Rotating Beam Fatigue Life Optimization of Aluminium Metal Matrix Composite

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Abstract

In this work, a model was developed using Taguchi technique to study the factors influencing the fatigue life of aluminium matrix composite. Aluminium 6061 is reinforced with weight percentage Al_2O_3 particles. Stir casting method is used to prepare the specimens. Experiments were conducted for rotating beam fatigue testing by RR Moore method. The effect of applied load, weight fraction (%) and sizes of the particles on the fatigue life was investigated. It is observed that as applied load and weight fraction increases, fatigue life is decreases. The larger particle size and less weight fraction is have positive effect on the endurance of the specimen. The optimum values of the life cycle is observed at 120 microns particle size, 5 kg load with 5% weight fraction. The forecast model indicates that the significant parameter that impacts the fatigue life was particle size, followed by applied load and weight percentage of reinforcement. Confirmation test reveals that, the model results were observed to be near to the experimental values.

Keywords: Taguchi analysis, aluminium matrix composite, rotating beam fatigue, stir casting

1. Introduction

Technological advancements have made materials and its applications to have all scopes covered from cost to the strength. Metal matrix composites (MMC) have evolved with greater strength to weight ratio compared to its counter parts. Composite materials gain enhancement in properties based on the interaction between the matrix and the reinforcement. The primary function of the reinforcement in MMCs is to carry most of the applied load, where the matrix binds the reinforcements together, and transmits and distributes the external loads to the individual reinforcement [1]. Now a days many parts in vehicle and in aerospace have been replaced by metal matrix composites due to their excellent mechanical properties, high strength, stiffness, high wear resistance. The interest for developing metal matrix composites have been significantly increased to be used in high performance functional applications [2]. The composites can be produced by including distinctive sorts and types of reinforcements. The particle-reinforced composites are more broadly utilized, which can be fabricated by liquid stir casting, powder metallurgy, Spray deposition etc [3]. Aluminium is a light weight material is extensively used many applications for enhancing the performance by decreasing. The matrix is ductile, however its structure made stronger by addition of hard ceramic particles such as Silicon Carbide and Alumina particles [4].Aluminium metal matrix composites reinforced with ceramic particles have improved mechanical properties [5].

Statistical Taguchi method developed by Taguchi and Konishi [6]. To improve the quality and optimize the process for manufacturing the components, this technique is extensively used. Now it has been used in many fields including medical and bio technology industry [7]. In this work, tests were carried out for various factors and the results obtained are the most significant factors with optimized combination were selected for providing optimal fatigue life for the aluminium matrix composite.

Optimization Technique

The Taguchi methodology for quality systems and system engineering is widely used and tested [9]. This approach was effectively applied in the research of metal matrix composites [10]. The process parameters used in the study were weight percentage of reinforcement, applied load, and size of the reinforcement. Table 1 shows the parameters and its three levels

TABLE 1. Process parameters and its Levels

Factors	Level 1	Level 2	Level 3
Particle size (Microns)	30	60	120
Load (Kg)	5	10	15
Wt%	5	10	15

Experimental Procedure

Aluminium 6061 was chosen as the base matrix material, Alumina (Al_2O_3) particles were added as the reinforcements. The stir casting technique is used in composite manufacturing as this allows for uniform reinforcement distribution and is economical to use for small or for mass production. Stirring rpm and duration of the rotation of the stirrer is vital for uniform mixing of the particles. The procedure is repeated for various wt% of the reinforcements. Solidified castings were machined in a lathe machine for the given standard as shown in figure 1

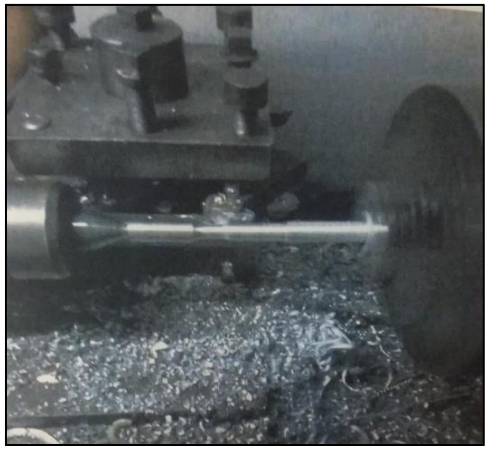

Figure 1: Specimen turning in Lathe machine

The fatigue test was conducted by R R Moore testing machine as shown in figure 2. The fatigue tests were performed for different specimens of varying wt% of the reinforcements. The test specimens are aluminium with 5%Wt, 10%Wt, 15%Wt. fraction of alumina particles were prepared in accordance with the ASTM standard. The loading for each specimen is started with 5 kg. The digital indictor shows the revolutions made by the specimen and once the failure occurs the machine automatically stops and the final reading of the cycles were recorded. The above procedure is repeated for rest of the specimens for same wt% of the reinforcements for different loads ranges for 10kg, and 15kg. Similarly the process is repeated for different wt% and the final S-N (Bending Stress v/s Number of cycles to failure) curve is plotted.

Figure 2: RR Moore fatigue testing machine

Results and Discussions

Using Minitab software, the fatigue life assessment parameters were analyzed, particularly intended for this purpose. The S / N ratio for all combinations were listed below. The results of fatigue life cycles for all 9 combinations were tabulated (Table 2)

TABLE 2. Experimental Results for L9 orthogonal array with S/N ratio

Sl No	Particle size in microns	Load in Kg	Weight Fraction in %	Cycles	S/N Ratio
1	30	5	5	27981	88.9373
2	30	10	10	20164	86.0915
3	30	15	15	13221	82.4253
4	60	5	10	35073	90.8995
5	60	10	15	21651	86.7096
6	60	15	5	28103	88.9751
7	120	5	15	55318	94.8573
8	120	10	5	53880	94.6286
9	120	15	10	38858	91.7896

for all possible combinations of the factors and levels the signal to noise ratios have been calculated and tabulated.

Influence of Each Factor on Fatigue Limit

An average of all fatigue life cycle values was taken for each level of the individual parameter. Table 3 shows these values. The difference between the maximum and minimum average valve (Delta) was calculated for each parameter. The greater the Delta value, the higher the fatigue life cycle of the composite is influenced by that parameter. Fatigue life cycle corresponding to the parameter level has been plotted for each parameter and is shown in Figure 3(a). Using S / N Ratio, similar calculations were made.

Table 3: Response Table for Means

Level	Particle Size in microns	Load in Kg	Weight fraction in %
1	20455	39457	36655
2	28276	31898	31365
3	49352	26727	30063
Delta	28897	12730	06291
Rank	1	2	3

The response table for S/N ratios for various combinations were shown in table 4. It is tabulated for large the better method of calculating the fatigue life cycle since the number of cycles considered to be as large as possible for the given combination of the parameters.

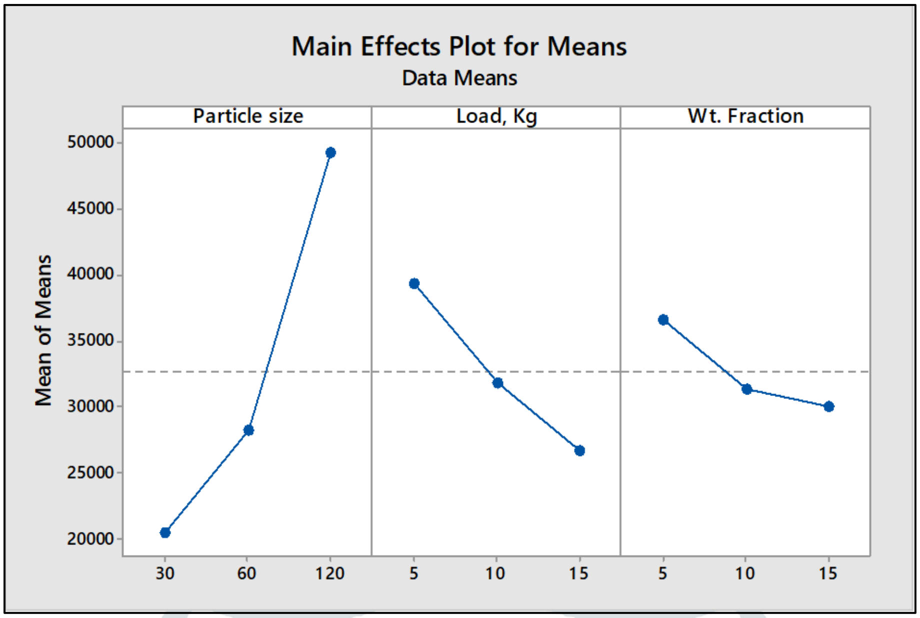

Figure 3(a): Main effect plot for means

As the percentage of reinforcement increases from 30 to 120, fatigue life increases due to decrease in clogging and uniform distribution of the reinforcement particles due to high inertia as shown in figure 4(a), further increasing in the load is decreasing the fatigue life of the specimens. Fatigue life decreases as the wt% of the reinforcement increases. This tendency is mainly due to clogging of the particles for the given value of the matrix materials. .

Table 4: Response Table for Signal to Noise Ratios -Larger is better

Level	Particle Size in microns	Load in Kg	Weight Fraction in %
1	85.82	91.56	90.85
2	88.86	89.14	89.59
3	93.76	87.73	88.00
Delta	07.94	03.83	02.85
Rank	1	2	3

As the applied load increases, due to micro cracks on the surface, may lead to earlier failure. The particle size is the most significant factors followed by load and the wt% of the reinforcements in controlling the fatigue life cycle for the specimen.

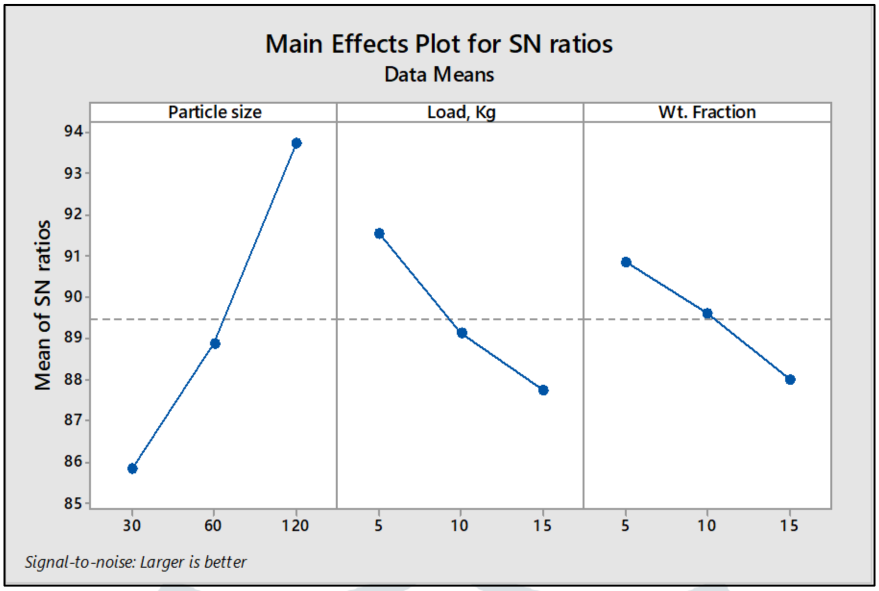

Figure 4(a): Main effects plots for S/N ratios

Analysis of Variance

The result of analysis of variance (ANOVA) for fatigue life is shown in table 5. ANOVA is also used to determine each input parameter's percentage contribution [10]. This helps to find out the parameter that contributes most among all the sources that are responsible for the response variation. It should be noted from table 5 that particle size has greater influence fatigue life (78.58%). Followed by load (14.42%) & weight fraction (4.28%) which are less dominant factors, respectively, the error (2.72%) is well within the limit

Table 5: ANNOVA of Fatigue life cycle estimation

Source	DF	Adj SS	Adj MS	F-Value	% Contribution
Particle size in microns	2	1340386785	670193392	28.92	78.58
Load in Kg	2	245930622	122965311	5.31	14.42
Weight fraction %	2	73120585	36560292	1.58	04.28
Error in %	2	46344645	23172322		02.72
Total	8	1705782636			100.00

Regression Analysis and Confirmation Test

Based on the experimental outcomes, a regression model was created, which creates a correlation between the important parameters. The regression equation for fatigue life is as follows:

$$\text{Fatigue life (Cycles)} = 29238 + 325.4 \text{ Particle size} - 1273 \text{ Load} - 659 \text{ Wt. Fraction (\%)}$$

It was noted from the above equation that the particle size coefficient was positive. This reveals that the fatigue life of composites improves as particle size increases. The coefficient associated with the applied load and weight fraction (%) of the reinforcement is negative, which reveals that the fatigue life reduces as proportion is increasing for reinforcement (%) and load. Confirmation experiment was performed to validate the findings gained from the study and a comparison was made between the experimental values and the calculated values created from the regression model. The confirmation experiment and its outcomes are presented in Table 6. Based on the confirmation experiment, it is observed that the error with experimental values and calculated values was minimal (4.1%). The regression model thus acquired from the L9 array can be efficiently used to predict the fatigue life of aluminium matrix composite with excellent precision.

TABLE 6. Results for Confirmation Experiment

Sl NO	Particle size in microns	Load In Kg	Weight fraction in %	Regression cycles	Experimental Cycles	Error in %
1	120	5	5	58626	61089	4.1

CONCLUSIONS

Aluminium matrix composites has been fabricated by stir casting method with alumina ($Al_2 0_3$) particles as reinforcements. Experiments were performed on the basis of Taguchi's technique and it was noted that particle size of reinforcement (78.58%) had the greatest contribution towards the fatigue life prediction followed by applied load (14.42%), Weight percentage of the reinforcement in the matrix (4.28%) From the S/N ratio plot, it was found that particle size 120 microns, load 5 Kg and Weight fraction 5% provides maximum fatigue life. An equation of regression was developed to predict the fatigue life for the current model. To validate the theatrical values, confirmation test was conducted and the results are matched with minimal error of 4.1%. Thus, Taguchi's technique was efficiently used to forecast the fatigue life cycle of aluminium matrix composites.

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