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Vibration Characterization of SiCp and Fly Ash Dispersion Strengthened Aluminium 5083 Composites

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Abstract

The requirements of current day engineering applications is based on high damping materials which exhibit superior mechanical properties as well as high damping limit for vibrations. In structures made of metals and composites, it is difficult to achieve high damping limit and great mechanical properties at the same time. This is majorly due to the infinitesimal systems that result in "microscopic mechanisms and parameters affecting the mechanical strength". However, to accomplish a metal matrix composite system with unique properties of better mechanical properties as well as vibration characteristics; essential techniques involving the fabrication of hybrid composites with Aluminum 5083 as the base metal and Silicon carbide and fly ash as the reinforcement is considered. The composition of each of the reinforcements dispersed plays a particular part in affecting the damping characteristics or mechanical strength. In the current paper, the results of vibration tests carried out on hybrid Aluminium metal matrix composite plates as well as the results obtained from computational analysis using ANSYS software are interpreted to effectively determine the damping ratio, frequency, magnitude, phase angle and presented to understand the dynamic behavior of composite materials under the effect of different parameters.

Keywords: *Vibration, characteristics, damping ratio, frequency, magnitude, phase angle, aluminium, metal, matrix, composites*

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INTRODUCTION

Composite materials have been used from past many centuries. They can be dated back to early humanity's history right from paleolithic and chalcolithic age to the current day engineering domain. “Composite materials can be portrayed as the mix of at least two materials homogeneous on a macroscopic scale and heterogeneous on a microscopic scale to shape a significant material with distinct properties”. The advantage of composites is that the general properties are superior to those of the properties of individual constituents. “The properties that can be upgraded in the midst of the hybridization of a composite material by and large include strength; hardness; corrosion protection; surface characteristics; weight, fatigue life”. In late decades, as “a result of the high strength to-weight and toughness to-weight proportions, particulates-reinforced aluminum metal matrix composites have been extensively used for a few applications, namely aircraft structures and high speed turbine blades”. In like way, mechanics of metal matrix composites have been genuinely focused on and handbooks controlling the framework and testing of composite materials have been developed.

The utilization of composite materials is consistently expanding in the domain of smart structures for its considerable strength to weight proportions. However vibration damping capacities is a noteworthy obstacle for its utilization in shrewd structures, particularly those inclined to seismic fluctuation. The composite plates are most recent expansion to the basic materials that can be utilized for spans of overhead structures, sky strolls and alternative houses and shops that are discovering its way in savvy urban areas over the globe. Composite plates if fused with reasonable fortifications have the ability to damp the vibrations and turn into a suitable material to meet the infrastructural needs of keen urban areas.

The dynamic conduct of thin isotropic rectangular plates has evolved into a broad thought as a result of its wide spectrum of applications. Thin plate structures have a considerable measure of applications, stretching out from those of automobile components up to space development. The enthusiasm for this kind of structure has immediately extended due to present day stringency, especially in aircraft structures in which light weight is mandatory. Nevertheless, this sort of structure can incite unwanted instances of high vibration. After some time, vibration effects can have whole deal and furthermore transient failure for the structure. Appropriately, the acknowledgment and restriction of damage to thin plate structures at the transient period of change can streamline metal matrix composite structures.

The present work is focused on the experimentations for the vibration characteristics of a metal matrix composite plate, with objectives encompassed with two subsections. Specifically, the metal matrix composite plate that vibrates with twisting and torsion is inspected for its utilization in structures subjected to seismic variability and vibrational dynamics.

LITERATURE REVIEW

Complete information on vibration investigation of plates has been given in research accomplished by A. Pagani *et al.* [1] in which strategies was presented for effective utilization of FFT techniques as a part of different subordinate frameworks. Plate hypothesis is broadly concerned with design issues including vibration in composite structures. Extensive work has been carried out by Adnan Naji Jameel, R. M. *et al*. [2] and there is vast literature available in the domain of the vibration investigations of split plates. In view of the findings interpreted in their paper, vibration studies of a metal matrix composite plate is considered to be a major area of concern, it is seen that the vast majority of the papers have interpreted the vibrations in plates with cracks. These cracks have a tendency to be situated along the edge of the plate, or have been centrally located. Just a couple of papers have explored the vibration examination of a plate with a crack which isn't evenly or vertically adjusted along one side of the plate, giving ample opportunity for subsequent research in the domain.

B. Sidda Reddy *et al.* [3] determined a logical answer for "infinite plate with a crack subjected to a discretionary shear force at the crack surfaces, and extended the finite element alternating technique to the investigation of a thin cracked plate in bending with single or multiple mixed mode cracks". Boscolo M. [4] tentatively examined the impact of the lengths, positions, and inclination angles of the cracks and slits on the "natural frequencies and relating mode shapes of clamped rectangular plates with straight limited openings, utilizing free vibration examination by applying the continuous strategy of time averaged holographic interferometry".

D. Ngo-Cong [5] connected the Ritz technique to examine the impacts of area, length, and introduction of side cracks with an extraordinary relocation work for the free vibration examination of rectangular plates with side splits. Furthermore, Dinghe Li [6] guaranteed the primary distributed vibration information for cracks situated in different precise positions by applying the Ritz technique to investigate the free vibration of a "simply supported and completely free square plate" with an interior through split having a discretionary area. Research works carried out by Dozio, L [7] and Dutta K. K., [8] proposed another arrangement of acceptable capacities for the Ritz strategy which contained certain extraordinary highlights, ready to portray appropriately the singularities of moments and shear forces at the crack tips, and which can meet the discontinuities of the avoidance and slant angle over the split. Investigations were completed for edges with crack orientation changing from 0° to 45°, in steps of 15°, and they found that for simply supported square plates, the initial four frequencies diminished when the crack initiation introduced at the edge expanded to cause the fracture. In any case, on account of completely free square plates, the pattern was unique, and an expansion in the crack introduced at the edge caused a decline in the first and third frequencies, yet an increment in the second, fourth and fifth frequencies. It is important still to build up a profound comprehension of the induction of the model of a split plate, particularly for the nonlinear case. Much research work has been embraced on the straight model, and there are limited nonlinear models accessible for vibration issues in cracked plates. A nonlinear induction of the differential condition in light of traditional plate hypothesis for displaying a break in a plate for a nonlinear model was started by F. Moleiro [9]. The thought behind this idea was to decrease the issue of a three-dimensional surface split to a semi two-dimensional issue. The sort of crack considered by these investigators was a section through split situated at the middle and parallel to the other side of the plate. Huu-Tai Thai [10] rearranged this line-spring model for surface defects in a plate keeping in mind the end goal to foresee the crack initiation parameters, for example, the J-indispensable model or split opening models at the beginning of a surface split. In his improvement the split front was supplanted with a crack of steady profundity which decreased the coupled essential conditions to a couple of straight logarithmic conditions, which was more advantageous to execute computationally. At that point the premise of this disentangled line-spring model was utilized by J.L. Mantari [11] to propose a diagnostic model for a calculated surface split under biaxial forces for exploring the impact of the load proportion and the crack introduction on the "estimations of stress concentration factors for fracture in the plate due to vibrations". J.N.Wei *et al.* [12] have done extensive work on the damping behaviour of aluminium composite plates reinforced with macroscopic graphite particulates. The characterization of vibration behaviour was carried out using a multifunction internal friction apparatus (MFIFA). "The internal friction (IF), as well as the relative dynamic modulus, was measured at frequencies of 0.5, 1.0 and 3.0 Hz over the temperature range of 25°C to 400°C". From the critical analysis of the results, it is evident that the damping capacity of the materials increases with the increase in the volume fraction of graphite particulate reinforcements". However, there is only incipient information information available on vibration characterization of aluminium hybrid metal matrix composites and thus there exists a wide scope for effectively carrying out research and interpreting the findings.

MATERIALS AND PROCESSES

The materials and processes is discussed as under:

Material Selection

"Aluminium Alloy 5083" is a high performance alloy with magnesium as the major alloying element and traces of manganese and chromium. It is very impervious to corrosion to seawater and chemicals. Aluminium alloy 5083 holds extraordinary quality subsequent to welding. It has the most elevated strength out of all the non-heat treatable alloys yet it isn't prescribed for use in temperatures above 65°C. Silicon carbide reinforcement which is known for its supreme refractory characteristics, hardness and wear resistance is used as the reinforcement along with "C – type fly ash, designated as ASTM C 618 that originates from subbituminous and lignite coals. Its composition consists mainly of calcium, alumina, and silica".

Composition

The composition for the Aluminium 5083 metal matrix composites is fixed after thorough evaluation of the existing literature and suitable rationale with a prerequisite that the Weight percentage of the reinforcements should not exceed 15% of the weight. The designation of the specimen and its composition is as given in the Table 1.

Table 1: *Composition of Aluminium 5083 Specimens.*

Sl. No.	Designation	Wt.% of SiCp	Wt.% of Flyash
1.	A0	0	0
2.	A1	3	5
3.	A2	5	5
4.	A3	7	5
5.	A4	9	5

Processing of Aluminium Composites

Traditional stir casting technique has been used for synthesis of "Silicon carbide and fly ash particulates dispersion strengthened hybrid metal matrix composites". The main problem of this strategy is to get satisfactory wetting of strengthened particles by liquid metal and to get a homogeneous disseminating. In the present investigation, "hybrid aluminum metal matrix composites" were synthesized by preheating the reinforcements and dispersing them in the matrix phase accompanied by stirring action at relatively high rpm. The dispersion of the reinforcements is assessed by micro-structural examination.

Stir casting is an extraordinary handling procedure to process metal matrix composites. In this procedure, blending activity of the stirrer makes the reinforcements be consistently scattered in matrix material and causes exceptional plastic distortion that yields a dynamic re-crystallization. Stir Casting ensures better and homogenized grain structure, and in addition changes the hardness, corrosion characteristics, and wear protection of the material.

Composites with predefined composition are melted in electrical resistance furnace fitted with vortex generator. The graphite crucible is stacked with Al 5083 alloy and the temperature is kept up at 850°C which is 200°C more than the melting temperature of Al 5083 alloy. After fluid state of Al 5083 alloy is attained, degasification is carried out by dispersing hexachloroethane tablets into the liquid metal. The slag framed on the surface of fluid metal is scooped out. The fluid metal is reinforced with preheated mixture of Silicon carbide and fly ash. The uniform mixing of weighed measure of the preheated reinforcement particles in the fluid metal is accomplished by enduring mixing of the blend using a vortex generator i.e., the total aggregate of reinforcements required is processed and brought into dis-solvable condition in three stages instead of dispersing by a single go to ensure "better wettability of particles with the fluid metal". At each stage, i.e. earlier and after introduction of reinforcement particles, mechanical stirring of the fluid metal is carried out for a period of 20 minutes by using zirconium coated steel impeller. The stirrer is preheated before immersing into the liquid metal, generally to the height of 2/3rd of the fluid metal from the base and is kept operational at a speed of 400 rpm. The molten metal dispersion strengthened with the reinforcements is poured down through the bottom pouring attachment to the die - setup. This die - setup is preheated to around 400°C to limit the flaws in casting. The plates thus obtained are machined to a length of 300 mm with thickness of 5 mm.

EXPERIMENTAL PROCEDURE

The experimental setup comprises of accelerometer probes mounted on the plate, an amplifier to amplify the recorded frequency of vibration, modal 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 1.

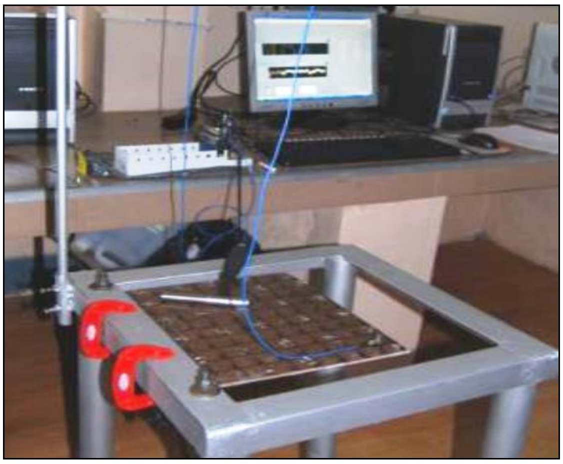

Fig. 1: *Vibration Setup.*

The procedure of vibration characterization of aluminium plates involves the "use of accelerometer mounted on the aluminium plates by means of bees wax, that eventually captures the vibration and transduces the vibration to useful signals which are subsequently input to the second channel of the analyzer, where it is digitally processed for obtaining the frequency spectrum that is transformed using fast fourier analysis. The FFT analysis of the frequency data of the excitations will lead to better understanding of the vibration and its damping coefficient en-route the Lab VIEW software".

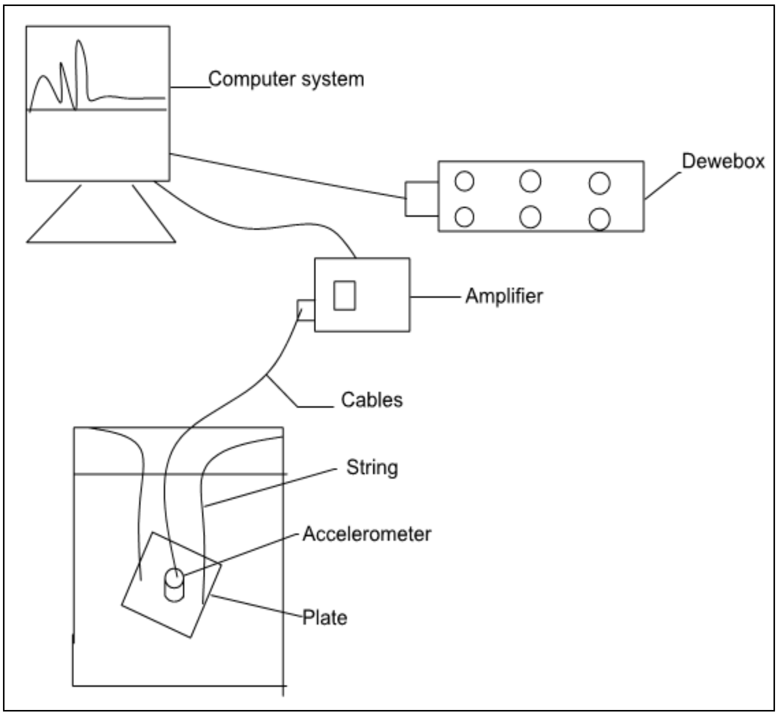

Fig. 2: *Schematic of Vibration Test Setup.*

The vibration test is carried out in order to determine “the natural frequency, damping ratio, magnitude, phase angle of the composite plates fabricated for different compositions”.

The governing equation of the system [13], considered for evaluating the vibration characteristics is as follows:

$$m\ddot{x} + c_v\dot{x} + kx = 0 \qquad \text{Eq 1}$$

With the initial conditions as

$$\begin{cases} x(t=0) = x_0 \\ \dot{x}(t=0) = v_0 \end{cases} \qquad \text{Eq 2}$$

“This equation of motion is a second order, homogeneous, ordinary differential equation (ODE). If all parameters (mass, spring stiffness and viscous damping) are constants, the ODE becomes a linear ODE with constant coefficients and can be solved by the characteristic equation method”.

The characteristic equation formulated for the vibration in current condition of cantilever support is,

$$ms^2 + c_v s + k = 0 \qquad \text{Eq 3}$$

The solution of given equation determines the two independent roots for the damped vibration and they characteristically fall into any one of the following three cases.

(i) “If $c_v^2 - 4mk < 0$, the system is termed under damped. The roots of the characteristic equation are complex conjugates, corresponding to oscillatory motion with an exponential decay in amplitude”.

(ii) “If $c_v^2 - 4mk = 0$, the system is termed critically-damped. The roots of the characteristic equation are repeated, corresponding to simple decaying motion with at most one overshoot of the system's resting position”.

(iii) “If $c_v^2 - 4mk > 0$, the system is termed over damped. The roots of the characteristic equation are purely real and distinct, corresponding to simple exponentially decaying motion”.

To simplify the solutions coming up, we define the critical damping c_c, the damping ratio ζ, and the damped vibration frequency ω_d as,

$$c_c = 2m\sqrt{\frac{k}{m}} = 2m\omega_n \qquad \text{Eq 4}$$

$$\zeta = \frac{c_v}{c_c} \qquad \text{Eq 5}$$

$$\omega_d = \sqrt{1-\zeta^2}\,\omega_n \qquad \text{Eq 6}$$

where the natural frequency of the system ω_n is given by,

$$\omega_n = \sqrt{\frac{k}{m}} \qquad \text{Eq 7}$$

"Note that when $\omega_d = \omega_n$, the damping of the system is zero (i.e. undamped). The time solutions for the free SDOF system are based on the extent of damping. This is further used in our work for calculation of damping ratio and frequency".

COMPUTATIONAL ANALYSIS

Modal analysis is carried out using ANSYS software to effectively determine the natural frequencies and mode shapes of the composite plate, since "the natural frequencies and mode shape are critical parameters in design of a structure for dynamic loading conditions".

Modal analysis carried out in the ANSYS software is a linear type of analysis, which ignores all the nonlinearities in the composite plates (Figures 2–5).

The basic steps involved in the modal analysis of the composite plates include modeling the composite plates, applying loads and boundary conditions, meshing and subsequent pre – processing procedures before processing and obtaining the modal data and reviewing the results.

RESULTS AND DISCUSSION

The "fast fourier transform (FFT) vibration (Figures 6–9)" tests carried out for each of the composite plates yields with the results of frequency response function (FRF) modal data that are tabulated and validated with the results of computational analysis carried out in ANSYS software (Table 2).

FRF and Computational Modal Data for A0 Specimen

The modal frequency and damping ratio as determined by FRF of the Al 5083 Plate (A0 specimen) varies from 40.382 Hz and 0.793E-3 respectively for mode 1 to 314.178 Hz and 0.914E-3 respectively for mode 4 and is in close agreement with the computational modal data.

Table 2: *FRF and ANSYS Modal Data for A0 Specimen.*

Mode No	Modal Frequency (Hz)	Damping Ratio (E-3)	Magnitude	Phase Angle	Modal Frequency (Hz) From ANSYS	Error (%)
1	40.382	0.793	0.181	134.614	40.279	2.551E-5
2	111.156	1.291	0.023	5.832	110.451	6.342E-5
3	292.349	1.963	1.122	162.616	293.153	2.750E-5
4	314.178	0.914	0.862	125.563	314.892	2.273E-5

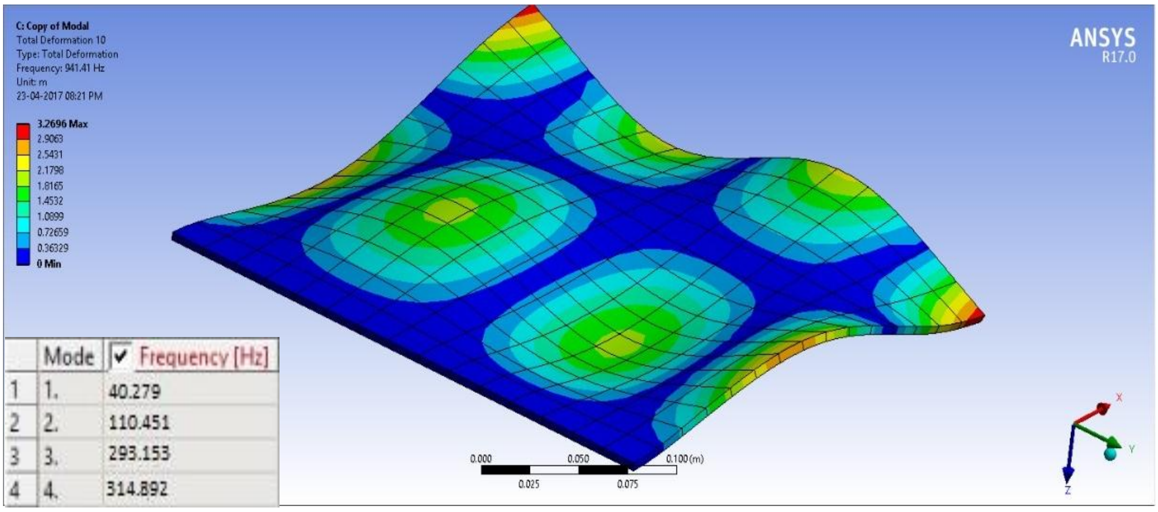

Fig. 3: *Modal Contour Plot for A0 Specimen in ANSYS.*

FRF and Computational Modal Data for A1 Specimen

The modal frequency and damping ratio as determined by FRF of the "Al 5083/3 Wt.% SiCp/5 Wt.% fly ash" plate (A1 specimen) varies from 42.934 Hz and 0.731E-3 respectively for Mode 1 to 406.621 Hz and 2.563E-3 respectively for mode 4 and is in close agreement with the computational modal data (Table 3).

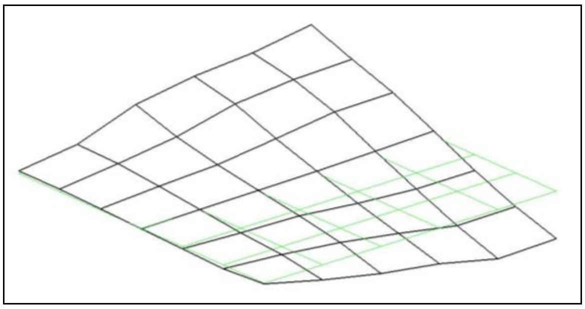

Fig. 4: *Modal Plot from FFT Analysis for A0 Specimen in Lab VIEW.*

Table 3: *FRF and ANSYS Modal Data for A1 Specimen.*

Mode No	Modal Frequency (Hz)	Damping Ratio (E-3)	Magnitude	Phase Angle	Modal Frequency (Hz) From ANSYS	Error (%)
1	42.934	0.731	0.141	159.143	42.176	17.611E-5
2	111.048	1.440	0.017	15.533	110.185	7.771E-5
3	327.214	1.385	0.404	95.148	329.740	7.719E-5
4	406.621	2.563	0.034	108.122	406.981	88.534E-5

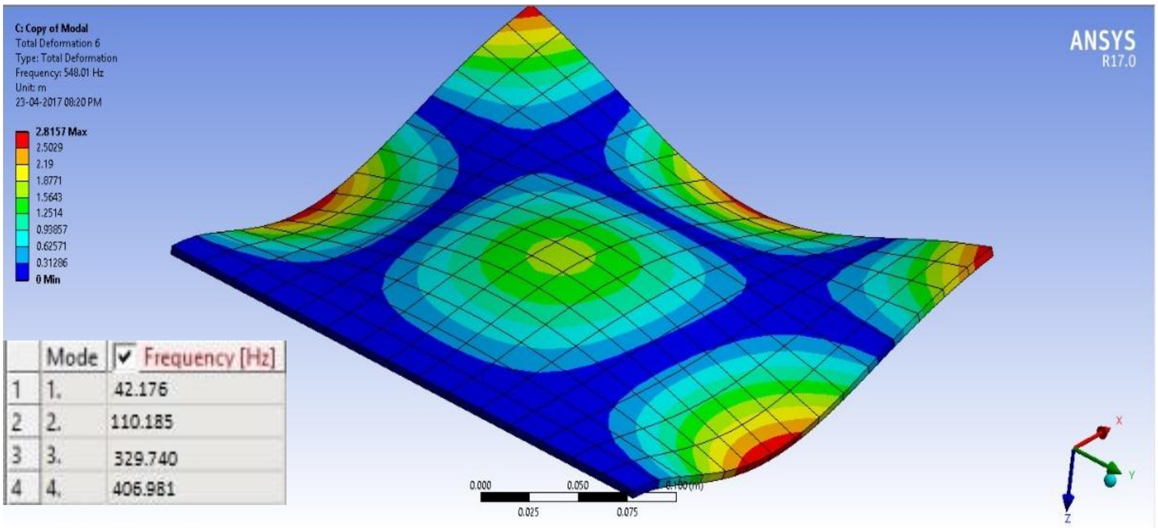

Fig. 5: *Modal Contour Plot for A1 Specimen in ANSYS.*

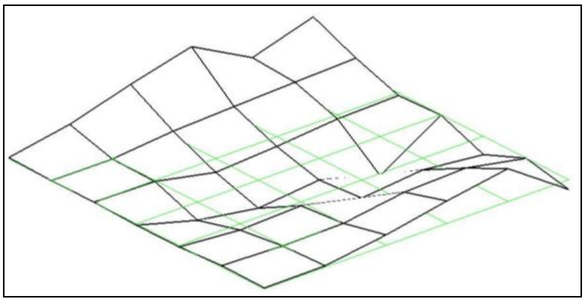

Fig. 6: *Modal Plot from FFT Analysis for A1 Specimen in Lab VIEW.*

FRF and Computational Modal Data for A2 Specimen

The modal frequency and damping ratio as determined by FRF of the "Al 5083/5 Wt.% SiCp/5 Wt.% Fly ash" Plate (A2 specimen) varies from 39.988 Hz and 1.294E-3 respectively for mode 1 to 345.933 Hz and 1.704 E-3 respectively for mode 4 and is in close agreement with the computational modal data (Table 4).

FRF and Computational Modal Data for A3 Specimen

The modal frequency and damping ratio as determined by FRF of the "Al 5083/7 Wt.% SiCp/5 Wt.% fly ash" plate (A3 Specimen) varies from 35.144 Hz and 0.775E-3 respectively for Mode 1 to 321.471 Hz and 2.150 E-3 respectively for mode 4 and is in close agreement with the computational modal data (Table 5).

Table 4: *FRF and ANSYS Modal Data for A2 Specimen*.

Mode No	Modal Frequency (Hz)	Damping Ratio (E-3)	Magnitude	Phase Angle	Modal Frequency (Hz) From ANSYS	Error (%)
1	39.988	1.294	0.152	162.956	39.928	1.521E-5
2	111.985	1.824	0.012	44.638	110.176	16.151E-5
3	255.924	1.548	0.236	48.453	256.189	1.035E-5
4	345.933	1.704	0.030	6.664	347.162	3.554E-5

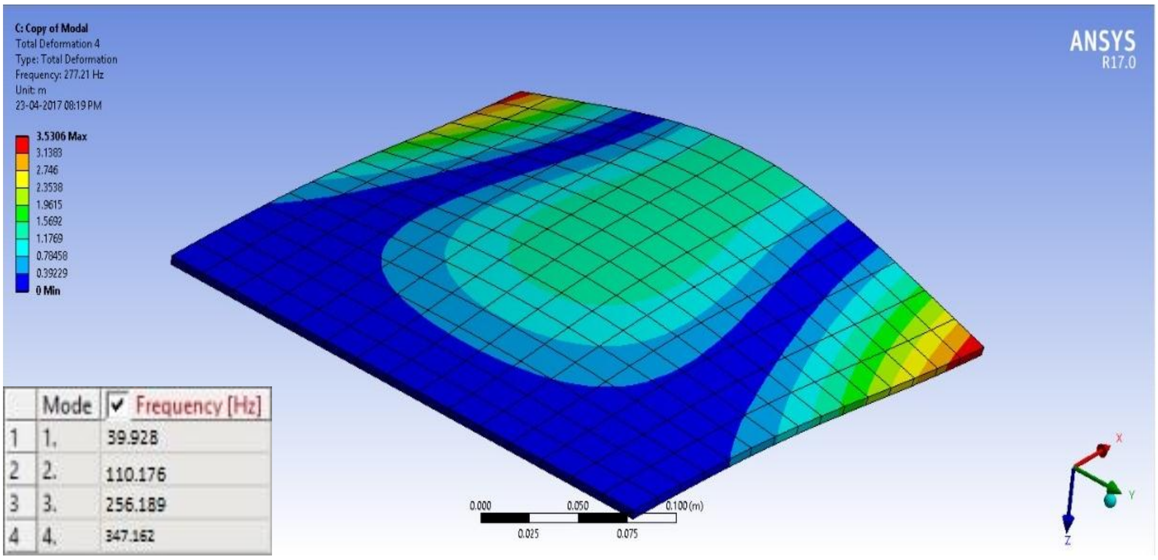

Fig. 7: *Modal Contour Plot for A2 Specimen in ANSYS.*

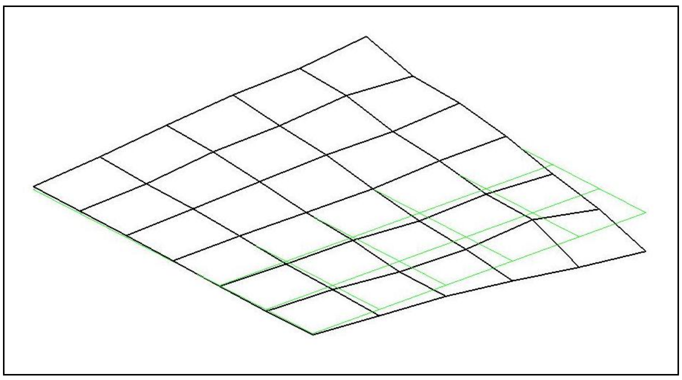

Fig. 8: *Modal Plot from FFT Analysis for A2 Specimen in Lab VIEW.*

Table 5: *FRF and ANSYS Modal Data for A3 Specimen.*

Mode No	Modal Frequency (Hz)	Damping Ratio (E-3)	Magnitude	Phase Angle	Modal Frequency (Hz) From ANSYS	Error (%)
1	35.144	0.775	0.185	159.098	35.217	2.077E-5
2	150.472	1.791	0.054	54.108	151.698	8.147E-5
3	247.684	3.271	1.048	106.800	248.168	1.954E-5
4	321.471	2.150	0.705	113.896	321.965	1.537E-5

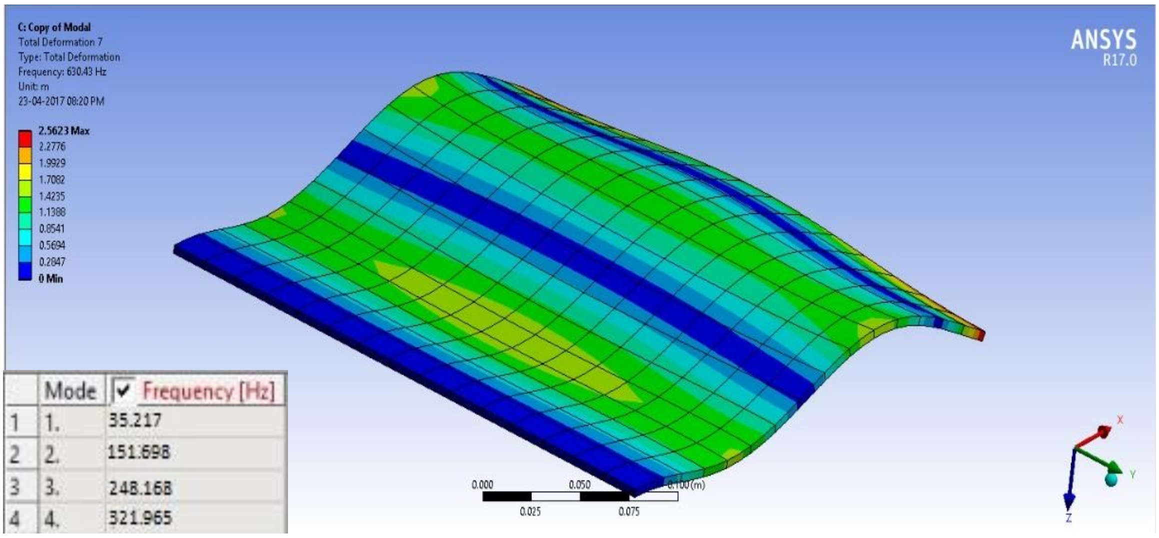

Fig. 9: *Modal Contour Plot for A3 Specimen in ANSYS.*

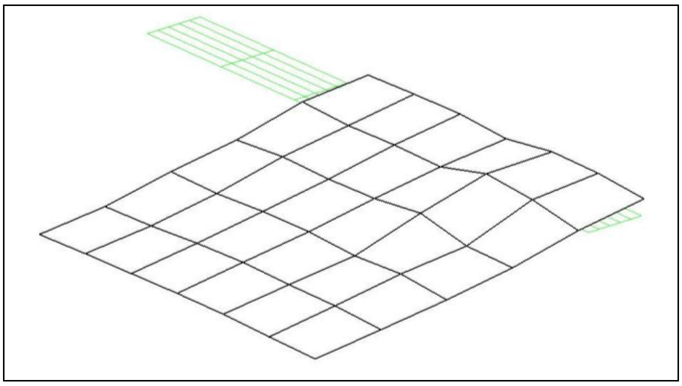

Fig. 10: *Modal Plot from FFT Analysis for A3 Specimen in Lab.*

Statistical Modeling

Table 2 shows the obtained results using ANOVA. The coefficient of determination is the ratio of the sum of squares of the predicted responses (corrected for the mean) to the sum of squares of the observed responses (Kansal *et al.* 2005). The value of R2 and adjusted R2 is over 99%. This means that mathematical model provides an excellent explanation of the relationship between the independent variables and the response (EWR). The obtained values of standard deviation and R2- predicted evidence that the proposed model is adequate to predict the response. The associated p-value for the model is lower than 0.05 (i.e. $\alpha = 0.05$, or 95% confidence) indicates that the model is considered to be statistically significant (Figures 10–12).

FRF and Computational Modal Data for A4 Specimen

The modal frequency and damping ratio as determined by FRF of the "Al 5083/9 Wt.% SiCp/5 Wt.% Fly ash" Plate (A4 specimen) varies from 38.553 Hz and 1.349E-3 respectively for mode 1 to 341.525 Hz and 1.866 E-3 respectively for mode 4 and is in close agreement with the computational modal data (Table 6).

Table 6: *FRF and ANSYS Modal Data for A4 Specimen.*

Mode No	Modal Frequency (Hz)	Damping Ratio (E-3)	Magnitude	Phase Angle	Modal Frequency (Hz) From ANSYS	Error (%)
1	38.553	1.349	0.1187	147.33763	38.617	1.660E-5
2	124.666	1.329	0.0503	82.6755	124.876	1.684E-5
3	256.228	3.387	3.8068	151.7778	257.980	6.837E-5
4	341.525	1.866	0.2772	95.8499	342.782	3.680E-5

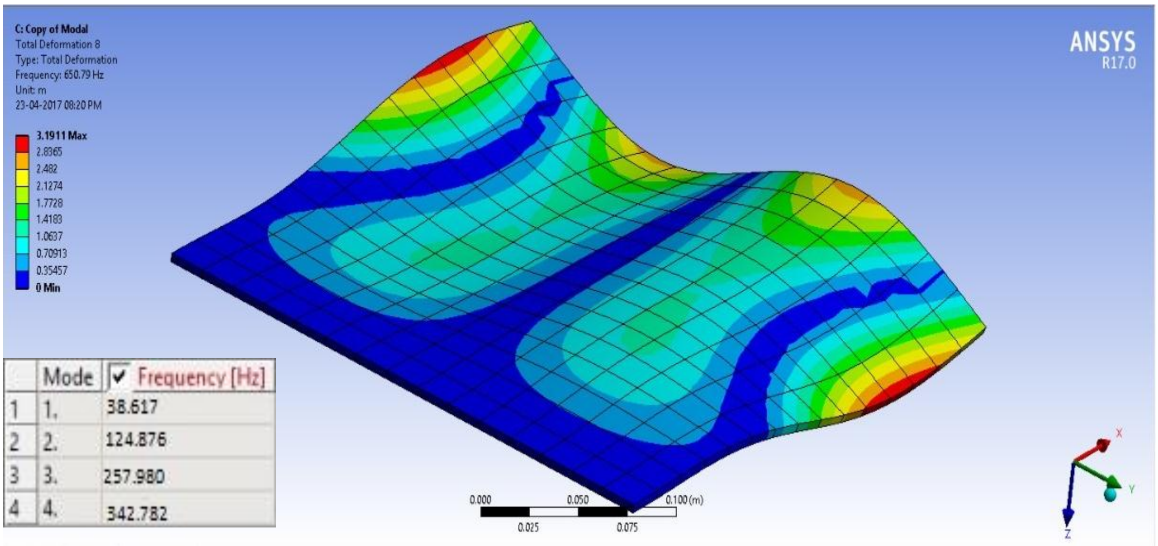

Fig. 11: *Modal Contour Plot for A4 Specimen in ANSYS.*

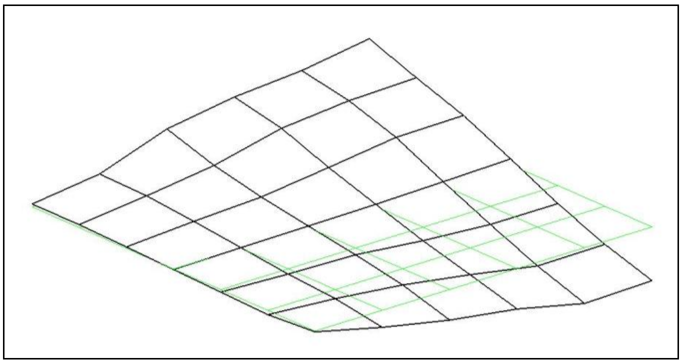

Fig. 12: *Modal Plot from FFT Analysis for A4 Specimen in Lab.*

CONCLUSION

The composite plates synthesized and tested for vibration characteristics by Cantilever limit conditions utilizing data acquisition system have given results that are interpreted and validated with computational results. Frequency response functions are acquired by FFT. Quantitative outcomes are displayed to demonstrate the impacts of various parameters like weight percentage of SiC Particulates and fly ash particulates. The test recurrence information is in reasonable understanding and in good agreement with the computational data. The outcomes give a review of vulnerability in dynamic properties. For Cantilever condition, it is discovered that the modal frequency of plate increases initially with the addition of reinforcements of Silicon carbide of 3 Wt.% and fly ash of 5 Wt.%, however with the further addition of silicon carbide, the modal frequency of the composite plate tends to decrease.

The appropriateness of the present experimentation is depicted with the expectation of complimentary vibrations of various auxiliary setups for straight and additionally nonlinear Eigen analysis. It is discovered that the damping characteristics of the plates increases with the addition of silicon carbide reinforcements to the Aluminium 5083 Matrix material.

Results acquired from FRF data of FFT analysis by data acquisition system and interfaced with computer using Lab VIEW software is in agreement with results of computational analysis carried out using ANSYS software. The results are steady with both the FRF analytics technique and limited contrast approaches, yet nonlinear eigen analysis of limited distinction strategy are disordered and non-predictable. Henceforth, utilizing linear modal analysis techniques in computational approach measurements as for various material properties has resulted in approximate values in close relation with the experimental values.

FRF modal information for various plates likewise give an unmistakable prediction of the frequency, damping ratio, magnitude and phase angle for different specimens with changing composition of silicon carbide particles and fly ash particles. The modal frequency has a tendency to change between 35–410 Hz while the FRF magnitude shifts from 0.012–1.122 for various specimens and different mode shapes, damping ratio fluctuates in the range of 0.731–3.387 and phase angle differs in the range of 4°–175°.

From basic assessment of the information acquired, clear inferences can be drawn in light of the outcomes that the hybrid metal matrix composites with weight percentage of silicon carbide above 7 and weight percentage of flyash at 5 can basically diminish the vibrations for its application in structures that are inclined to seismic vibrations.

Further to this, the critical analysis of the information uncovers the evidence that the basic damping coefficient for silicon carbide strengthened composite plates are two folds higher than that of general solid materials utilized for dynamic structures. Thus, the metal matrix composites can be effectively utilized for dynamic applications.

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