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Statistical Analysis of Free Vibration Response of Aluminium Matrix Composite Plate manufactured by Stir Casting Process by using Taguchi Method

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Abstract— **Composite material is a combination of two or more materials having compositional variations and depicting properties distinctively different from those of the individual materials of the composite. Aluminum hybrid reinforcement technology is a response to the dynamic ever increasing service requirements of such industries as transportation, aerospace, automobile, marine, etc. Manufacturing of aluminum alloy based casting composite by stir casting is one of the most economical methods of processing MMC. Composite material is manufactured by reinforcing A356 alloy with Al_2O_3 and fly ash particles. Analysis is done to study the vibration response characteristics i.e. natural frequency and amplitude of composite plates to find effect of various parameters on these response characteristics. By using MINITAB software, results are computed and statistical data is presented to determine the influence of input parameters on vibration response**

Index Terms—**Metal matrix composite, Stir casting, Taguchi analysis, DOE, Amplitude, Natural frequency.**

I. Introduction

Since the early 1960, there is demand for new and improved engineering materials with advancement of modern technology interest in the areas of aerospace; auto-motive industries had forced a rapid development of metal matrix composites. Over the past two decades, metal matrix composites (MMCs) have been transformed from a topic of scientific and intellectual interest to a material of broad technological and commercial significance. Therefore metal matrix composites (MMCs) are the forerunners amongst different classes of composites. High demands on material for better overall performance has led to extensive research and development efforts in the composites fields. MMCs offer a unique balance of physical and mechanical properties. Among the composites field, the Aluminium based metal matrix composite materials are widely used. Aluminium based MMCs have received increasing attention in recent decades as engineering materials with most of them possessing the advantages of high strength, hardness and wear resistance[1]. The stir casting method is widely used among the different processing techniques available. Stir casting usually involves prolonged liquid-reinforcement contact. To meet emerging need, innovations in materials processing enabled achieving an enhancement in stiffness, realization of high strength to weight ratio, an improvement in wear resistance, maintaining strength at elevated temperatures. Most of the research work has been dealing with Aluminium matrix and various reinforcements requiring the light weight in combination of high strength and high stiffness. This is because Aluminium is lighter in weight which is first requirement in most of the industries [2].

Now days in modern structures, structural components are many times modeled as plates. Such models are widely used in the field of civil, mechanical, aerospace, marine and automobile engineering. Plates and their differential characteristics enable engineers to design better and lighter structures. Determination of dynamic response of these structures is needed when these are subjected to external complicated dynamic loads such as earthquake, wind, impact and wave forces. Determination of natural frequencies is the major step of dynamic analysis [3]. In this present investigation an attempt is to find the influence of different parameters such as aspect ratio, thickness and Reinforcement percentage of composite plate on natural frequency and to establish correlation between aspect ratio, thickness and reinforcement percentage and combined effect of these parameters on natural frequency of the Aluminium composite plate using Taguchi and analysis of variance techniques.

II. Experimental Methodology

Manufacturing of composite by stir casting process

In a stir casting process, the reinforcing phases (usually in powder form) are distributed into molten Aluminum by mechanical stirring. Mechanical stirring in the furnace is a key element of this process. The resultant molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting [4,5].

An electric induction furnace was used for the stir casting process. After cleaning A356 ingots, they were cut to proper

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sizes, weighed in requisite quantities and were charged into a cast iron crucible placed in the furnace, at 400°C. The alloy started melting with elevated temperature. One percent by weight pure Magnesium is added into the charge at 600°C after confirming the semisolid state to improve wettability between matrix and reinforcement. Then material was hold for about an hour until its temperature gain reached 800°C. The scum powder was added into the melt which resulted into accumulation of impurities at the surface of liquid melt. The scum was removed. Degasification tables of Hexachloroethane were added for removal of gases from the molten alloy.

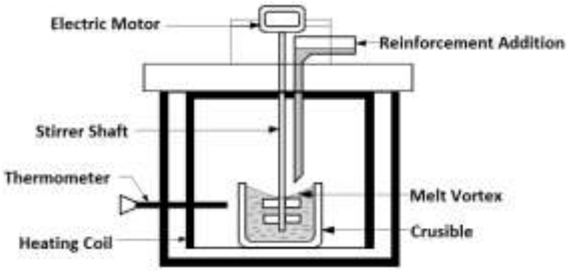

Fig.1 Stir Casting Setup (Schematic)

The amount of scum powder and degasification agent used was 0.05 percent by weight of A356. Fly ash and Alumina were weighed separately in 2, 4 and 6 percent each. The combination of reinforcement was preheated to 300°C - 400°C for 1 hour before pouring in to the melt of Aluminium Alloy. This was done to facilitate removal of any residual moisture as well as to improve wettability and to avoid chemical reaction.

Fig.2 Mechanical stirring

The molten metal was stirred with a stirrer at speed of 300 rpm for 7-10 minutes. A vortex was created in the melt because of stirring where preheated fly ash and Alumina were poured centrally into the vortex at 0.5 gram per second feed rate. The stirrer was moved down slowly, from top to bottom by maintaining a sufficient clearance from the bottom. The stirrer was then pushed back slowly to its initial position. The pouring temperature of the liquid was kept around 800°C. Liquid Composite was poured in the MS permanent mould with uniform pouring rate, keeping pouring distance constant, to maintain the fluidity of melt. Mould also was preheated at 300°C – 400°C for 1 hour. Casting was made in permanent rectangular metal mould [6,7].

Experimental modal analysis

Effect of aspect ratio, thickness and reinforcement on vibration characteristics of plate such as natural frequency under CFFF and CFCF condition is determined using experimental method [9,10].

Fig.3 Plate fixed with CFFF condition

Fig.4 Plate fixed with CFFF condition

Free vibration analysis is carried out by using impact hammer and FFT analyzer. Natural frequency and amplitudes are recorded for each case. Effect of various parameters on response is studied by using Taguchi method.

Fig.5 Experimental modal test

III. Taguchi Method

Taguchi DOE process is made up of three main phases: the planning phase, the conducting phase and the analysis phase. A major step in the DOE process is the determination of the combination of factors and levels which will provide the desired information. The Taguchi technique is a powerful design experiment tool for acquiring the data in a controlled way and to analyze the influence of process variable over some specific variable which is unknown function of these process variables and for the design of high quality systems. Taguchi creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment. The experimental results are analyzed using analysis of means and variance to study the influence of parameters [8]. The major aim of the present investigation is to analyze the influence of parameters like aspect ratio, thickness, reinforcement weight % on natural frequency of

Aluminium A356/alumina/fly ash hybrid metal matrix composites using Taguchi technique.

A. Planning of Experiments

In present work, three-level design was used with three factors. Three input factors were namely weight percentage of reinforcement, aspect ratio and thickness of the plates. The response variable was natural frequency of the plate. The response was measured in the form of natural frequency for first three modes.

The experiment specifies three principle parameters including weight percentage of reinforcement, aspect ratio and thickness as the process parameters.

Table 1 Parameters and levels in Taguchi Design

Design Parameter	Level 1	Level 2	Level 3
Aspect Ratio	1	1.5	2
Thickness (mm)	3	6	9
Reinforcement (%)	4	8	12

B. Conducting the Experiment

The experiments were carried out to analyze the influence of above parameter on natural frequency of composite plates. If the full factorial design were used, it would have $3^3 = 27$ runs. The L9 $(3)^3$ array requires only 9 runs, a fraction of the full factorial design. The standard Taguchi experimental plan with notation L9 $(3)^3$ was chosen based upon the degree of freedom. The degrees of freedom for the orthogonal array should be greater than or at least equal to those of the process parameters.

Table 2 L9 array for Taguchi analysis

Experiment	Aspect Ratio	Thickness (mm)	Reinforcement (%)
1	1	3	4
2	1	6	8
3	1	9	12
4	1.5	3	8
5	1.5	6	12
6	1.5	9	4
7	2	3	12
8	2	6	4
9	2	9	8

The experiments were conducted based on the run order generated by Taguchi model and the results were obtained.

C. Taguchi analysis

This analysis includes the ranks based on the delta statistics, which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. The analyses of the experimental data were carried out using MINITAB 16 software, which is specially used for DOE applications. The experimental results were transformed into signal-to-noise (S/N) ratios. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. The S/N ratio for amplitude using 'smaller the better' characteristic and for natural frequency 'larger the better' is calculated and plotted.

By varying design parameters one at a time, the study of 3 design parameters at 3 levels would require 27 (3^3) possible experimental evaluations. The time and cost to conduct such a detailed study during advanced design is prohibitive. Naturally, we would like to reduce the number of experimental evaluations to a practical point, yet reach a near optimal solution. The problem is to choose an appropriate parameter configuration. Taguchi's approach to parameter design provides an answer.

IV. Result and Discussion

The experiments were conducted as per orthogonal array and the natural frequency results obtained for various combinations of parameters are obtained. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 16.

Case (I) Smaller is better

The effect of input parameters such as aspect ratio, thickness and increase in reinforcement percentage is analyzed for amplitude. The following table gives the MINITAB results predicted for smaller is better condition.

Taguchi analysis: Max amplitude versus aspect ratio, thickness, and reinforcement for smaller is better.

Table 3 Response table for SN ratio (CFFF)

Level	Aspect Ratio	Thickness	Reinforcement
1	20.65	22.50	22.13
2	20.13	20.43	21.22
3	22.66	20.50	20.09
Delta	2.53	2.07	2.04
Rank	1	2	3

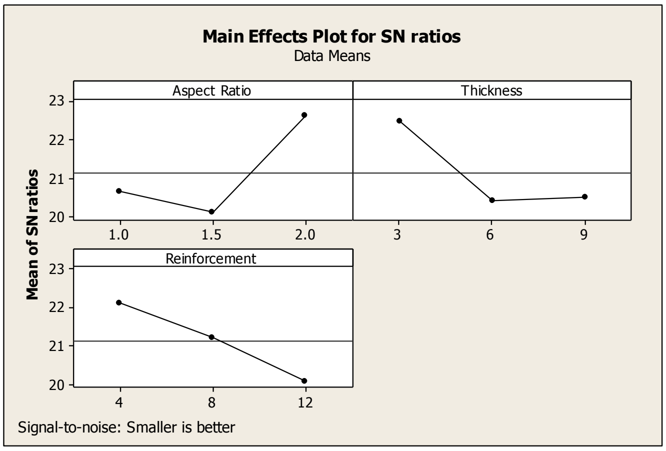

Fig.6 Main effect plot for SN ratios (smaller is better) CFFF

Fig.6 shows S/N ratios for smaller are better condition. In this case for aspect ratio 1.5, thickness 6 and 12% reinforcement the graph shows least value of amplitude. Here rank 1 is assigned to aspect ratio hence it greatly affects the amplitude followed by thickness and reinforcement respectively.

Fig.7 shows S/N ratios for smaller are better condition. In this case for aspect ratio 1, thickness 3 and 8% reinforcement the graph shows least value of amplitude. Here rank 1 is assigned to reinforcement hence it greatly affects the amplitude followed by aspect ratio and thickness.

Table 4 Response table for SN ratio (CFCF)

Level	Aspect Ratio	Thickness	Reinforcement
1	18.01	18.42	19.66
2	19.61	18.84	17.35
3	18.53	19.03	19.69
Delta	1.60	0.61	2.34
Rank	2	3	1

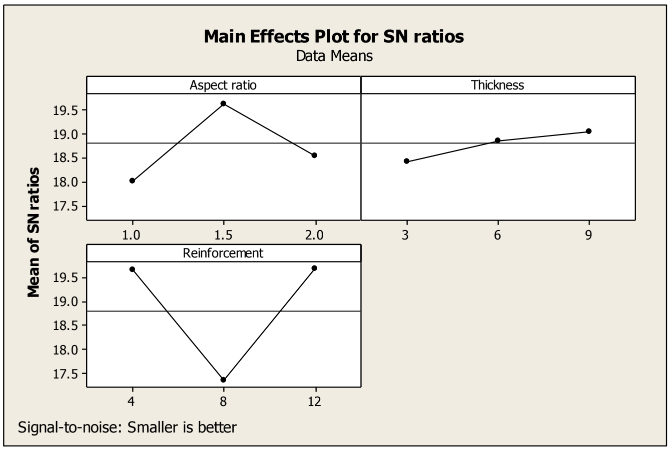

Fig.7 Main effect plot for SN ratios (smaller is better) CFCF

Case (II) Larger is better

Taguchi analysis: Max frequency versus aspect ratio, thickness, reinforcement for larger is better.

To know the maximum natural frequency of various composite plates for aspect ratios 1, 1.5,2 and thickness 3, 6, 9 and hybrid reinforcement percentage 4,8,12. The following table is obtained from MINITAB software.

Table 5 Response table for SN ratio (CFFF)

Level	Aspect Ratio	Thickness	Reinforcement
1	53.54	51.76	55.26
2	55.12	54.65	54.10
3	53.75	56.00	53.05
Delta	1.58	4.24	2.22
Rank	3	1	2

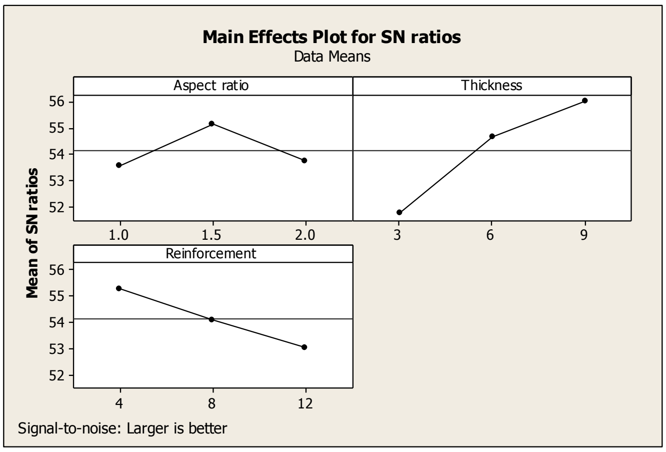

Fig.8 Main effect plot for SN ratios (larger is better) CFFF

For above case effect of all three input parameters is analyzed on maximum natural frequency of composite plate samples. Fig.8 shows the S/N ratios for larger is better condition. In which for aspect ratio 1.5, thickness of 9 mm and for reinforcement of 4% the model shows maximum value of frequency. Here the rank 1 is assigned to thickness hence it greatly affects the natural frequency.

Table 6 Response table for SN ratio (CFCF)

Level	Aspect Ratio	Thickness	Reinforcement
1	63.07	61.99	63.76
2	64.45	64.38	63.94
3	62.78	63.93	62.60
Delta	1.67	2.38	1.34
Rank	2	1	3

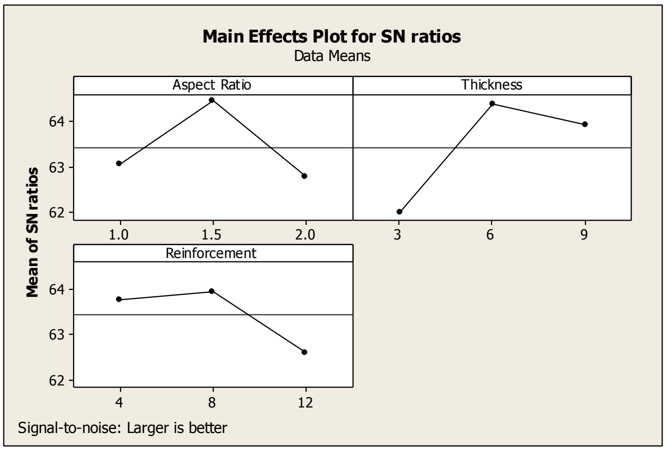

Fig.9 Main effect plot for SN ratios (larger is better) CFCF

For above case effect of all three input parameters is analyzed on maximum natural frequency of composite plate samples. Fig.9 shows the S/N ratios for larger is better condition. In which for aspect ratio 1.5, thickness of 6 mm and for reinforcement of 8% the model shows maximum value of frequency. Here the rank 1 is assigned to thickness hence it greatly affects the natural frequency followed by aspect ratio and reinforcement.

V. Conclusion

1) Aluminum matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of fly ash and Al_2O_3 particles.

2) Stir casting is very efficient, simple and cost effective method of manufacturing of Aluminium matrix composites and also it is most suitable for mass production.

3) Taguchi analysis is successfully done for various levels and parameters.

4) Vibration amplitude was highly influenced by aspect ratio in CFFF condition followed by thickness and reinforcement respectively. Also it was highly influenced by reinforcement in CFCF condition followed by aspect ratio and thickness.

5) Natural frequency of A356/Alumina/Fly ash hybrid reinforced composite plate was highly influenced by thickness in CFFF condition followed by reinforcement and aspect ratio respectively. Also it was highly influenced by thickness in CFCF condition followed by aspect ratio and reinforcement.

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