Effect of addition of bismuth on the vibration analysis of Mg-Al/Mg$_2$Si composites processed using stir casting technique

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Abstract. In this work, the experimental and finite element simulation solutions of vibration characteristics of the Mg-Al/Mg$_2$Si composite has been carried out. The influence of the geometrical structures, percentage of bismuth and material properties on the natural frequency and the material damping of the Mg-Al/Mg$_2$Si composites has been studied. The fast fourier transform (FFT) analyzer has been utilized to find the first three natural frequencies and the modal damping experimentally of the said composite. Finite element simulation method also has been adopted to find the natural frequencies and their mode shapes for the Mg-Al/Mg$_2$Si composites specimens. From the results of the experimental and analytical method it is identified that the composite material exhibits the set of natural frequencies and the modal damping. It is also observed that the modal damping increases with increase in the addition of bismuth.

Keywords: Mg-Al/Mg$_2$Si composites, Vibration analysis, damping, natural frequencies.

1. 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 Mg$_2$Si particles has shown higher potential due to its low density and higher hardness values, so Mg$_2$Si 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 Mg$_2$Si 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 Mg$_2$Si in the
Al and Mg metal matrix composites for obtaining fine microstructure and improved mechanical properties.

Schaller and Mayencourt [7] worked on the vibration behaviour 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/Mg2Si 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 behaviour 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 Si powder (99.95% purity) are utilized as the basic materials to prepare the Mg-Al/Mg2Si composites. Mg ingots and Al ingots brought from Jagada Industries, Virudhunagar and cut into smaller pieces with the help of power hacksaw in order to keep ingot inside the crucible properly. Si powder brought from Jedee Enterprise, Mumbai powder having the size of 23 microns.

2.2 Modification material

The Mg-Al/Mg2Si composites were modified with bismuth (Bi). The Bi powder brought from Jedee Enterprise, Mumbai and the powder having the size of 44 microns. Bismuth (Bi) is an element with low melting point (271°C) and it as self-lubricating property during friction process.

2.3 Processing of Mg-Al/Mg2Si composites

Commercially pure Mg ingot and Si powder were used as the starting materials to prepare the Mg-Al/Mg2Si composites. The melting process was carried out in a steel crucible location in a 2kW electric resistance furnace under argon gas protective atmosphere. The processing of Mg metal matrix composites were carried out in inert gas atmosphere only because of flammable property of magnesium with oxygen. The furnace containing bottom pouring arrangement ant it is provided with inert gas atmosphere.

About 88.3wt.%Mg and 9wt.%Al were melted and superheated to 760°C, and 2.7wt.%Si powder preheated 200°C and packed in aluminium foil was added in to the Mg-Al melt. The melt was held at 760°C for 10min and stirred about 7min at a speed of 600rpm for the complete dissolution of silicon. After that, different amount of bismuth powder (0.7wt.%, 1.4wt.% and 2wt.%) preheated at 200°C to remove moisture and gases from the surface of the particulates. Finally, the composite melt was poured into a steel mould (size of 3mm×5mm×120mm) preheated at 400°C.

3. Experimentation

The experimental setup for conducting modal analysis is shown in Fig 1. The Mg-Al/Mg2Si test specimen is fixed. A point is marked at the middle of the Mg-Al/Mg2Si test specimen for mounting accelerometer to measure acceleration of vibration. Mg-Al/Mg2Si test specimen can be excited for free vibration at various points and response is observed using OROS software for coherence. Once
coherence is observed, the results are stored and the point of excitation is changed. The photograph of the test setup is shown in Fig 1.

![Experimental setup](image)

**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.

![FFT analyzer result](image)

**Figure 2** Result obtained through the FFT analyzer showing Spectrum and Coherence.

### 4. Results and Discussion

#### 4.1 Experimental Results
Figure 3  Spectrum showing natural frequency of Mg-Al/Mg2Si+0.0 wt.% Bi.

Table 1  Experimental Model Analysis results of Natural Frequencies of Mg-Al/Mg2Si

| 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

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

| SL No | \(\omega\) in Hz | \(\omega_1\) in Hz | \(\omega_2\) 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 the natural frequencies of the said composite. ANSYS is capable of solving the many structural, dynamic, fluid, heat transfer etc kind of the practical problems.
The three-dimensional model is created using the 8-noded element called SOLID45. This element has three degrees of freedom at all the 8 nodes at X, Y, and Z directions. A general description of element input is given in Element Input.
The geometric model is created in ANSYS. The finite element model is built using SOLID45 element, for the modal analysis of the Mg-Al/Mg2Si alloy. Modal analysis was carried out and result of the analysis is 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                                         |

4.4 Mode Shapes
Mg-Al/Mg2Si+0.0 wt.% Bi

Figure 5 Mode shapes
The data collected from both experimental and FEM analyses are shown in table below.

| No. | Experimental results in Hz | ANSYS results in Hz | % Deviation |
|-----|----------------------------|---------------------|-------------|
| 1   | 555                        | 570                 | 2.60        |
| 2   | 3273                       | 3463                | 5.47        |
| 3   | 7546                       | 8284                | 8.9         |

5. Conclusion

From the present study the following conclusions are made:

- The processing of Mg-Al/Mg2Si composites can be successfully synthesized by in-situ method.
- From the Comparison of FEM and Experimental. The results obtained by both the methods agree with each other with a deviation of about 2%-9% Damping. Thus, the better agreement in the experimental and finite element simulation results has been observed.
- From this work it is concluded that by the use aluminium and silicon with magnesium, it gives a good damping property and high density.

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