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Vibration Characteristics of Al6061-TiO2-Gr Hybrid Metal Matrix Composites-An Experimental Approach

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Abstract:-- **The present work deals with the objective of characterizing the dynamic behavior of metal matrix composites processed using stir casting method. An important outcome in the dynamic analysis of composite structure is the determination of their natural frequencies, mode shapes and damping ratio. This is important because composite material structures often operate in complex surrounding conditions and are sometimes exposed to a variety of dynamic excitations. In this work, an experimental modal analysis approach is used to characterize the vibration behavior of MMC plate. The hybrid MMCs was prepared with varying weight proportions of TiO2 particles for 4%, 8% and 12% and graphite of 3% constant weight. The results obtained were indicates that the increase in the natural frequency and damping ratio due to addition of titanium dioxide and constant proportion of graphite with aluminium alloy 6061.**

Index Terms:- Titanium Dioxide, graphite, stir casting, natural frequency, mode shapes, damping ratio.

1. INTRODUCTION

Metal matrix composites having its specific significance in weight-critical applications, when the matrix material and reinforcements are combined to obtain high-damping and low-density characteristics. The ceramic reinforced alloys were found to have significant improvement in mechanical characteristics and damping behavior which may be depends upon the uniform distribution and bonding of reinforcement in the matrix.

The present work includes the study of the dynamic properties of the Al+TiO_2+Gr hybrid metal matrix composite specimens. The Al+TiO_2+Gr hybrid composites specimens were fabricated using stir casting route. The dynamic properties of the MMCs were investigated through scaling the dynamic properties of specimens. Free vibration method is used to measure frequency response and damping factor.

Structural damping of any materials is an essential characteristic to be considered during the design of structures wherein, the selection of suitable material is a challenging work for the designer. Aluminium, due to its high strength to weight ratio is used extensively in aerospace and automobile industry. Alloying aluminium with titanium dioxide and graphite to suit the application of structural damping has huge scope of study. Titanium Oxide (TiO_2) and graphite (Gr) particles were used as reinforcement phases for the present study.

High damping capacity materials reduces the unpleasant vibrations released by the machine elements which are subjected to fatigue stress. Damping in composite materials is a very important property affecting the dynamic behavior of structures near resonant vibration levels. The demand for high damping material is quickly and continuously growing in a variety of fields like aerospace, mechanical and civil system.

2. LITERATURE REVIEW

Many researchers have made an attempt to improve the damping capacity of the materials with the use of unconventional material processing innovations of metals and its alloys. With the development of metal matrix composite material the damping capacity, physical and mechanical properties of material can be improved to a varied extend by addition of reinforcements into the metals and its alloy. The MMC manufacturing provides the modification of resultant properties by varying the volume fractions of reinforcement and geometries and selecting high damping materials as reinforcements.

Suresh K S et al [1] studied the dynamic behaviour of Al 6061 – Si & Mg metal matrix composites. The experimental modal analysis carried out through impact testing. From the testing confirms that the damping decreases as natural frequency range increases when Si content is high and again damping increases when Mg content is high.

Arunkumar Airodagi et al [3] carried out an investigation to evaluate damping characteristic of LM6-Fly ash-Nickel MMC. The outcome shows that the damping ratio and loss

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factor increase with increasing percentage of fly ash and constant percent of nickel and again the damping ratio and loss factor increases with increasing percentage of nickel keeping fly ash content constant and observed that the increment of damping ratio is more predominant with increasing percentage of nickel when compared to increasing percentage of fly ash.

K. Ramesh et al [4] investigated the damping behavior of the Al-Ni metal matrix composites fabricated by gravity stir casting. Damping ratio is found by free vibration test with an impact hammer and data acquisition systems and observed that MMCs with higher Ni content is having good damping characteristics.

A.P.Kumbhar et al [6] written a review on the effect of reinforcement percentage on vibration response and mechanical properties of metal matrix composite has been investigated. Composite material was prepared by varying SiC by stir casting method. The result shows that, addition of SiC in aluminium matrix increases natural frequency.

3. SELECTION OF MATERIALS

Aluminium and its alloys are mostly used matrix material for the development of Metal Matrix Composites (MMCs). This is mainly due to the broad spectrum of unique properties it offers at relatively low processing cost. Some of the attractive property combinations of Al based matrix composites are: high specific stiffness and strength, thermal conductivity, and low thermal expansion. Aluminium is found to have damping capacity and hence it is considered as a matrix. TiO_2 (rutile) is a soft solid powder. Graphite is a soft grayish-black substance. The average particles size of TiO_2 and graphite are 44 microns and 149 microns respectively. The composition of Al 6061 is given in table 3.1 and material properties are given in table 3.2.

Table 3.1: Chemical composition of Al 6061

6061 Aluminum Alloy Composition by Weight %								
Mg	**Si**	**Cu**	**Fe**	**Mn**	**Zn**	**Ti**	**Cr**	**Al**
1.2	0.2	0.3	0.5	0.1	0.12	0.14	0.3	balance

Table 3.2: Material property of Al6061, TiO_2 and Gr

Material	Density (g/cc)	Poisson's ratio	Elastic Modulus (GPa)	Melting point (°C)
Al6061	2.7	0.33	68.9	582-652
TiO_2	4.23	0.27-0.29	230-288	1,843
Gr	2.75	0.17-0.23	4.1-27.6	3500ºC

4. PREPARATION OF MMCs

In conventional stir casting method, reinforcement is mixed into the molten metal by mechanical stirring. Mechanical stirring is the most important step in casting process, which decides the uniform distribution of reinforcing particles in molten matrix materials. After the mechanical mixing, the molten metal is directly transferred to a shaped mould prior to complete solidification. The essential thing is to create the good wetting between particulate reinforcement and aluminum melt. The distribution of the reinforcement in the final solid depends on the wetting condition of the reinforcement with the melt, relative density and rate of solidification etc. Distribution of reinforcement depends on the geometry of the stirrer, melt temperature and the position of the stirrer in the melt.

4.1 PREPARATION OF Al 6061, TiO_2 AND Gr COMPOSITE

The stir casting setup was prepared initially. The Al 6061 with 0%, 4%, 8%, 12% of TiO_2 powder and 3% graphite powder combines and MMCs were prepared using stir casting technique. The compositions of metal matrix composites are given in table 4.1. The reinforcement materials are preheated to a temperature of around 1000ºC [7]. The process starts with the melting of Al6061 in furnace and preheated reinforcement materials are added in suitable proportions and then mechanical stirring will takes place for at least 20 min. The stirring speed and time and geometry of the stirrer will go to decide the uniform distribution of titanium dioxide and graphite powder. After stirring scum powder is added to remove the slag and flux which is present in molten metal. After stirring the molten metal is poured into the prepared mould and solidification takes place. For present work mould is prepared to get the plate of dimension 150*150*5 mm and plate is finished by grinding process. The major steps and prepared MMC as shown in figure 4.1.

a) Pouring molten metal

b) Casted product

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c) Plate for testing

Fig 4.1: Stir casting process

Table 4.1: Compositions of metal matrix composites

Samples	**Compositions**
1	Al6061
2	Al6061+4%TiO_2+3%Gr
3	Al6061+8%TiO_2+3%Gr
4	Al6061+12%TiO_2+3%Gr

5. EXPERIMENTAL DETAILS

The free vibration test is conducted on fabricated MMCs samples to find out the vibration characteristics. The density and porosity of MMCs are determined.

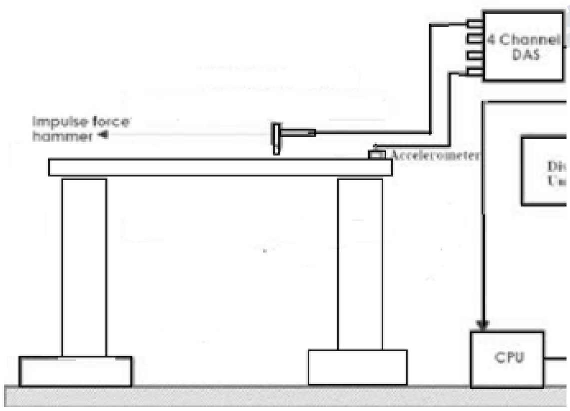
5.1 DENSITY AND POROSITY

The theoretical density was calculated by the rule of mixture, actual density was measured by Archimedes principle and porosity of the composites was obtained by theoretical and actual densities.

5.2 VIBRATION TEST

The figure 5.1 shows the schematic experimental setup, the vibrations of the plate are measured by using the following equipment. Table 5.1 gives the hardware details.

- Accelerometer- the device used to measure acceleration forces.
- Impact Hammer to apply initial excitation.



- Multi-channel vibration analyzer (DAQ) - to measure voltage, current, pressure, or sound with a computer.
- Personal Computer (PC) - loaded with Lab view software for vibration analysis.

Fig 5.1: Schematic experimental Setup

Table 5.1: Hardware details

Sl.no.	**Component name**	**Sensitivity**
1	Impulsive force hammer	2.172 mV/N (Plastic/Vinyl)
2	Accelerometer	10.24 mV/m/s²
3	Data acquisition system (CDAQ)	4 channel,±V, 24 Bit software
4	Software	LAB VIEW-2009 version

The experimental setup comprises of accelerometer probes mounted on the plate, an amplifier to amplify the recorded frequency of vibration, impact hammer, cables and data acquisition system interfaced with the computer for recording the data which is subsequently analyzed and interpreted using Lab VIEW software. The plate is held in cantilever condition, the photograph of the entire experimental setup is as shown in Figure 5.2.

Fig 5.2: Experimental Setup

Experimental procedure is as follows

- The test specimens were made of Hybrid metal matrix composites with a cross-section of 150*150mm.
- The specimen is attached to the fixtures and the experiment is conducted for different compositions. Tri-axial accelerometer is then attached away from the clamping boundary by the aid of paraffin wax.
- Lab view software is used for Vibration measurements.
- The connections of DAQ, accelerometer, Impact Hammer, are as shown in fig 5.1.
- 42 Pre-trigger samples are taken by Impact Hammer and are recorded.

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- The reading is plotted in the FRF graph (from fig 6.1 to fig 6.4).
- The peak obtained in the FRF graph is considered as excitation frequency. The natural frequencies are obtained by numerical results and excitation frequencies which are closer to natural frequency are considered as resonance conditions.
- Natural frequency and damping ratio of the system is found out by FRF test using impact hammer.

6. RESULTS AND DISCUSSION

This work presents the result for selected hybrid MMCs in accordance with the design and methodology. The work is carried out for different weight percentage of TiO_2 and fixing 3% of graphite. The Fast Fourier transform (FFT) tests carried out for each of the composite plates yields with the results of frequency response function (FRF) modal data that are tabulated in addition to this density and porosity data are analyzed.

6.1 DENSITY AND POROSITY RESULTS

The theoretical and actual density values are increasing while adding reinforcement into the matrix which is given in the table 6.1.

Table 6.1: Density of MMCs

Sl. No.	Hybrid composite	Theoretical Density g/cm³	Experimental density g/cm³	Porosity %
1	Al 6061	2.7	2.675	0.925
2	Al 6061 + 4%TiO_2 + 3%Gr	2.7471	2.664	3.02
3	Al 6061 + 8%TiO_2 + 3%Gr	2.8083	2.667	5.03
4	Al 6061 + 12%TiO_2 + 3%Gr	2.8695	2.685	6.42

It can be observed from the table 6.1 that the densities of composites are higher than that of their base matrix. Further, the density increases with the percentage of reinforcement content increased in the composites. The increase in the amount of reinforcement during stir casting, the porosity of the composites was also increased because of pore nucleation at the reinforcement particulate surfaces. This increases the generation more gas bubbles and decreases the liquid metal flow in the composites.

6.3 VIBRATION RESULT

The Fast Fourier transform (FFT) tests carried out for each of the composite plate's yields with the results of frequency response function (FRF) modal data that are tabulated.

Table 6.2: FRF Data for Specimen 1

FRF data for Al 6061				
Mode No	**Natural frequency Hz**	**Damping Ratio**	**Magnitude**	**Phase Angle**
1	83.62	0.0023	1.14	120.93
2	124.03	0.0017	1.45	107.62
3	147.79	0.0030	0.53	148.47

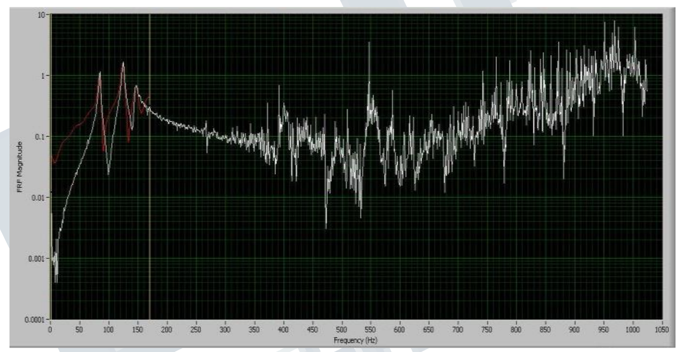

Fig 6.1: FRF graph for specimen 1

Table 6.3: FRF Data for Specimen 2

FRF data for Al 6061 + 4%TiO_2 + 3%Gr				
Mode No	**Natural frequency Hz**	**Damping Ratio**	**Magnitude**	**Phase Angle**
1	88.45	0.0014	0.63	60.93
2	126.71	0.0022	0.45	138.84
3	185.55	0.0035	0.31	138.14

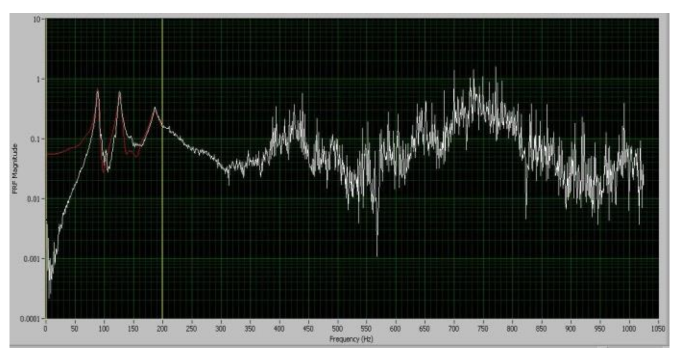

Fig 6.2: FRF graph for specimen 2

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Table 6.4: FRF Data for Specimen 3

FRF data for Al 6061 + 8%TiO_2 + 3%Gr				
Mode No	**Natural frequency Hz**	**Damping Ratio**	**Magnitude**	**Phase Angle**
1	97.951	0.0022	0.17	142.5
2	108.811	0.0033	0.13	158.25
3	174.388	0.0013	0.27	148.01

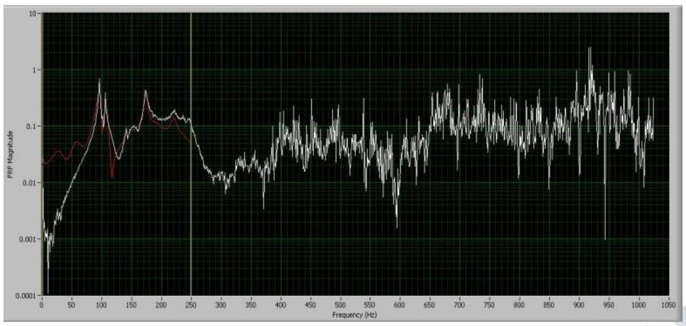

Fig 6.3: FRF graph for specimen 3

Table 6.5: FRF Data for Specimen 4

FRF data for Al 6061 + 12%TiO_2 + 3%Gr				
Mode No	**Natural frequency Hz**	**Damping Ratio**	**Magnitude**	**Phase Angle**
1	122.25	0.0011	1.2	110.98
2	188.74	0.0017	0.18	153
3	220.30	0.0018	0.28	124.29

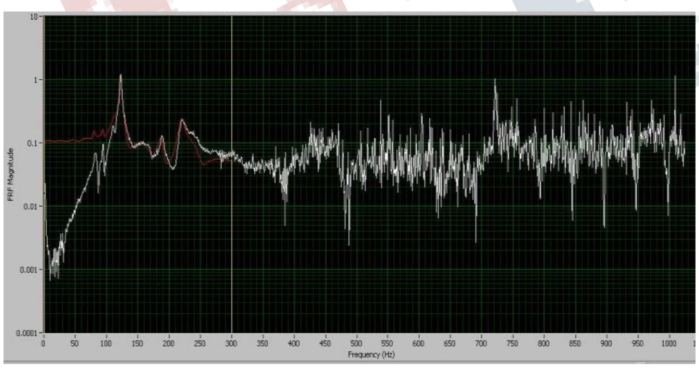

Fig 6.4: FRF graph for specimen 4

FRF modal information for plates such as natural frequency, damping ratio, magnitude and phase angle for different specimens with changing composition of titanium dioxide particles and fixed percent of graphite. Magnitude is the amplitude of the associated frequency. This tells about the strength of the frequency. The natural frequency has a tendency to change between 83–185 Hz while the FRF magnitude shifts from 0.13–1.45 for various specimens and different mode shapes, damping ratio fluctuates in the range of 0.0011–0.0035 and the phase angle is the difference between a measurement point and a reference point in terms of a fraction of a cycle for the frequency being measured. The phase tells you how all the frequency components align in time. It differs in the range of 60°–158°.

7. MODE SHAPES

The three different mode shapes are extracted from the Lab view software, those are bending mode, twisting mode, double bending mode.

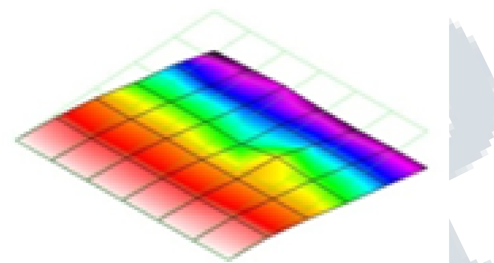

Fig 7.1: Lower bending mode

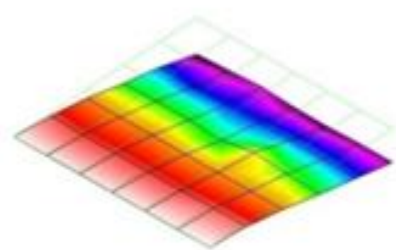

Fig 7.2: Upper bending mode

Figure 7.1 and 7.2 shows the mode shape of mode 1 that corresponds to lower and upper bending mode.

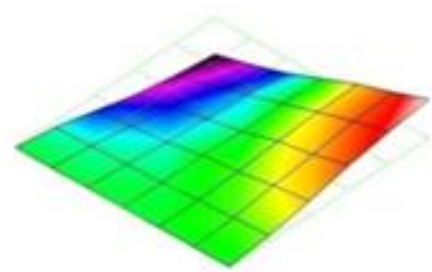

Fig 7.3: Lower twisting mode

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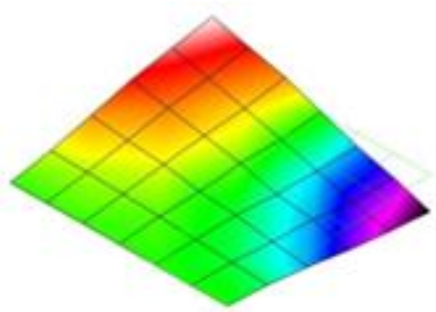

Fig 7.4: Upper twisting mode

Figure 7.3 and 7.4 shows the mode shape of mode 2 that corresponds to lower and upper twisting mode.

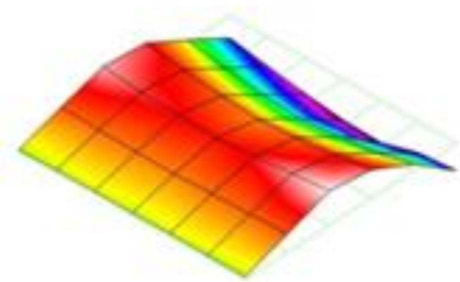

Fig 7.5: Lower double bending mode

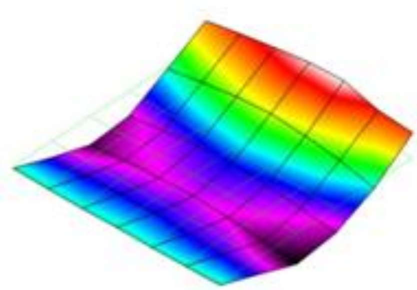

Fig 7.6: upper double bending mode

Figure 7.5 and 7.6 shows the mode shape of mode 3 that corresponds to lower and upper double bending mode.

8. Conclusion

The main objective of the work was to investigate the vibration characteristics of Al 6061 based hybrid metal matrix composites. The hybrid MMCs composite plates are synthesized by casting technique and tested for vibration characteristics by Cantilever limit conditions utilizing data acquisition system. Frequency response functions are acquired by FFT. Quantitative outcomes are displayed to demonstrate the impacts of various parameters like weight percentage of 0%, 4%, 8% and 12% of TiO_2 and keeping 3% graphite constant. Experimental Modal Analysis of the hybrid MMCs is done successfully by using FFT Analyzer respectively. The number of modes obtained through experimental modal analysis is less due to the specimen thickness is less and specimen size is small. From the experiment it is clear that natural frequency increases with increase in the titanium dioxide and keeping the graphite percentage fixed into the matrix. But in specimen 3 some amount of natural frequency reduced. The damping ratio fluctuates in the range of 0.0011–0.0035. The density increases with increase in the percentage of reinforcement into the composites.

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