OPTIMIZATION OF TENSILE AND FLEXURAL MODULUS OF SILICA GEL REINFORCED ALUMINIUM MMC BY USING TAGUCHI METHOD

Anuj Dixit[1], Kaushik Kumar[2]

[1]*Student-Department of Mechanical Engineering, Birla Institute of Technology, Mesra, Ranchi, Jharkhand, India*
[2]*Associate Professor- Department of Mechanical Engineering, Birla Institute of Technology, Mesra, Ranchi, Jharkhand, India*

Abstract

In the last two decades, the requirement of manufacturing industries for light weight machines and machine parts are growing. Aluminium Metal Composites (AMCs) have unique feature high strength to weight ratio. It's hardness and mechanical properties make it versatile in various type of application like in engine assembly, aeronautics and other types of engineering application. In an aviation industry, aluminium composite having advantage of light weight and high mechanical properties like hardness, tensile strength, flexural strength etc, are used for body, propeller and other part of plane. In this present analysis, aluminium composite was fabricated with six different percentage of filler silica gel. The tensile and flexural moduli are calculated at three different speeds to examine the mechanical properties of composite. The results were computed by help of L18 orthogonal array. On the basis of Taguchi's method, the plan of experiment was executed to perform test by taking two design factors, speed and percentage of filler. Using Taguchi optimization method, optimum combination of these two factors was found. Tensile modulus and flexural modulus were analyzed on ANOVA (ANalysis Of VAriance) and generate regression equation. To analyze tensile modulus and flexural modulus 'Larger is Better' was taken. In this analysis, it is observed that percentage of filler content is most dominating factor which affecting tensile modulus and flexural modulus. At last, the experimental results were validated by the confirmation tests.

Keywords— *Aluminium Composite, Silica Gel, Taguchi Method, ANOVA*

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1. INTRODUCTION

The requirements prepared on materials for superior overall performances are so large and various that no one material can suit them. This led to a recovery of the ancient concept of combining different materials in fundamental composite material system that outcome in a performance unachievable by the individual element, and offers vast advantages. Composites are materials in which two phases are jointed, usually with strong interfaces between them.

They generally consist of a continuous part called the matrix and discontinuous part in the form of fibers, whiskers or particles called the reinforcement [1]. The generally used metallic matrices are Al, Mg, Ti, Cu and their alloys. These metals are chosen matrix materials for the fabrication of MMCs. The reinforcements being used are fibers, whiskers and particulates [2]. The advantages of particulate-reinforced composites over others are their formability with cost advantage [3] Further, they are capable with heat and tribologocal properties [4], [5].

Aluminum matrix composites (AMCs) are rising as advance engineering materials due to their strength, ductility and toughness. The aluminum matrix is getting strengthened when it is reinforced with the hard ceramic particles like SiC, Al2O3, and B4C etc. It is also used in high temperature applications such as in automobile engines and in other rotating and reciprocating parts such as piston, drive shafts, brake- rotors and in other structural parts which require light weight and high strength materials [6].

To improve mechanical properties, various type of reinforcement is added with aluminium [7]. The tensile and flexural modulus of aluminium composite was increaed, when ceramic material is used as reinforcement [8]. There are various type of ceramic used to reinforce the aluminium. Among all ceramic, silica gel has relatively high hardness because it is substance of purified quartz crystal. It has approximate same density (2.65 g/cm^3) of aluminium which is helpful for production of uniform Aluminium Metal Matrix Composite (AMMC). The melting point (1600-1730^{0}C) of silica gel is quite high as compared to aluminium.

Our study is based on the optimization of Tensile and flexural strength of silica gel reinforced aluminium composite and define combine factor which give the optimum result. The mechanical properties of silica gel reinforced AMMC depend on two variable factors, which are percentage of reinforcement and machine speed. There are six percentage of reinforcement (0%, 2%, 4%, 6%, 8%, and 10%) and three speed variation (2mm/min, 3mm/min, 4mm/min).

2. DOE (DESIGN OF EXPERIMENT)

There are different types of optimization method which are Taguchi method, Genetic algorithm, Artificial Neural Network etc.[9]. Here we have used Taguchi method. Taguchi is a design process which provides simple, efficient and planned technique for optimization. According to Taguchi [10], DOE is important statistical process to examine the effect of different variable simultaneously and identify order of steps which must follow a particular order to get better the performance of procedure. Taguchi method chooses few numbers of experiments and gets information exactly. All experiments have a definite number of combinations of factor and level. According to Fisher RA [11], In DOE procedure, to obtain desired outcome, it is essential to determine right arrangement of factor and level. In Taguchi method, standard orthogonal array develops the plan of experiments. To standardize quality characteristic, Taguchi gave loss function which is also called Signal to Noise ratio(S/N ratio) in statistical form. Taguchi method uses a specific design orthogonal array to reduce number of experiments [12]. The experiment results are then validated by ANOVA of dominating factors [13].

3. EXPERIMENTAL DETAIL

3.1 Specimen Preparation

To prepare the specimen, aluminium is melted at 8000C and then silica gel is added in the molten aluminium. The mixture of ceramic and molten metal was stirred by mild steel stirrer at the speed of 500 to600 rpm. The molten composite metal is poured into a mould and cooled at ambient temperature. The above process is again repeated for other percentage (0, 2, 4, 6, 8, and 10) of ceramic.

3.2 Plan of Experiment based on Taguchi Method

According to Taguchi process, the test plan was planned considering two factors at mixed type which provides L18 orthogonal array with two column and eighteen rows. The L18 orthogonal array has seventeen degree of freedom. Taguchi process provides experiment examination in form of Signal to Noise ratio (S/N ratio) using the MINITAB 16 software [14]. The level of variable are given below in Table (1)

The S/N ratio for Tensile modulus and Flexural modulus can be denoted by 'Larger is Better'. It is calculated by given formula

$$\eta = -10\, log(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}) \quad (1)$$

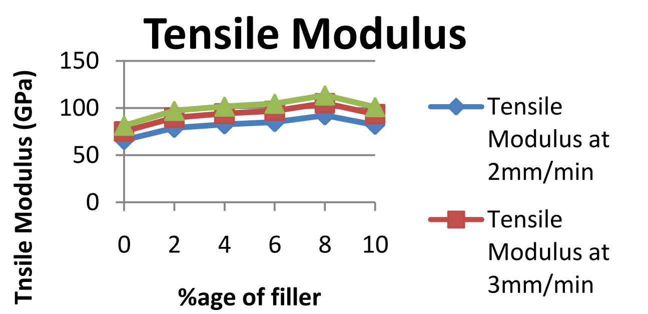
Table 1. Levels of control factor (Variable) used in Test

	Level						
Control Factor	1	2	3	4	5	6	**Units**
Filler	0	2	4	6	8	10	**%age**
content(A)							
Speed(B)	1	1	1	1	1	1	**mm/min**
	2	2	2	2	2	2	
	3	3	3	3	3	3	

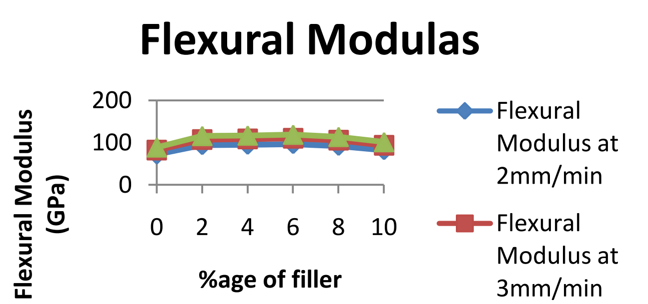
4. RESULT AND DISCUSSION

4.1 Tensile and Flexural Modulus Test Result

The tensile and flexural modulus was evaluated with six different percentages at three various speeds. The graph of tensile modulus and flexural modulus with percentage of reinforcement is shown in Fig. 1. The experiment disclosed that both tensile modulus and flexural modulus of composite increased by increase in percentage of reinforcement upto 8% and 6% respectively. When ceramic is added up beyond 8% and 6% both tensile modulus and flexural modulus respectively decreased as increase in the reinforcement loosens the bonding between the matrix and the reinforcement and hence less modulus is found.



(a)

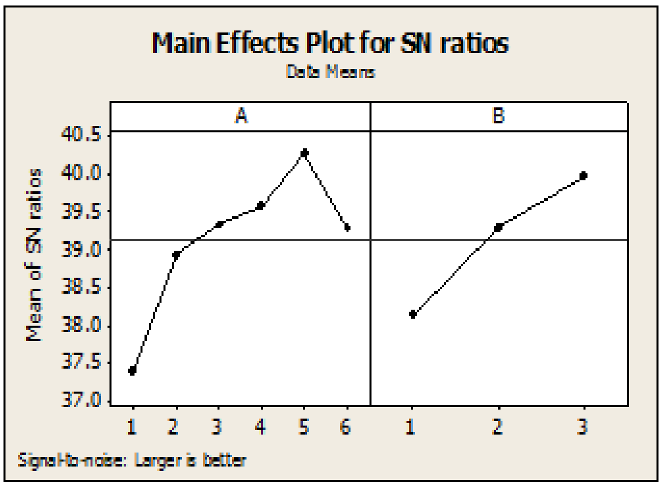


(b)

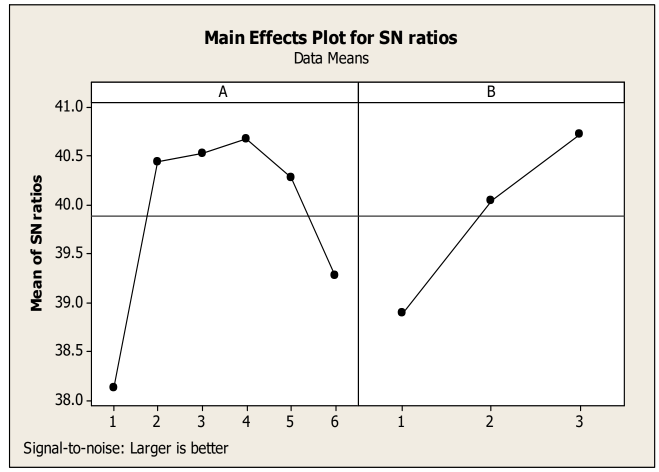
Fig. 1. (a) Tensile Modulus; (b) Flexural Modulus

4.2 Taguchi Analysis for Tensile Modulus and Flexural Modulus

Experimental results for tensile and flexural modulus are shown in Table 2. S/N ratio is evaluated for each combination in their table. Response tables of modulus and the result as in table 3 and 4 respectively provides the influence of every control factor (A and B) on the responses in the study. The main effects plot for S/N ratio is shown in Fig. 2 (a) and (b) for tensile modulus and flexural modulus respectively. The significance of every factor is calculated form the slope of main effect plot. The line of high slope angle shows that such parameter will be more dominating, so from the Fig. 2 (a) and (b), it can be inferred that percentage of reinforcement is more significant than speed. High value of S/N ratio conform high quality so from Fig 2,it can be referred that A5B3 and A4B3 are an optimum combination of design parameter for tensile modulus and flexural modulus respectively. Thus this study defines that percentage of reinforcement is most effective factor for both tensile and flexural modulus of aluminium with 8% of silica gel reinforcement as depicted in table 3 & 4.



(a)



(b)

Fig. 2 Main effects plot for S/N ratio for (a) Tensile Modulus; (b) Flexural Modulus

Table 2 Tensile Modulus and Flexural Modulus test result with S/N ratio

%age	**Speed**	**Tensile Modulus (GPa)**	**S/N Ratio (Tensile Modulus)**	**Flexural Modulus (GPa)**	**S/N Ratio (Flexural Modulus)**
0	2	66.01889	36.3934	71.92795	37.1380
0	3	75.36184	37.5430	82.10715	38.2876
0	4	81.45074	38.2179	88.74104	38.9625
2	2	78.81995	37.9327	93.93809	39.4568
2	3	89.9745	39.0824	107.2321	40.6065
2	4	97.24404	39.7573	115.896	41.2814
4	2	82.51816	38.3310	94.80573	39.5367
4	3	94.19608	39.4807	108.2226	40.6864
4	4	101.8067	40.1555	116.9665	41.3612
6	2	84.95206	38.5835	96.42952	39.6842
6	3	96.97442	39.7331	110.0762	40.8339
6	4	104.8095	40.4080	118.9698	41.5087
8	2	92.07416	39.2828	92.1558	39.2905
8	3	105.1044	40.4324	105.1976	40.4401
8	4	113.5964	41.1073	113.6971	41.1150
10	2	82.05582	38.2822	82.11787	38.2888
10	3	93.66831	39.4319	93.73914	39.4384
10	4	101.2363	40.1067	101.3128	40.1133

The control factors are very important in S/N ratio and it is noticed from table 3 & 4 that percentage of reinforcement getting a rank 1, is obviously the dominating factor on tensile modulus as well as flexural modulus than speed.

Table 3 S/N ratio Response Table of Tensile Modulus

Level	**Percentage of Reinforcement(A)**	**Testing Speed (B)**
1	37.38	38.13
2	38.92	39.28
3	39.32	39.96
4	39.57	
5	40.27	
6	39.27	
Delta	2.89	1.82
Rank	1	2

Table 4 S/N ratio Response Table of Flexural Modulus

Level	**Percentage of Reinforcement(A)**	**Testing Speed (B)**
1	38.13	38.90
2	40.45	40.05
3	40.53	40.72
4	40.68	
5	40.28	
6	39.28	
Delta	2.55	1.82
Rank	1	2

4.3 Analysis of Variance

Analysis of Variance (ANOVA) used to determine significance of process parameters over the quality feature and proportion of participation of factors and also influence of interaction on responses [15]. The summation of squared deviation from mean S/N ratio gives the percentage contribution of the factor. By executing ANOVA, it can be concluded which factor is most dominating. ANOVA table for tensile modulus and flexural modulus are presented in table. 5 and 6 respectively. From table. 5 & 6, it is noticed that percentage of filler silica gel is most contributing factor on tensile and flexural modulus followed by speed.

Table 5 Analysis of variance table for Tensile Modulus

Source	Degree of Freedom	Sequential Sum of Squares	Adjusted Sum of Squares	Adjusted Mean of Squares	F
A	5	1408.22	1408.22	281.64	273.95
B	2	1093.36	1093.36	546.68	531.74
Error	10	10.28	10.28	1.03	
Total	17	2511.86			

Table 6 Analysis of variance table for Flexural Modulus

Source	Degree of Freedom	Sequential Sum of Squares	Adjusted Sum of Squares	Adjusted Mean of Squares	F
A	5	1750.33	1750.33	350.07	273.95
B	2	1304.70	1304.70	652.35	510.50
Error	10	12.78	12.78	1.28	
Total	17	3067.80			

4.4 Confirmation Test

Confirmation test validates the test results and to estimate the accuracy of test. Comparisons of actual value and estimated value are presented in table.7 and 8 respectively. The increment of S/N ratio for initial to optimal condition for tensile modulus is 0.626 dB and for flexural modulus is 0.5731 dB.

Table 7 Confirmation Table for Tensile Modulus

Parameter	**Mean Parameter**	**Optical Parameter**	
		Experimental	**Predicted**
	A3B2		A6B3
Tensile Modulus	94.19608	113.5964	101.2363
S/N Ratio	39.4807	41.1073	40.1067

Table 8 Confirmation Table for Flexural Modulus

Parameter	**Mean Parameter**	**Optical Parameter**	
		Experimental	**Predicted**
	A3B2		A6B3
Flexural Modulus	108.2226	118.9698	101.3128
S/N Ratio	40.6864	41.5087	40.1133

5. CONCLUSION

The tensile and flexural modulus of silica gel reinforced aluminium composite was estimated with the variation of percentage of reinforcement and testing speed. Optimization of tensile modulus and flexural modulus were performed by Taguchi technique. It can be validated by ANOVA which give percentage of filler content most affected the tensile as well as flexural modulus at 95% confidence level. The confirmation test represents the improvement of S/N ratio. In case of Tensile modulus the improvement of S/N Ratio was observed as 0.626 dB whereas for Flexural the same was 0.5731 dB.

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