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Vibrational Analysis of Al 6061–Si and Mg Metal Matrix Composites

Suresh K S[1], Chethana B M[2], Deviprasad N Mirashi[3], Bhagya N M[4]
[1, 2, 3, 4]*Assistant Professor, Bapuji Institute of Engineering & Technology, Davangere*

Abstract: The dynamic behaviour of Al 6061 – Si & Mg Metal Matrix is determined by characterizing its properties under different modes of vibration both experimentally and numerically. The experimental modal analysis carried out through impact testing. The analyser is a combination with PC used as the data acquisition unit. The input force and output response is measured by force transducer and accelerometer respectively. The modal analysis carried out by using ANSYS software. The modal parameters obtained from the analysis can be used to analyse the system behaviour.
Keywords: Modal Analysis, Al 6061 – Si & Mg Metal Matrix, FFT Analyser, FEM, ANSYS

I. INTRODUCTION

Engineering systems possessing mass and elasticity are capable of relative motion. If motion of such system repeats itself after a given interval of time, the motion is known as vibration. Vibrations are caused by the movement of components within the machine due to internal or external excitation. Vibration of a machine may reduce the life of its components, particularly those most highly loaded. Oscillatory stresses included in a machine part, supports, building structures, and also in connections tend to produce failures of these items due to structural fatigue. Machine tools subjected to excessive vibrations may produce poor finishes; some precision equipment (optical system, microscope, gauges, and micro assembly equipment) cannot be effectively used at all in the presence of vibration. Any small change in the machine behavior shall change the vibration pattern of the machine. Hence vibration monitoring and analysis provides reliable information on machine operating condition. Knowing the severity of the problem appropriate corrective action can be taken at the most appropriate time.

Most of the mechanical troubles in a machine cause vibration. By analysing vibration most of problems of rotating machines can be identified such as:

1) Unbalance (Static, Couple, Quasi-Static) and misalignment (angular, parallel)
2) Mechanical looseness, Structural weakness, Soft foot
3) Resonance, Beat Vibration
4) Mechanical Rubbing
5) Problems of belt driven machines
6) Journal bearing defects
7) Anti-friction bearing defects (Linear Race, Outer race, cage, Rolling elements)
8) Gear problems (Tooth wear, tooth load, gear eccentricity, backlash gear misalignment, cracked or broken tooth).

A. *Vibration Analysis*

Vibration refers to mechanical oscillations about an equilibrium point. The oscillations may be periodic such as the motion of a pendulum or random such as the movement of a tire on a gravel road.Vibration analysis is a non-destructive technique which helps early detection of machine problems by measuring/ evaluating vibration. Vibration analysis, properly done, allows the user to evaluate the condition of equipment and avoid failures. Maintenance personnel can minimize unplanned downtime by scheduling needed repairs during normal maintenance shutdowns. Unscheduled downtime may cost tens of thousands of rupees per hour. Fortunately, modern vibration analysis equipment and software predict developing problems so that repair happens before disaster strikes. While these sophisticated tools offer many automated features and capabilities, it still takes a basic understanding of vibration analysis to use them effectively. In the past, vibration analysis required dialing an instrument through the full spectrum to identify frequencies at which vibration was prominent. The latest generation of vibration analyzers has more capabilities and automated functions than their predecessors had. Many units display the full vibration spectrum of three axes simultaneously--providing a snapshot of what is going on with a particular machine.

Vibration analysis can also be used in determining some of the material properties such as damping factors, frequency etc. It has many advantages

1) It is a non-destructive test
2) It does not effect machine operation
3) It does not interfere with production scheduling
4) The data is quantitative and readily lends itself to computer trending.

B. Phases of Vibration Analysis

A Vibratory system is a dynamic system for which the variables such as excitations (Inputs) and responses (Outputs) are time dependent. The response of the vibrating system generally depends on the initial conditions as well as external excitations. Thus the analysis of a vibrating system involves mathematical modeling, derivation of the governing equations, solutions of the equations, & interpretation of the results.

1) *Step1: Mathematical Modeling:* The purpose of the mathematical modeling is to represent all the important features of the system for the purpose deriving the mathematical or analytical equations governing the behaviour of the system. The mathematical model should include enough detail to describe the system in terms of equations without making it too complex.
2) *Step2: Derivation of governing equation:* Once the mathematical model is available, we use the principle of dynamics & derive the equations that describe the vibration of system. The equation of motion can be derived conveniently by drawing the free body diagram of all the mass involved. The free body diagram of a mass can be obtained by isolating the mass & indicating all externally applied forces, the reactive forces, & the inertia forces.
3) *Step3: Solution of the governing equations:* The equation of the motion must be solved to find the response of the vibrating system. Depending on the nature problem, we can use any one of the following techniques for finding the solution; standard methods of solving differential equations, Laplace transformation methods, matrix methods, and numerical methods.
4) *Step4: Interpretation of the results:* The solution of the governing equation gives the displacements, velocities and accelerations of the various masses of the system. These results must be interpreted with a clear view for the purpose of the analysis and the possible design implifications of the results.

C. Properties of Al-Si-Mg Alloy

Al-Si-Mg Alloy have the potential for excellent castability, good weldability, good thermal conductivity, high strength at elevated temperature and excellent corrosion resistance. Besides having low density, higher electrical & thermal conductivity, Al alloys have higher resistance to corrosion at ambient temperature that makes it very suitable to make wear resistance components in automobile industry. The mechanical properties of an Al alloy are highly dependent on its microstructure. By alloying & heat treatment the strength, toughness, stiffness, hardness & ductility of the alloy can be adjusted to meet requirement set by the application of the final product. Castings are the main use of Al-Si-Mg alloy, although some sheets or wire is made for welding & brazing, & some of the piston alloys are extruded for forging stock. Often the brazing sheet has only a cladding of Al-Si-Mg alloy & the core consist of some other high melting alloy. Silicon is the main alloying element: it imparts high fluidity & low shrinkage, which result in good castability & weldability. The low thermal expansion coefficient is exploited for pistons, the high hardness of the Si particles for wear resistance. The maximum amount of silicon in cast alloys is of the order 22-24% Si, but alloys made by powder metallurgy may go as high as 40-50% Si.

Magnesium is a ductile, silver-white, chemically active metal with a hexagonal close-packed crystalline structure. It is malleable when heated. Magnesium is one of the alkaline-earth metals in Group 2 of the periodic table . Magnesium excess leads to better corrosion resistance but lower strength and formability; silicon excess produces higher strength without loss of formability and weldability, but some tendency to intergranular corrosion. Machinability of the alloys is good, especially in the aged tempers. Iron and manganese in normal amounts have little effect on machinability; excess silicon reduces it slightly. Additions of cadmium, bismuth and lead do not improve machinability as well as they do in magnesium-free alloys; magnesium combines with them to produce hard particles that act as chip breakers but increase wear of the tools. The density of the magnesium is about 2/3 of that of aluminum and a quarter of that of steel. Magnesium is the lightest among metallic materials which are being used practically. Although magnesium alloy has a higher density than plastics, its tensile strength and Young's modulus per unit weight are higher than plastics. This enables to make a lighter part by using magnesium alloy than plastics. The thermal conductivity of magnesium alloy is much higher than that of plastics. Magnesium casings of electronic appliances can dissipate heat, which is generated in the electronic circuit, much more effectively than plastic casings Alloys prepared from the powders exhibit somewhat higher strengths especially at elevated temperatures. In wrought products ultimate tensile strengths of 200-400 MPa, with elongations correspondingly from 22-23% are obtained. Poor casting technique may reduce the properties, although the Al-Si-Mg alloys are among the least sensitive to such variables as gas content, design of castings, rate of cooling & feeding. High purity find special treatments can produce properties some 10-20% better than average, &, conversely, secondary alloys tend to have lower ductility than do primary ones. Casting under pressure improves properties towards those of forgings. Increasing silicon content increases strength at the expense of ductility, but this effect is not very marked. At the higher cooling rates, normal with metal mould castings, the silicon is already somewhat refined without modifications & the improvement from modification is reduced

Al-Si-Mg alloy are widely used in the following fields:

1) Automotive Industry
2) Aircraft Industry
3) Civil Infrastructure
4) Machine Tool Industry
5) Sheet Metal Applications

II. PROCESSING OF AL-SI-MG ALLOYS BY CASTING

An Al-Si-Mg alloy of various compositions as well as commercially pure Al castings has been processed by using simple gravity casting route.

A. *Procedure*

The Al ingot pieces were melted in the gasified furnace. After melting Al melt was super-heated to desired temperature (about 750^0 C). The required amounts of silicon and magnesium particles were added to the Al melts while stirring with stirrer at suitable speed. The molten Al-Si-Mg alloys were poured into a split type permanent mould & it was allowed for solidification. The Al-Si-Mg alloy ingot was taken out from the mould. The specimens were prepared from as- cast alloys for determination of damping properties.

Various compositions of Al-Si-Mg castings are as follows:

1) 95%Aluminium + 4%Silicon + 1% Magnesium (by weight)
2) 95% Aluminium + 3% Silicon +2% Magnesium (by weight)
3) 95% Aluminium + 2% Silicon +3% Magnesium (by weight)
4) 95% Aluminium +1% Silicon +4% Magnesium (by weight)

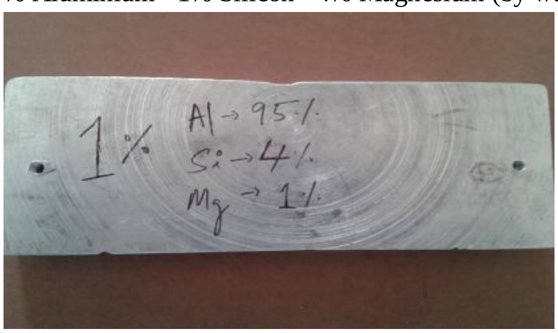

Fig 1: 95%Aluminium + 4%Silicon + 1% Magnesium

Fig 2: 95% Aluminium + 3% Silicon +2% Magnesium

Fig 3: 95% Aluminium + 2% Silicon +3% Magnesium

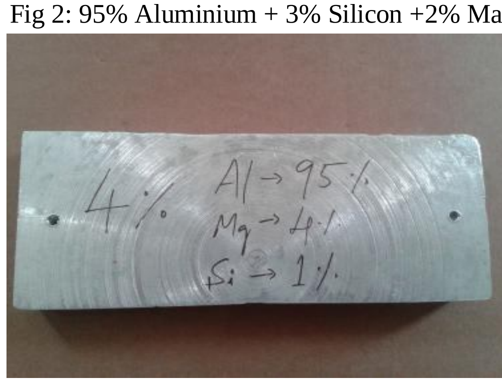

Fig 4: 95% Aluminium +1% Silicon +4% Magnesium

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III.MATERIAL PROPERTIES

A. To Find the Material Properties of Al-Si-Mg Alloy Using Tensile Test

For analytical analysis, the material properties such as youngs' modulus, poissons ratio and density of materials are required.

B. To Find Youngs' Modulus

Youngs' modulus is the ratio of stress to strain. Here youngs' modulus is determined by load verses deformation. Tensile test is conducted by using universal testing machine to find the deflection for corresponding load. The tensile test conducted for different compositions of casting are as shown in the figure. Graph is plotted for the observed deflection and load. Slope gives the value of youngs' modulus of the material.

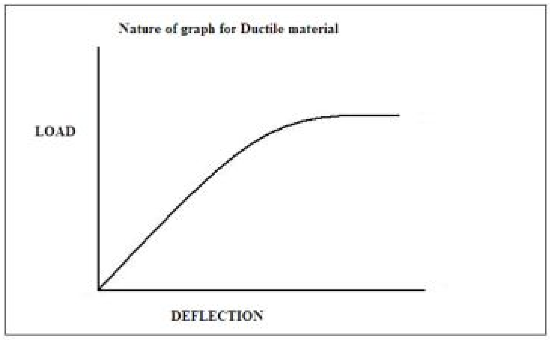

Fig 5: Graph of Load verses Deflection

(a)

(b) (c) (d)

Fig 6: Tensile Test for Different Compositions

1) *To Find Density Of Material:* Density of material is defined as the mass of material per unit volume. The test specimen are weighed using the digital weighing machine to find the mass. The volume of the specimen is determined using Archimedies' principle. Archimedies' principle states that "The buoyant force on the submerged object is equal to the weight of liquid displaced".The volume of the material is obtained in terms of cubic centimeter which is converted to cubic meter.

C. Use Water Displacement To Measure Volume

When you want to try and measure the volume of an irregularly shaped object, it is often difficult and complicated to do. The easiest method to achieve this is known as the "water displacement method". This is the most commonly used technique and is very simple and accurate. The steps for the water displacement method are listed below.

Fig 7: Shows Water Displacement to Measure Volume

1) Write down the following equation on a piece of paper:
   [(b) - (a)] = Volume of odd shaped object
2) Find a graduated cylinder that will be large enough to fit the object being measured into.
3) Fill the graduated cylinder enough so that when placed in the graduated cylinder, the object will be fully submerged in the water. Also be careful not to put in so much water that the water level will rise past the graduated cylinder's markings when the object is placed in the graduated cylinder.
4) After filling the graduated cylinder to a level that will allow us to put our object in without spilling, record the volume of the water as (a) in your equation that we wrote down in Step 1. Make sure to read the meniscus when determining volume.
5) After the water's volume has been recorded, carefully place the object in the graduated cylinder and record this volume as (b) in your equation that we wrote down in Step 1.
6) Now we want to calculate the volume of the irregularly shaped object that we placed in the graduated cylinder. To this, subtract the volume of the water alone from the volume of the water and object using the equation that we wrote down in Step 1: [(b) - (a)] = Volume of odd shaped object.

From the experiment volume of the test specimens is calculated and followed by density.

Using the above references and methods we have obtained the young's modulus, Poisson's ratio, and density for all the three test specimens and are shown in Table 1.

Table 1: Material Properties for Al-Si-Mg Alloys

Material	Young's modulus GPa	Poisson's ratio	Density Kg/m^3
95%Al- 4%Si -1%Mg	64	0.33	2492
95%Al -3%Si- 2%Mg	66	0.33	2414
95%Al -2%Si- 3%Mg	68	0.33	2356
95%Al -1%Si- 4%Mg	70	0.33	2222

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IV. METHODOLOGY

A. Experimental Modal Analysis

An experimental modal analysis consists of five phases:

1) Building the test set up: suspending test object, attaching transducers, connecting the data acquisition system, calibration.
2) Acquisition of the data and most often, the estimation of frequency response functions.
3) System identification phase: the determination of vibration characteristics of the system from the measured input –output data.
4) Validation of the obtained results. All these phases are necessary to reach the fifth phase.
5) Using the obtained information for improving the system in a systematic way.

The experimental modal analysis starts from measurements of dynamic input forces and output responses on (a prototype of) the system of interest. These measurements are most often transformed into frequency response function that is the ratio between output and input as a function of frequency. The frequency response functions can be expressed in terms of modal parameters. Hence the experimental modal analysis consists of estimating these parameters from the measured frequency response functions.

a) *Experimental Setup:* In a modal analysis test a vibration force has to be applied to the structure. An exciter system or a hammer impact serves this purpose. Force transducer will measure the (input) force. Motion transducer measures the (output) vibration motion. These signals are processed by an analysis system that will digitize them and use them for estimation on the frequency response function. This procedure is repeated for several excitation and response combinations. All frequency response functions are stored on a disc memory of the analysis system. During the next phase, the analysis system will determine the modal characteristics (system poles, mode shape vectors, participation function) of the structure under investigation, based upon the measured frequency response function. Animation graphical tool will simulate on the screen the modal deformations based upon a wire frame model. Fig : 5 illustrates the schematic representation of experimental setup [5] used for modal analysis.

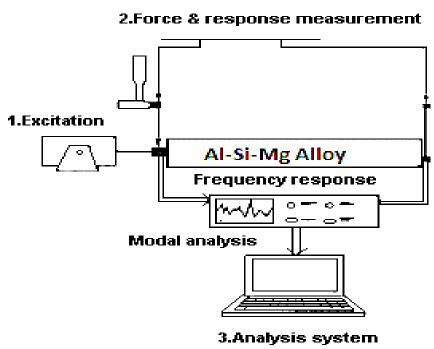

Fig 8: FFT Experimental Setup

b) *Instrumentation*

i) *Exciter Systems:* Any vibration test system requires a device to subject the test object to some vibration motion. Such device may be attached to the structure or free from it. The exciter systems are of two types

ii) *Fixed Excitation System:* The most classical set up consist of one or more shakers standing on the ground (or fixed to some frame) and attached to the structure. Other is attached to the structure only. In these cases, the shaker affects to some extend the dynamic behavior of the structure.

iii) *Non-Fixed Excitation System (Hammer):* The aim of exciting the structure under investigation is to generate a certain force level over a specified frequency range. An impact input e.g., using a hammer, generates relatively, smoothly evolving force level unto a specific frequency

Fig 9: Hammer will be instrumented with a force transducer

The energy level and the frequency span are determined by the force of the user, the weight of the hammer, the hardness of the hammer tip and the compliance of the impact point on the structure. The closer the input force approximates a direct impulse (zero duration, infinite amplitude, unit energy content), the wider the excited base band frequency span will be. A hard hammer tip, a low hammer weight, a lower force and hard test object surface will generally cause a short contact time between hammer and the text object. Hence the signal will be close to a direct impulse and the excited base band frequency span will reach unto a high frequency (up to 10 kHz). This hammer excitation is especially suitable for lightweight, relatively stiff constructions. Heavy hammers with soft tips will cause long contact time.

c) *Force And Motion Transducers:* Once the structure is vibrating due to an induced force, from a fixed exciter or a hammer impact, input and output quantities to the mechanical system need to be measured. The systems input generally are the forces. Force transducers will measure these input forces. The system outputs generally are the displacements, velocity or accelerations at various locations of interest on the structure. Motion transducers will measure these outputs.

i) *Force Transducers:* In most modal analysis measurements piezoelectric force transducers replaced the more classical dynamometers with strain gauges. Figure shows the principle construction of a piezoelectric force transducer. The force acting on the transducer deforms the piezoelectric crystal, thus generating a charge over the crystal.The main characteristics are the maximum force, minimum and maximum frequency (which depends on the load) and sensitivity. The force range is in between 0.0005 to 250000 N. the mass is ranging from 8gms to 550gms.

ii) *Motion Transducers:* Motion transducer is device that produces an electrical signal of the vibratory motion it is subjected to. A good transducer should add any spurious components to the signal and should produce signals uniformly over the frequency range of the interest.Different types of transducers respond to different parameters of the vibration source like as follows, Proximity probe: Displacement, Velocity probe: Velocity, Accelerometer: Acceleration

iii) *Accelerometer:* Accelerometer is a Piezo–Electric Accelerometer and it can be considered the standard vibration transducer for machine vibration measurement. In our experimental setup we are using ICP accelerometer, which is mounted on the Al-Si test specimen. The Fig shows the ICP accelerometer.

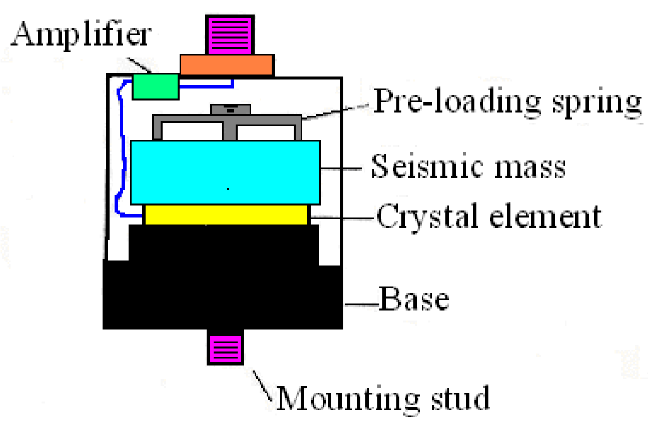

Fig 10: Accelerometer

The seismic mass is clamped to the base by an axial bolt bearing down on a circular spring. Piezo – electric element is squeezed between the mass and its base. When a piezo electric material experiences a force, it generates an electric charge between its surfaces. When the accelerometer is moved up and down direction, the force required to move the seismic mass is born by the active element. According to Newton's second law, this force is proportional of the mass. The force on the crystal produces the signal, which is therefore proportional to the acceleration of the transducer.

d) *Fast Fourier Transform Analyser:* A French mathematician and scientist, Fourier, as a natural progression of his Fourier series theory, discovered Fourier transform. The Fourier series theory states that any waveform, however completed, can be expressed as a series of two or more simple sine waves & cosine waves, if the waveform is periodical that is, composed of the same repeated waveforms. The mathematical expression of this theory is called Fourier series. Fourier transform wave involves expansion of the Fourier series from $-\infty$ to $+\infty$ and developed

Fig 11: Fast Fourier Transform analyser with accelerometer

It is not always clear the extent to which a signal can be actually measured and determined as periodical, especially when measuring the waveform up to infinity, as it becomes fainter & fainter. Thus, in general, only a part of the observed waveform is cut out & Fourier transform performed on this period of waveform assuming that the waveform is infinitely repeated. Originally this Fourier transform calculation required a tremendous number of multiplication calculations. However, J.W. Cooley & J.W. Turkey proposed a method of calculation that reduces the number of individual calculations by taking the number of data items is assumed to be 1024, the no. of multiplications that are 1024*1024 =10484576, is reduced to 10240. This method was called Fast Fourier Transform acronym, FFT.FFT analysis also called spectrum analysis, which is defined as the transform of a signal from a time domain representation into a frequency domain representation.

Advantages of FFT

i) By using this instrument defects can be rectified at an early stage. This avoids further damage to the machines. So the losses can be minimized.

ii) By this instrument, defects can found out without disturbing the production process so there is continuous production of plant.

iii) It increases the overall productivity and hence the profit.

iv) These analyses can be used as reference in analysis of vibration in various machines.

B. Modal Analysis Using FEM

Now a day, in the design of mechanical structures, the dynamic behavior gets more attention. Life time under cyclic loading, levels of vibration or noise radiation, interaction between control systems & structure vibrations, are often important constraints for the designer. The analysis of the dynamic behavior is however not straight forward. Designers can easily determine modal parameter of a mechanical structure by numerical methods. The results of this investigation are expected to correlate closely with experimental results. Experimental measurements on prototype give information about the structure in the configuration of the test only, finite element models allow predicting the dynamic behavior of the structure under various loading & boundary conditions, but the reliability of the finite element models is often not guaranteed.Model updating techniques verify & correct these finite element models by means of the experimental data. The result of a model updating analysis is a finite element model that is more reliable for further predictions.

Secondly the existence of the finite element models of the structure to be tested will provide test engineers with a lot of valuable information to perform an analysis. This may increase the quality of data & reduce the testing time. Hence, this type of combining analytical & experimental models is a structured way of using the existent experience.Development of finite element model yields accurate & reliable predictions of the dynamic behavior of mechanical structure. The updating procedure starts with the constructions of finite element models. The structure is divided in elements that are connected in nodes. Each node has one or more degrees of freedom. Degrees of freedom represent displacement & deformation of the structure in a discrete form. Each piece of structural amterial contributes to overall mass stiffness & damping through element matrix. Assembly of all element matrices yields the global system matrices.

1) *Overview of ANSYS:* ANSYS is a general purpose finite element modeling package for numerically solving a wide variety of mechanical problems. These problems include: static/dynamic, structural analysis (both linear & non linear), heat transfer & fluid problems, as well as acoustic & electromagnetic problems [3].In general, a finite element solution may be broken into the following three stages. This is a general guide line that can be used for setting of any finite element analysis.

a) Preprocessing: Defining the problem

The major steps in preprocessing are given below:

i) Define key points/lines/areas/volumes
ii) Define element type & material/ geometric properties
iii) Mesh lines/areas/volumes as required

The amount of detail required will depend on the dimensionality of the analysis (i.e., 1D, 2D, axis-symmetric, 3D).

b) Solution: Assigning loads, constraints & solving

Here we specify the loads (point/ pressure), constraints (transitional & rotational) & finally solve the resulting set of equations.

c) Post processing: Further processing & viewing of the results

In this stage one may wish to see:

i) List of nodal displacements
ii) Element forces & moments
iii) Deflection plots
iv) Stress contour diagrams

V. RESULTS & DISCUSSIONS

A. Modal Analysis Experimental Set Up & Result

The experimental setup for conducting modal analysis is shown in Fig 12. The Al-Si test specimen is fixed. A point is marked at the middle of the Al-Si test specimen for mounting accelerometer to measure acceleration of vibration. Al-Si 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 12. 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 Al-Si test specimen for free vibrations. *Channel 2* is connected to the accelerometer which is used for measuring response of the Al-Si test specimen.

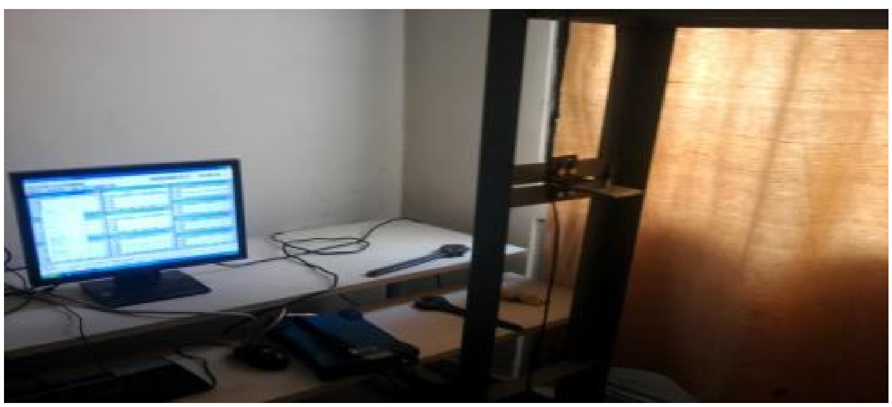

Fig 12: Experimental Setup

B. The Spectrum for channel 2 is available in Fig. 13 to 16

Fig. 13: Spectrum showing natural frequencies of Al-4%Si-1%Mg

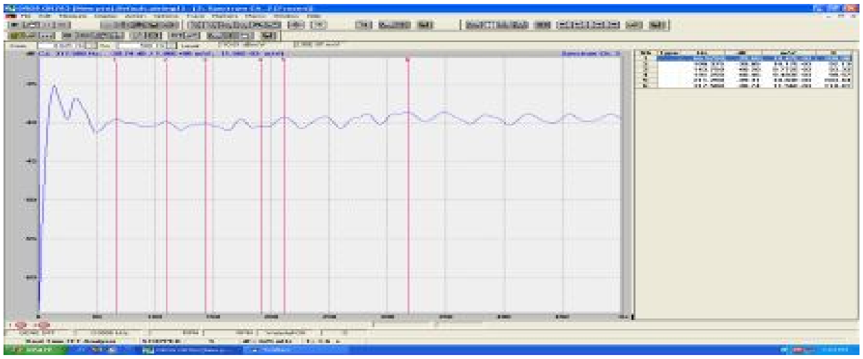

Fig. 14: Spectrum showing natural frequencies of Al-2%Si-3%Mg

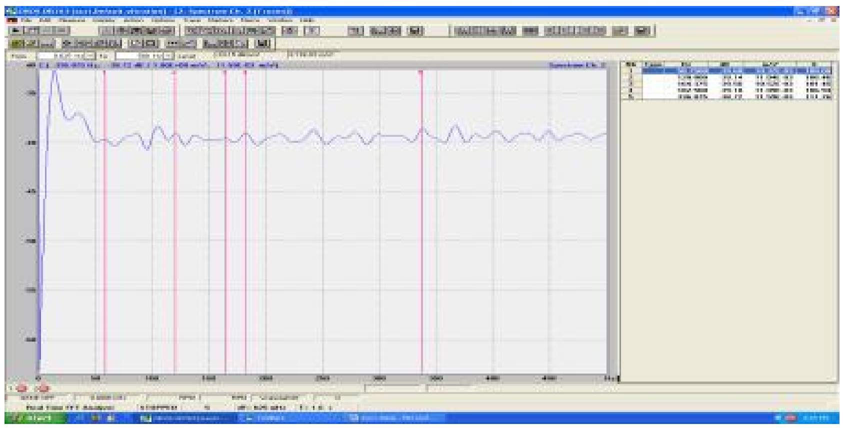

Fig 15: Spectrum showing natural frequencies of Al-2%Si-3%Mg

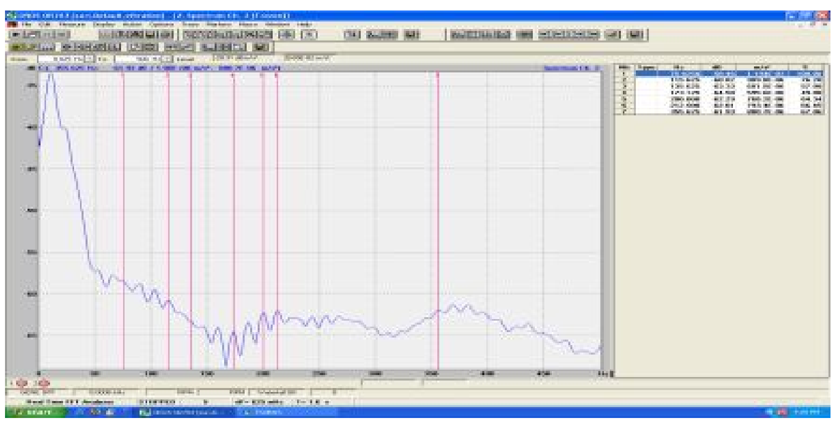

Fig. 16: Spectrum showing natural frequencies of Al-1%Si-4%Mg

By the experimental modal analysis, critical frequencies are found for Different composition of Mg & Si are shown in Table: 2

Table 2: Experimental Modal Analysis results of Al-Si Alloy

Mode No.	Natural Frequencies for Al –4%Si-1%Mg in Hz	Natural Frequencies for Al –3%Si-2%Mg in Hz	Natural Frequencies for Al –2%Si-3%Mg in Hz	Natural Frequencies for Al –1%Si-4%Mg in Hz
1	55.62	66.87	58.75	75.62
2	121.25	107.37	120.00	115.62
3	143.12	143.75	164.37	135.62
4	180.00	199.25	182.50	173.62
5	297.50	211.25	336.87	200.00

C. Modal Damping

Modal damping = $\dfrac{\omega_1 - \omega_2}{2\omega}$

Where ω is natural frequency and ω_1, ω_2 are -3 dB reduced frequencies to the natural frequency. The values of ω, ω_1, and ω_2 are taken from Figure 17 to 20

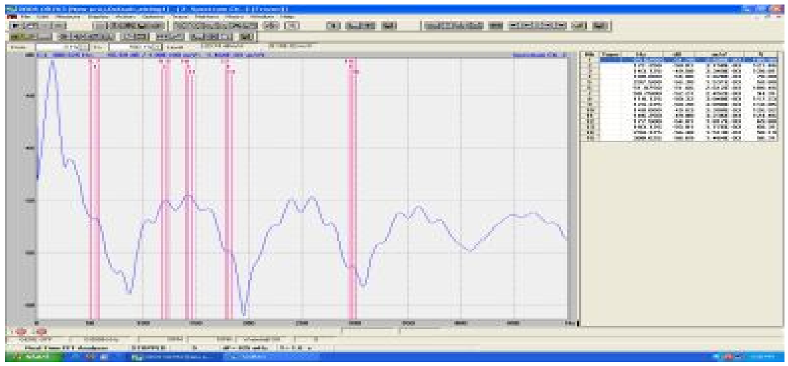

Fig 17: Spectrum showing natural frequencies of Al-4%Si-1%Mg

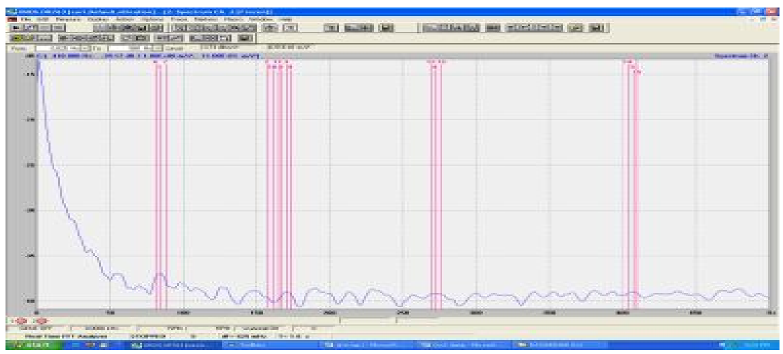

Fig 18: Spectrum showing natural frequencies of Al-3%Si-2%Mg

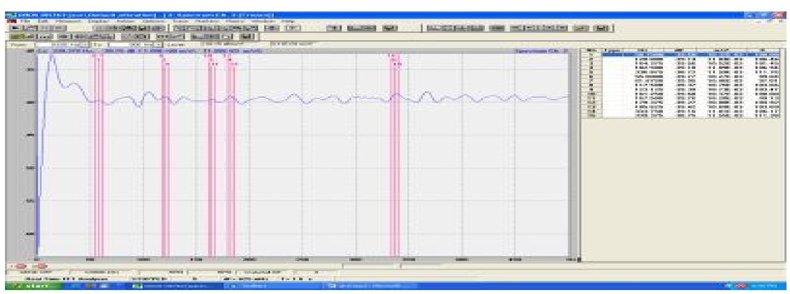

Fig 19: Spectrum showing natural frequencies of Al-2%Si-3%Mg

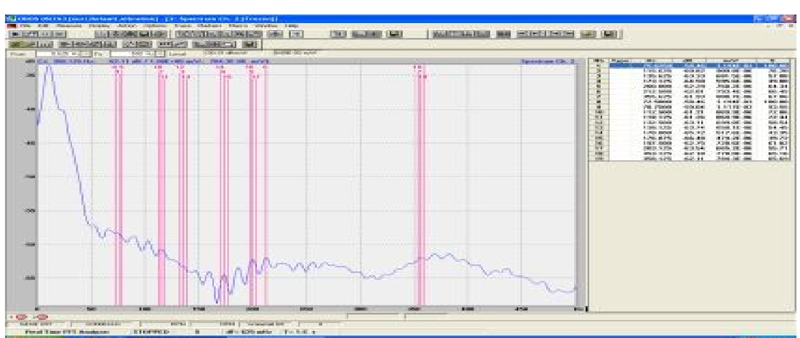

Fig 20: Spectrum showing natural frequencies of Al-1%Si-4%Mg

Modal damping was calculated at different natural frequencies and the details are available in table 3, 4, 5 and 6.

Table: 3 Modal damping of Al-4%Si-1%Mg

S No.	ω in Hz	ω_1 in Hz	ω_2 in Hz	Modal damping
1	121.25	118.12	124.37	0.025
2	143.12	140	146.25	0.021
3	180	177.5	183.12	0.015

Table 4: Modal damping of Al-3%Si-2%Mg

S No.	ω in Hz	ω_1 in Hz	ω_2 in Hz	Modal damping
1	109.37	106.37	112.37	0.024
2	143.75	140.75	146.75	0.020
3	191.25	188.25	194.25	0.015

Table 5: Modal damping of Al-2%Si-3%Mg

S No.	ω in Hz	ω_1 in Hz	ω_2 in Hz	Modal damping
1	120	117	123	0.025
2	164.37	161.25	167.5	0.019
3	182.5	179.37	185.62	0.017

Table 6: Modal damping of Al-1%Si-4%Mg

S No.	ω in Hz	ω_1 in Hz	ω_2 in Hz	Modal damping
1	115	112	118	0.026
2	135.62	132.5	138.12	0.020
3	173.12	170	176.87	0.019

From the above table 3 to 6 it is observed that, Damping decreases as natural frequency range increases when Si percentage is high. Again damping increases when Mg percentage is high.

D. Modal analysis results by ANSYS

The finite element model is built using SOLID45 element. For the modal analysis of the Al-Si-Mg alloy, the material properties used are given in the table 4.1. Modal analysis was carried out and result of the analysis is listed in table 7.

Table 7 Analytical Modal Analysis results of Al-Si-Mg Alloy

Mode No.	Natural Frequencies for Al-4%Si-1%Mg in Hz	Natural Frequencies for Al-3%Si-2%Mg in Hz	Natural Frequencies for Al-2%Si-3%Mg in Hz	Natural Frequencies for Al-1%Si-4%Mg in Hz
1	67.4	93	72	78
2	117.1	162	125	137
3	157	176	168	143
4	187	280	200	183
5	303	260	336	219

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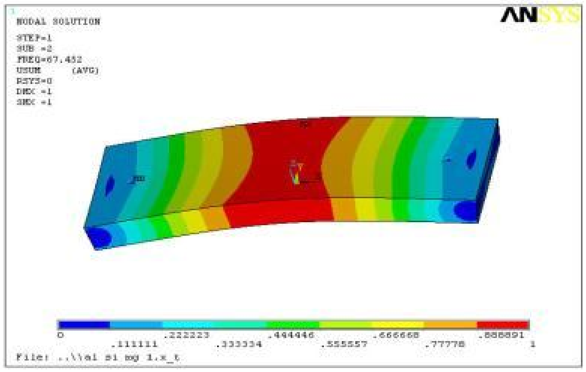
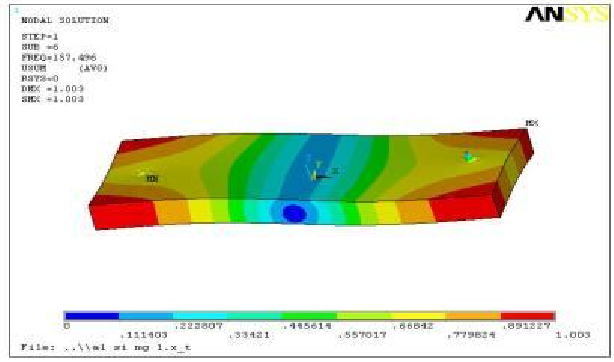
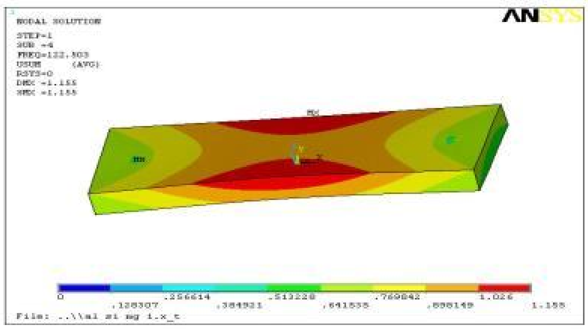


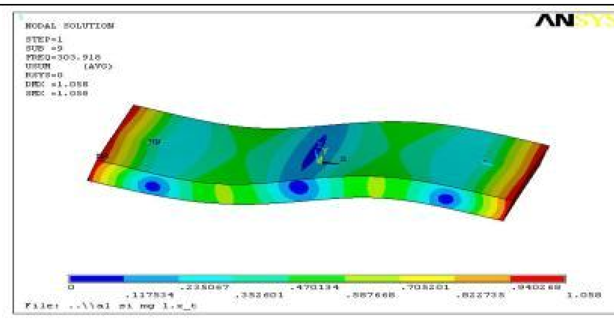
Mode shape at natural frequency 67.45 Hz



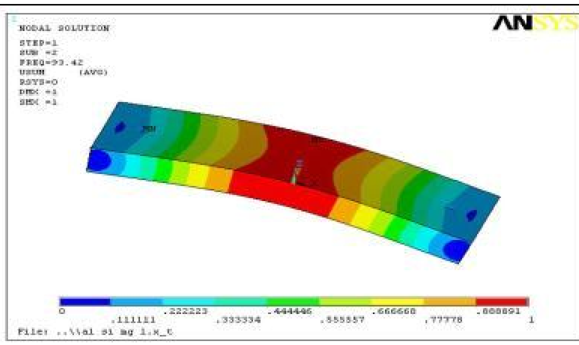
Mode shape at natural frequency of 157.49 Hz



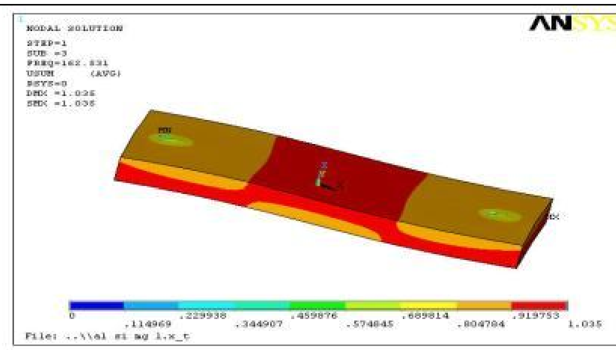
Mode shape at natural frequency of 122.50 Hz



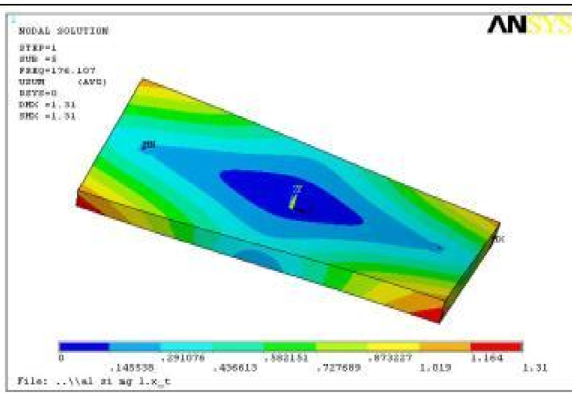
Mode shape at natural frequency of 303.91 Hz



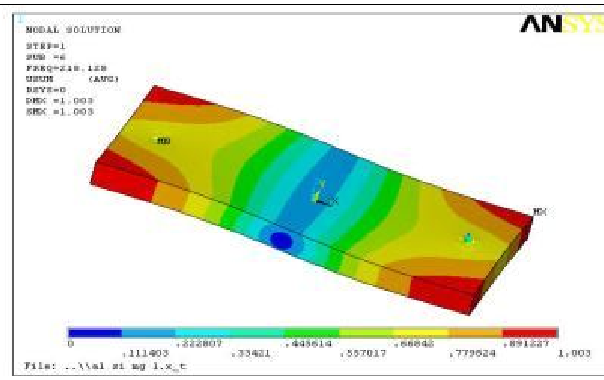
Mode shape at natural frequency of 93.42 Hz



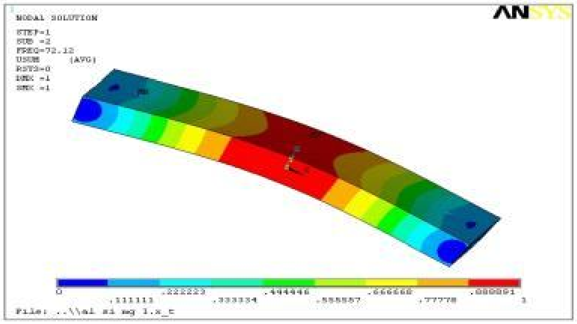
Mode shape at natural frequency of 162.53 Hz



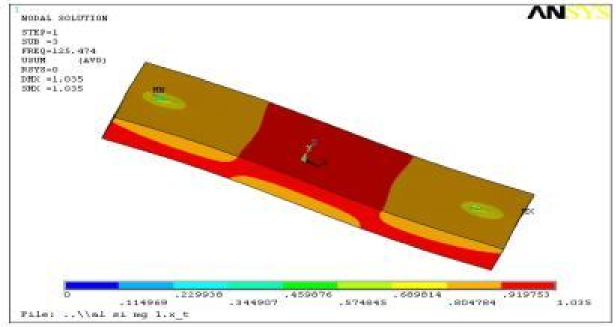
Mode shape at natural frequency of 176.10 Hz



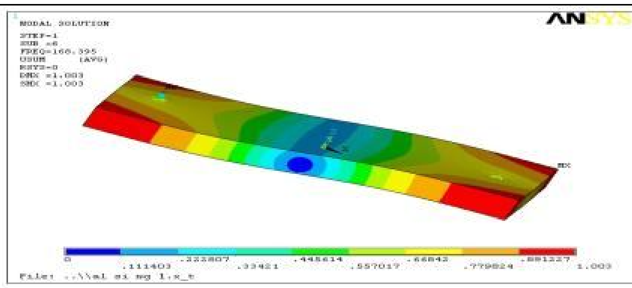
Mode shape at natural frequency of 218.12 Hz



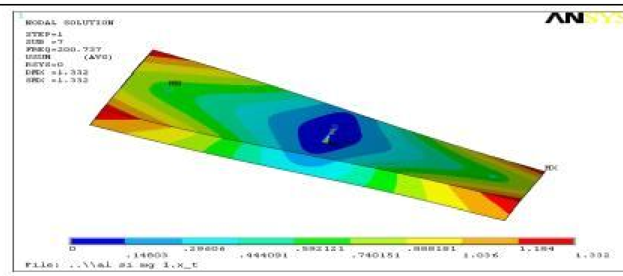
Mode shape at natural frequency of 72.12 Hz



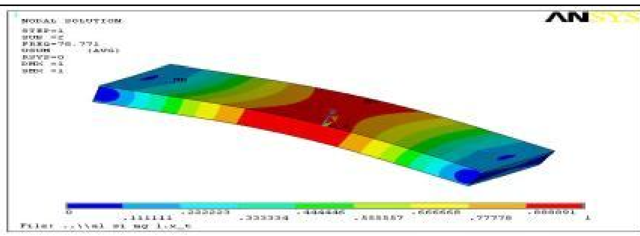
Mode shape at natural frequency of 125.47 Hz



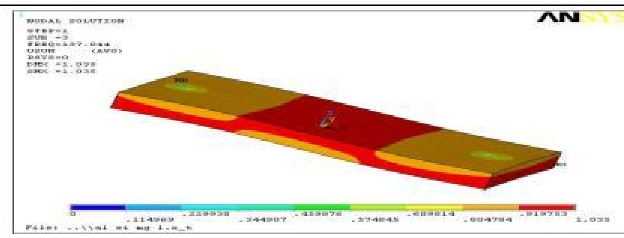
Mode shape at natural frequency of 168.39 Hz



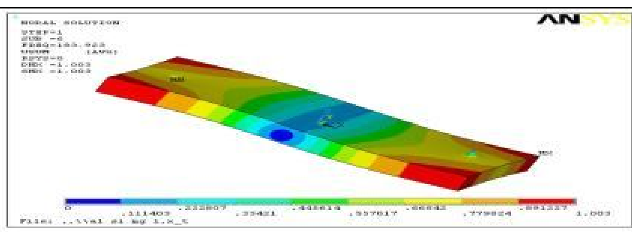
Mode shape at natural frequency of 200.73 Hz



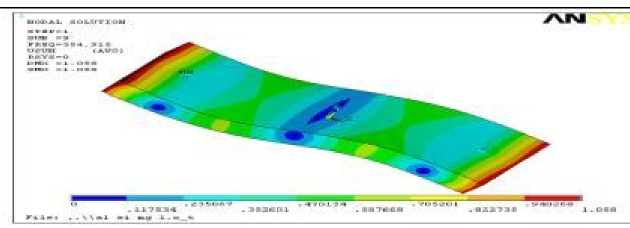
Mode shape at natural frequency of 78.77 Hz



Mode shape at natural frequency of 137.04 Hz



Mode shape at natural frequency of 183.92 Hz



Mode shape at natural frequency of 354.91 Hz

Fig 21: Mode Shape at different natural frequencies in Ansys

E. Comparison of Experimental and FEA Results

The data collected from both experimental and FEM analyses are shown in table below.

Table 8: Comparison of FEM and Experimental results of 95%Al-4%Si-1%Mg

Mode No.	Experimental results in Hz	ANSYS results in Hz	% Deviation
1	55	67.45	17.91
2	121	122.50	3.3
3	143	157.49	8.9
4	180	187.74	3.74
5	297	303.91	1.9

Table 9: Comparison of FEM and Experimental results of 95%Al-3%Si-2%Mg

Mode No.	Experimental results in Hz	ANSYS results in Hz	% Deviation
1	109	93.42	14.29
2	143	162.53	11.72
3	191	176.10	7.8
4	211	218.12	3.2
5	317	276.12	12.8

Table 10: Comparison of FEM and Experimental results of 95%Al-2%Si-3%Mg

Mode No.	Experimental results in Hz	ANSYS results in Hz	% Deviation
1	58	72.12	19.4
2	120	125.47	4
3	164	168.39	2.3
4	182	200.73	9
5	336	336.72	0.29

Table 11: Comparison of FEM and Experimental results of 95%Al-1%Si-4%Mg

Mode No.	Experimental results in Hz	ANSYS results in Hz	% Deviation
1	75	78.71	3.8
2	135	137.04	1.4
3	173	183.92	5.4
4	212	219.24	3.3
5	355	354.91	0.28

The results obtained by both the methods agree with each other with a deviation of about 0.28% – 19.4%. There is a good correlation between analytical and experimental values of the modal analysis.

VI. CONCLUSION

1) The Experimental and Numerical Modal Analysis of the Al 6061-Si-Mg Metal Matrix alloy successfully investigated by using FFT Analyzer and ANSYS respectively. Even though the number of modes obtained through Experimental Modal Analysis is less than that in Numerical Modal Analysis, the experimental results backup the Numerical results.
2) The results obtained by both the methods agree with each other with a deviation of about 0.28% – 19.4%. There is a good correlation between Numerical and experimental values of the modal analysis.
3) Density of the Al-Si-Mg alloy decreases with increase in Si-Mg content.
4) From the experiment it is found that, damping decreases as natural frequency range increases when Si content is high. Again damping increases when Mg content is high.

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