.7 wt.% Bi) in Hz
1	555	546
2	3415	3349
3	10017	9849

4.2 Modal Damping

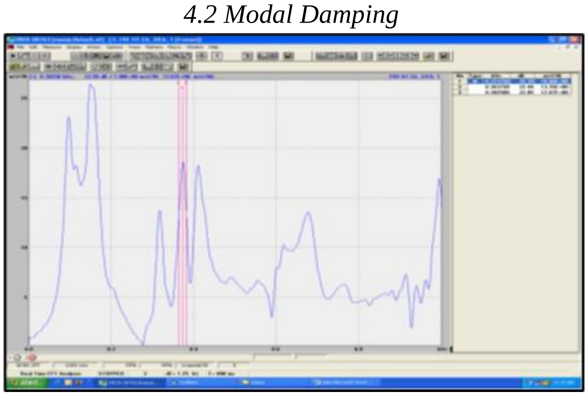

Figure 4: Natural Frequencies Spectrum

Table 2(a) Model damping of Mg-Al/Mg2Si+0.0 wt.% Bi

SL No	ω in Hz	ω1 in Hz	ω2 in Hz	Modal damping
1	373	382	363	0.025
2	515	526	503	0.019
3	666	679	625	0.011

Table 2(b) Model damping of Mg-Al/Mg2Si+0.7 wt.% Bi

SL No	ω in Hz	ω1 in Hz	ω2 in Hz	Modal damping
1	118	127	107	0.084
2	147	158	135	0.078
3	179	194	168	0.072

4.3 Modal Analysis Using FEM

The commercially available finite element simulation software, ANSYS, has been utilized to determine the natural frequencies of the Mg-Al/Mg2Si composite. ANSYS is capable of solving various structural, dynamic, fluid, and heat transfer problems.

A three-dimensional model is created using the 8-noded element called SOLID45. This element has three degrees of freedom at all eight nodes in the X, Y, and Z directions. A general description of element input is provided in the Element Input section.

The geometric model is created in ANSYS, and the finite element model is built using the SOLID45 element for the modal analysis of the Mg-Al/Mg2Si alloy. The results of the modal analysis are listed in Table 3.

Table 3 Analytical Modal Analysis results of Mg-Al/Mg2Si

Mode No	Natural Frequencies of Mg-Al/Mg2Si+0.0 wt.% Bi	Natural Frequencies of Mg-Al/Mg2Si+0.7 wt.% Bi
1	570	568
2	3463	3560
3	8284	10836

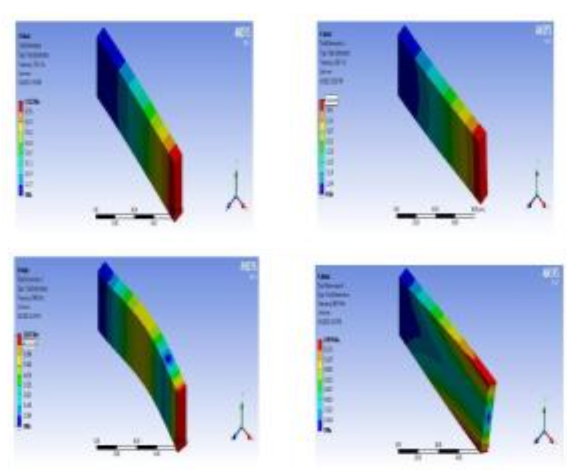

Figure 5 Mode shapes

Table 4 Comparison of FEM and Experimental results of Mg-Al/Mg2Si 0.0 wt % Bi

No.	Experimental results in Hz	ANSYS results in Hz	% Deviation
1	555	570	2.60
2	3273	3463	5.47

5. CONCLUSION

Based on the findings of this study, the synthesis of Mg-Al/Mg2Si composites using the in-situ method has been successfully achieved. Comparative analysis between Finite Element Method (FEM) simulations and experimental results shows a close agreement, with deviations ranging from 2% to 9% in damping characteristics. This alignment underscores the reliability of both approaches in predicting material behavior. The incorporation of aluminum and silicon into magnesium contributes significantly to enhanced damping properties and increased density

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