

Experimental Investigation Of Average Fatigue Life Of LM6 Alloy-Boron Carbide-Graphite Hybrid Composites

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Abstract - The main focus of this study is to comprehend the Fatigue properties of LM6 Aluminium Alloy-Boron Carbide-Graphite Hybrid Composites. The base metal, LM6 aluminum alloy, has the qualities of outstanding castability, medium strength, and low weight. While retaining good ductility, the addition of Graphite and Boron carbide improved the composites' tensile strength, hardness, and resistance to wear. For applications like drive shafts, housings, and structural supports, Boron carbide can offer exceptional stiffness and strength while keeping weight down.

Stir casting method was used to create composites with uniformly distributed Boron Carbide and Graphite particles in the LM6 matrix. Five distinct combinations of Boron Carbide (1, 2, 3, 4, 5 Wt%) with a constant weight percentage of Graphite (1 Wt%) were used to create the hybrid metal matrix composites. The fabricated specimens of composites were used to determine the Fatigue properties. From the S-N Curve test results, the average fatigue life of composites increased at all stress levels up to 5% addition of reinforcement.

Index Terms - Hybrid composites, Aluminium alloy LM6, S-N Curve, Stress levels.

INTRODUCTION

Fatigue is one of the key reasons for premature failure of mechanical system and its parts that are subjected to cyclic loads. The parts used in automobile, aerospace and space technology are fatigue-based design. Fatigue life is referred as the number of stress cycle or strain cycles the component, specimen or structure can withstand under a specific stress amplitude before failure occurs. A crucial factor in designing and evaluating the materials, especially those that undergo repetitive cyclic loading in real word applications. Due to the difference in surface condition and non-homogeneity in the material, similar parts and specimens fail at different lives even when subjected to the same fluctuating stress. Since the average value is used as a best as well as most informative estimator of sample, it is utilized to express the fatigue behavior of materials with respect to average life, which typically approximates the average life.

The average life is established by subjecting a number of test specimens to each of a number of levels of stress until failure occurs. The resulting data is plotted using stress on the ordinate and appropriate life on the abscissa. A line is fitted through the points to estimate the average life for each stress level. In other words, this line provides an accurate estimate of the average life for the population from which the test sample was taken, provided that a sufficient number of specimens have been examined at each stress level. As tests are typically conducted at multiple stress levels, many specimens are needed. But in many cases, especially for lab tests (as opposed to component tests), the S-N curve shape is already fairly well-established for the material. So, a common practice is to test at four to six different levels of stress, and even two levels may be enough at times. Use the remaining specimens for replication, permitting repeated trials with new specimens at the desired stress levels [1].

The methodology comprised using a rotating beam bending fatigue testing machine to perform fatigue tests under reversed loading. A three - stress levels fatigue test plan was selected to determine the average fatigue life and to plot the Stress-Life (S-N) curve as shown in Figure 1.

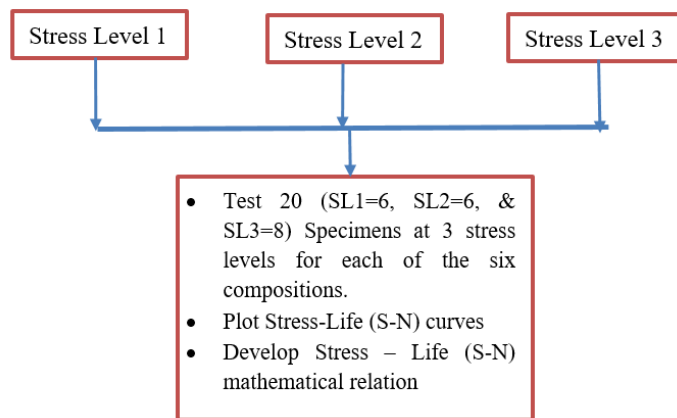


FIGURE 1. IDENTIFICATION OF STRESS LEVELS AND NUMBER OF SPECIMENS

LITERATURE REVIEW

When metal materials experience fluctuating or cyclic loads, the complex fatigue process starts. The failure occurs at a level of load way below the static fracture load after some number of cycles of loads. In the areas of material that have plastically deformed due to applied fluctuating loads, the fatigue fracture occurs. This occurs because although the material is subjected to elastic stress macroscopically, stress has the potential to exceed the yield stress of the material locally by virtue of concentration of stress. Local plastic deformation after a critical number of cycles of loading originates from these regions of stress concentrations and starts propagating a fatigue crack. Fatigue crack quickly propagates into final failure. Higher the stress concentration intensity, lower will be the time to start the fatigue crack. Addition of reinforcement into the metal matrix influences the general fatigue process significantly [2].

Ji Xia et al. performed test to determine tension behaviour and fatigue life estimation of Aluminum 2124A/ Silicon-particulate composites. S-N curves were generated based on the maximum stress at the minimum sample diameter. The fatigue strength at 10^7 cycles was 448 MPa, an increase of 205 MPa (83.2%) compared to monolithic 2124 with stress ratio $R = 0.1$. The fatigue strength is increased compared to Aluminium 7055 alloy at 10^6 Cycles [3].

Abdullah Goçer performed tests to determine Fatigue life and compression behavior of Aluminium 6061- Boron Carbide composites. The fatigue life of base metal increases with increasing the particle size of Boron Carbide. The maximum life is obtained using the base metal reinforced with Boron carbide with a size of 58 μm . Addition of Graphite increases the fatigue life of the composites [4].

V. Sivanath et al. performed fatigue life evaluation and impact studies of titanium carbide reinforced composites. They assessed the fatigue behavior of titanium carbide with 10, 12 and 15 weight percentages reinforced to aluminium matrix. They have reported that aluminium matrix with 15 weight percentage of titanium carbide exhibits fatigue strength of 248 MPa at 8,00,000 cycles compared to 133 MPa of matrix alloy [5].

H. Umesh et al. studied Fatigue characteristics LM6 Aluminium alloy reinforced fly ash composites. From the fatigue test it is seen that, for increase in 0-10% reinforcement to the LM6 matrix, there will be slight increase in the number of cycles required for failure. It is because of the increase in Aluminium Oxide and Silicon Carbide within the fly ash. After 10% i.e from 12 to 15 % addition of reinforcement, because of increase in brittleness, there will be a reduction in the number of cycles to failure by when compared with the number of cycles at 10%. Hence due to the reinforcement (fly ash) addition, there will be increases in fatigue life till maximum volume percentage addition, but after optimum value, we can see that there is decreasing the fatigue life [6].

M V Achutha et al. performed the estimation of fatigue life on aluminium hybrid metal matrix composites. They evaluated Fatigue life for 2.5 wt% Hybrid Aluminium - Silicon Carbide - Graphite composite is evaluated at various levels of stresses and compared with the LM25 base alloy. These composite shows that an improvement in the fatigue life compared to the LM25 base alloy [7].

Aluminium reinforced with ceramic particulate composites have been investigated extensively by many researchers for static and fatigue properties.

Although many studies have been conducted in the field of Aluminium-Boron Carbide particle composites, fatigue studies on these materials are limited. Graphite has a self-lubricating effect and enhances wear properties when combined with other metals. These characteristics of the materials used to make automobile engine parts may significantly lower the need for lubricants and extend their lifespan. Although there are a lot of studies on Al LM6 alloy with Boron Carbide in the literature, very few have looked at Al LM6 alloy, Boron carbide, and Graphite together.

It can be observed that attempts made to evaluate the vibration, fracture, and fatigue characteristics of Al LM6 - Boron Carbide - Graphite hybrid composites (Al-B₄C-Gr) are inadequate or not found. Thus, there is a more scope for investigation in this area.

From the above it is evident that little work has been reported on Fatigue characteristics of Al LM6 - Boron Carbide - Graphite (Al-B₄C-Gr) hybrid composites. Thus, there is a requirement to create fatigue behavior of composites to evaluate their suitability for various materials for Automotive and Marine Industries.

METHODOLOGY

Methodology adopted for this work is to Fabricate of Aluminium - Boron Carbide- Graphite metal matrix composites by using Stir - Casting method to determine Static mechanical characteristics and Fatigue life of composites. The next step is to identify the correct stress levels by means of Statistical approach.

Once the levels are identified, next step is to determine average fatigue lives and finally analyze this data to get fatigue life.

Analysis of Fatigue data using Statistics:

The approach is predicated on the idea that the fatigue life at a specific stress level is a random variable with a lognormal distribution. The true population life is approximated using student t distribution. The equations for percent error, sample log average life, and sample log standard deviation respectively are equation (1) to (3).

$$\text{The percent error can be shown as } = \pm \frac{S_1}{\hat{a}_1} \times \frac{t_{\frac{\alpha}{2}, \gamma}}{\sqrt{n}} \quad (1)$$

$$\text{Where } \hat{a}_1 = \sum_{i=1}^n \frac{x_{1i}}{n} \quad (2)$$

is the sample log average life

n is sample size,

γ is the degrees of freedom (n-1),

$\frac{\alpha}{2}$ is the degree of confidence which is equal to (1-α) and

S₁ is the sample log standard deviation given by,

$$S_1 = \left[\sum_{i=1}^n \left(\frac{x_{1i} - \hat{a}_1}{n-1} \right)^2 \right]^{1/2} \quad (3)$$

Figure 2 shows the ratio of percent error to the coefficient of variation as well as several confidence levels as y-axis and sample size as x-axis [8].

Based on these curves appropriate for different confidence levels, we can select based on the following presumptions acceptable sample size as shown in Table 1.

TABLE 1. SAMPLE SIZE REQUIREMENT FOR 5% ERROR AND 90% CONFIDENCE

Stress Levels	COV (%) (assumed)	Error / COV (%)	Sample size Required
0.9 x UTS	4	1.25	6
0.7 x UTS	5	1	6
0.5 x UTS	7	0.71	8
Total Sample Size			20

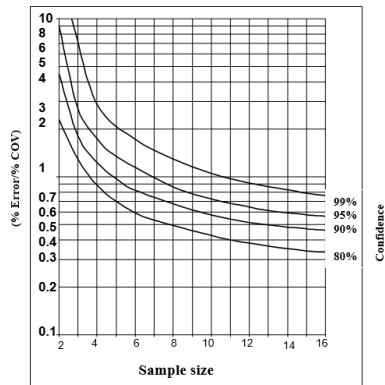


FIGURE 2. IDENTIFICATION OF STRESS LEVELS AND NUMBER OF SPECIMENS [9] [10]

EXPERIMENTAL WORK

Following are the Materials used for the experimentation work.

- Matrix - LM6 Aluminium alloy
- Reinforcement 01- Boron Carbide Microparticles
- Reinforcement 02 - Graphite Microparticles

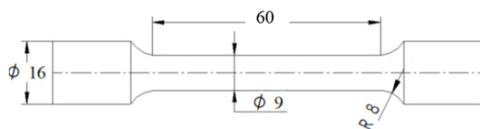
Stir casting method was adopted for the Fabrication of castings. A popular technique for creating metal matrix composites is stir casting, which uses mechanical stirring to distribute reinforcement particles uniformly throughout a molten matrix alloy.

Figure 2 shows the Stir Casting process, the matrix alloy is first melted, typically in a crucible or furnace. Once the Aluminium LM6 matrix alloy reaches the desired temperature, the reinforcement particulates, Boron Carbide and Graphite, are added to the molten matrix metal. The mixture is then subjected to mechanical stirring using a suitable stirring device or impeller [11].

Tensile test specimens were prepared as per the ASTM E8-04 as shown in Figure 3 and Fatigue test specimens shaped in a smooth cylindrical form were prepared in accordance as per the guidelines in ASTM standards E466-15 as shown in Figure 4.

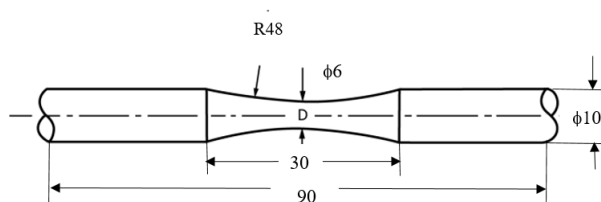


FIGURE 2. STIR CASTING APPARATUS



All dimensions specified in mm

FIGURE 3. TENSILE TEST SPECIMEN - GEOMETRY



All dimensions specified in mm

FIGURE 4. GEOMETRY OF FATIGUE TEST SPECIMEN

The specimens are tested to determine the Ultimate tensile strength as shown in Table 2 [11].

TABLE 2. TENSILE TEST RESULTS

Wt. % of Al LM6	Wt. % of B ₄ C	Wt. % of Gr	Ultimate Tensile Strength (MPa)	Young's modulus (GPa)
100%	0	0	135.20	67.82
98%	1	1	142.01	72.09
97%	2		148.20	76.54
96%	3		156.45	82.76
95%	4		168.23	86.55
94%	5		170.98	88.32

Figure 5 shows the 4 Point Rotating bending apparatus used for fatigue life of the specimens.

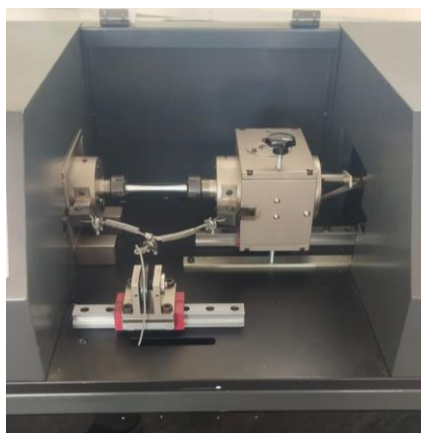


FIGURE 5. FOUR POINT ROTARY FATIGUE BENDING MACHINE

Calculation of Load (N) to be applied for Stress Levels (MPa) chosen

Figure 6 shows the positions of applied loads and reactions along with their respective locations. The section X-X represents the diameter of the test section where specimen failure occurs.

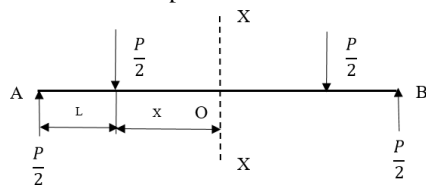


FIGURE 6. LOADS AND REACTION ACTING IN A FATIGUE TEST EQUIPMENT

$$\sigma_b = \frac{32 M}{\pi d^3} \quad (4)$$

Substituting $d = 6 \text{ mm}$

$$\sigma_b = \frac{32 M}{\pi d^3} = \frac{32 \times 50 P}{\pi \times 6^3} = 2.358 P \quad (5)$$

The equation (5) is used to estimate the quantity of load to be applied during the conduct of fatigue tests. The values of each stress levels and the values of load are mentioned in Table 3.

TABLE 3. THE VALUES OF STRESS LEVELS AND CORRESPONDING VALUES OF LOAD

Weight % of B ₄ C +Gr	Stress Levels (SL) (MPa)			Load (P) (N)		
	SL ₁ = 0.9 X σ_u	SL ₂ = 0.7 X σ_u	SL ₃ = 0.5 X σ_u	P ₁ = SL ₁ /2.358	P ₂ = SL ₂ /2.358	P ₃ = SL ₃ /2.358
0	121.68	94.64	67.6	52	40	29
1+1	127.81	99.41	71	54	42	30
2+1	133.38	103.74	74.1	57	44	32

3+1	140.81	109.52	78.23	60	47	34
4+1	151.41	117.76	84.12	65	50	36
5+1	153.88	119.69	85.49	66	51	37

RESULTS AND DISCUSSION

Fatigue tests were performed for specimens of different compositions. Results are discussed below.

Fatigue test results of Aluminium LM6 base alloy:

The fatigue life test results of all the LM6 specimens from the three different stress levels are shown in the Table 4. Equations 1 and 2 describe how the log-average and log-standard deviation were calculated and examined from the data. The COV was computed as shown in Equation 6.

$$\text{COV} = \frac{\text{log-Standard Deviation}}{\text{log-Average}} \quad (6)$$

The variation in life for all three stress levels is lower than the anticipated 4%, 5%, and 7%, with observed values of 3.63%, 2.68%, and 3.92% respectively. Because of this, there is no need to carry out further tests on additional test specimens.

TABLE 4. FATIGUE TEST RESULTS OF LM6 BASE ALLOY WITHIN 5% ERROR AND 90% CONFIDENCE

Sample No.	Stress Level 1 (121.68 MPa)		Stress Level 2 (94.64 MPa)		Stress Level 3 (67.6 MPa)	
	Cycles	Log life	Cycles	Log life	Cycles	Log life
1	299803	5.47	416557	5.62	623390	5.79
2	159153	5.20	590752	5.77	692365	5.84
3	189306	5.28	225970	5.35	299215	5.46
4	179203	5.25	224442	5.35	227143	5.36
5	95702	4.98	312312	5.49	794156	5.90
6	243121	5.38	311560	5.49	997590	5.99
7	-	-	-	-	221680	5.35
8	-	-	-	-	599201	5.78
Average	194382	5.26	346932	5.51	556843	5.68
Std. Deviation	64193	0.191	161892	0.148	265183	0.223
COV (log basis)	-	0.0363	-	0.0268	-	0.0392

It is evident that average fatigue life improves as stress level is reduced. Figure 7 illustrates the scatter of fatigue life test data alongside the average S-N curve for the Aluminium LM6 matrix alloy. As illustrated, there can be great variation in the fatigue lives of identical specimens subjected to identical fatigue loading.

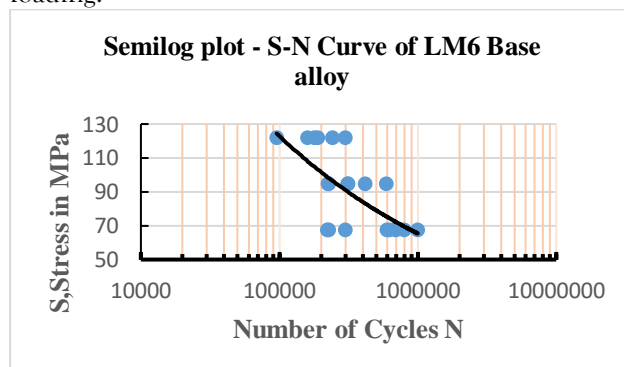


FIGURE 7. SCATTER OF FATIGUE LIFE WITH AVERAGE S-N CURVE FOR LM6 BASE ALLOY

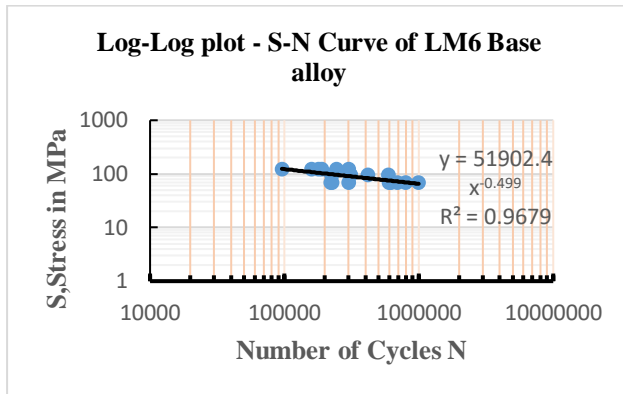


FIGURE 8. STRESS LIFE RELATION FOR LM6 BASE ALLOY USING POWER REGRESSION

The test data of the LM6 matrix alloys is plotted on log-log coordinates in the Figure 8. The best-fit line was calculated using a power regression approach, which is summarized in equation 7.

$$y = a x^b \quad (7)$$

In the equation, y represents the stress amplitude in MPa and x denotes the fatigue life in number of cycles, a and b are constants. The final outcome of the regression analysis is expressed by the correlation coefficient which is R^2 .

Equation 7 can be restructured the same way an equation is set in order to predict the number of cycles N at certain levels of stress S as shown in Equation 8.

$$x = \left(\frac{y}{a}\right)^{1/b} \quad (8)$$

It can be noticed from Figure 8 that the values of constants were determined as $a = 51902.4$ and $b = -0.499$. With b set at 0.9679 the regression correlation coefficient shows a good linear correlation. As stated the negative value of b indicates that there is a downward trend meaning as average number of cycles increases the stress level decreases. The above values of a and b were used in Equation 8 with a values between 67.6 to 121.68 MPa. The predicted number of cycles from the best fit equation are shown in Table 5. It can be seen that the experimental and estimated values are in good agreement with error values less than 15%.

TABLE 5. PREDICTION OF NUMBER OF CYCLES BETWEEN CHOSEN STRESS LEVELS FROM POWER REGRESSION FOR LM6 BASE ALLOY

Stress Level (MPa)	Average fatigue life (cycles)		Error (%)
	From Power Regression	From Experimental data	
67.6	605404	556843	8.02
75	491627	-	-
85	382563	-	-
94.64	308725	346932	12.37
105	250492	-	-
115	208746	-	-
121.68	186414	194382	4.27

Fatigue test results of Aluminium LM6, 1% B₄C, 1% Gr Composites:

The specimens of LM6, 1% B₄C, 1%Gr Composites undergone a fatigue test. The fatigue life test results of all the specimens from the three different stress levels are shown in the Table 6. The variation in life for all three stress levels is lower than the anticipated 4%, 5%, and 7%, with observed values of 2.81%, 4.81%, and 2.37% respectively. Because of this, there is no need to carry out further tests on additional test specimens.

S-N Curve in semi-log coordinates and log-log coordinates for this composition is as shown in Figure 9 and 10.

TABLE 6. FATIGUE TEST RESULTS OF LM6, 1% B₄C, 1% GR COMPOSITES LIFE WITHIN 5% ERROR AND 90% CONFIDENCE

Sample No.	Stress Level 1 (127.81 MPa)		Stress Level 2 (99.41 MPa)		Stress Level 3 (71 MPa)	
	Cycles	Log life	Cycles	Cycles	Log life	Cycles
1	191322	5.28	301422	5.48	353179	5.55
2	304128	5.48	248137	5.39	993151	6.00
3	149196	5.17	515261	5.71	631911	5.80
4	121680	5.09	102221	5.01	759667	5.88
5	146123	5.16	620185	5.79	499129	5.70
6	281778	5.45	501119	5.70	455644	5.66
7	-	-	-	-	789243	5.90
8	-	-	-	-	675612	5.83
Average	199038	5.27	381391	5.51	644692	5.74
Std. Deviation	69783	0.148	178590	0.265	193186	0.136
COV (log basis)	-	0.0281	-	0.0481	-	0.0237

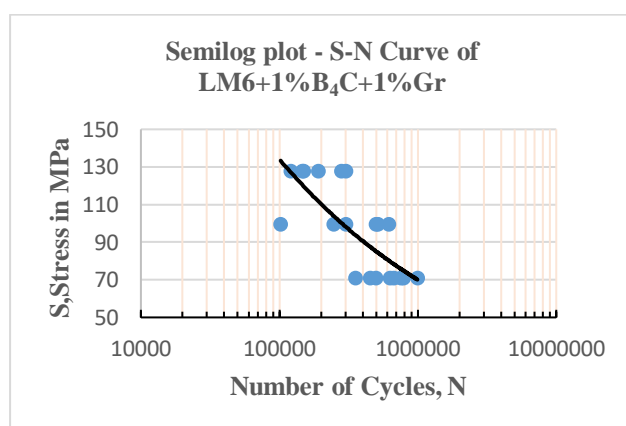


FIGURE 9: SCATTER OF FATIGUE LIFE AND AVERAGE S-N CURVE FOR LM6, 1%B₄C, 1%GR COMPOSITES

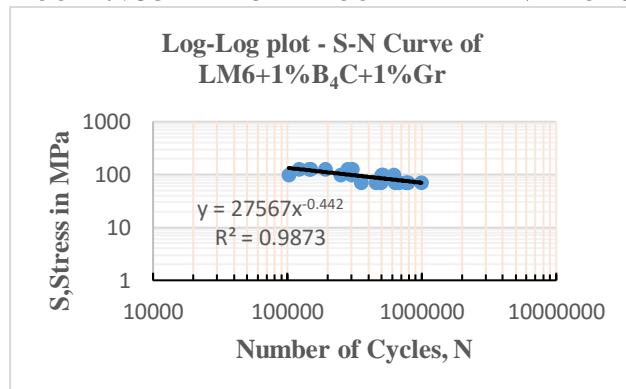


FIGURE 10. STRESS LIFE RELATION FOR LM6, 1%B₄C, 1%GR COMPOSITES USING POWER REGRESSION
 The above values of a and b were used in Equation 8 with a values between 71 MPa to 127.81 MPa. The predicted number of cycles from the best fit equation are shown in Table 7. It can be seen that the experimental and estimated values are in good agreement with error values less than 15%.

TABLE 7. PREDICTION OF NUMBER OF CYCLES BETWEEN CHOSEN STRESS LEVELS FROM POWER REGRESSION FOR LM6, 1% B₄C, 1% GR COMPOSITES

Stress Level (MPa)	Average fatigue life (cycles)		Error (%)
	From Power Regression	From Experimental data	

71	720714	644692	10.54
80	550170	-	-
90	421470	-	-
99.41	336556	381391	13.32
110	267667	-	-
120	219837	-	-
127.81	190610	199038	4.42

Fatigue test results of Aluminium LM6, 2%B₄C, 1%Gr Composites:

The specimens of LM6, 2% B₄C, 1%Gr Composites undergone a fatigue test. The fatigue life test results of all the specimens from the three different stress levels are shown in the Table 8. The variation in life for all three stress levels is lower than the anticipated 4%, 5%, and 7%, with observed values of 2.26%, 3.54%, and 2.76% respectively. Because of this, there is no need to carry out further tests on additional test specimens.

S-N Curve in semi-log coordinates and log-log coordinates for this composition is as shown in Figure 11 and 12.

TABLE 8. FATIGUE TEST RESULTS OF LM6, 2% B₄C, 1% GR COMPOSITES WITHIN 5% ERROR AND 90% CONFIDENCE

Sample No.	Stress Level 1 (133.38 MPa)		Stress Level 2 (103.74 MPa)		Stress Level 3 (74.1 MPa)	
	Cycles	Log life	Cycles	Cycles	Log life	Cycles
1	376543	5.58	302186	5.48	765401	5.88
2	393902	5.60	223712	5.35	876932	5.94
3	263765	5.42	314721	5.50	367891	5.57
4	189457	5.28	409876	5.61	693401	5.84
5	199764	5.30	718356	5.86	345921	5.54
6	245671	5.39	776001	5.89	907645	5.96
7	-	-	-	-	823401	5.92
8	-	-	-	-	873451	5.94
Average	278183	5.43	457476	5.61	706756	5.82
Std. Deviation	79951	0.123	212494	0.199	211943	0.161
COV (log basis)	-	0.0226	-	0.0354	-	0.0276

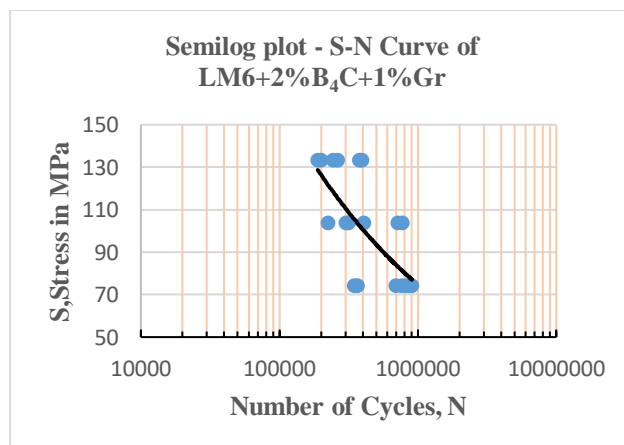


FIGURE 11: SCATTER OF FATIGUE LIFE AND AVERAGE S-N CURVE FOR LM6, 2%B₄C, 1%GR COMPOSITES

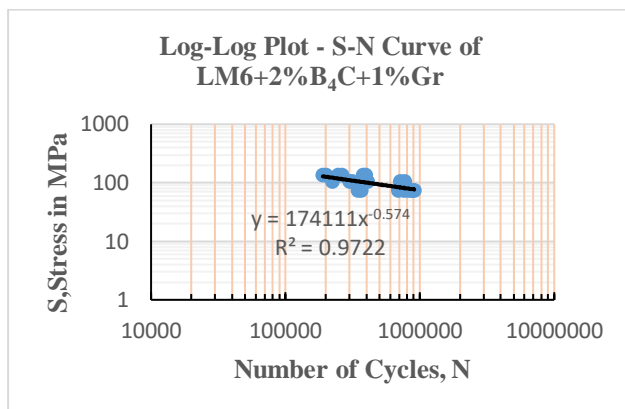


FIGURE 12. STRESS LIFE RELATION FOR LM6, 2%B₄C, 1%GR COMPOSITES USING POWER REGRESSION
 The values of a and b were used in Equation 8 with a values between 74.1 MPa to 133.38 MPa. The predicted number of cycles from the best fit equation are shown in Table 9. It can be observed that the experimental and predicted values are in good agreement with error values less than 15%.

TABLE 9. PREDICTION OF NUMBER OF CYCLES BETWEEN CHOSEN STRESS LEVELS FROM POWER REGRESSION FOR LM6, 2% B₄C, 1% GR COMPOSITES

Stress Level (MPa)	Average fatigue life (cycles)		Error (%)
	From Power Regression	From Experimental data	
74.1	746167	706756	5.28
85	587492	-	-
95	484003	-	-
103.74	415200	457476	10.18
115	346971	-	-
125	300058	-	-
133.38	267985	278183	3.80

Fatigue test results of Aluminium LM6, 3%B₄C, 1%Gr Composites:

The specimens of LM6, 3% B₄C, 1%Gr Composites undergone a fatigue test. The fatigue life test results of all the specimens from the three different stress levels are shown in the Table 10. The variation in life for all three stress levels is lower than the anticipated 4%, 5%, and 7%, with observed values of 2.26%, 3.54%, and 2.76% respectively. Because of this, there is no need to carry out further tests on additional test specimens.

S-N Curve in semi-log coordinates and log-log coordinates for this composition is as shown in Figure 13 and 14.

TABLE 10. FATIGUE TEST RESULTS OF LM6, 3% B₄C, 1% GR COMPOSITES WITHIN 5% ERROR AND 90% CONFIDENCE

Sample No.	Stress Level 1 (140.81 MPa)		Stress Level 2 (109.52 MPa)		Stress Level 3 (78.23 MPa)	
	Cycles	Log life	Cycles	Cycles	Log life	Cycles
1	382903	5.58	411281	5.61	692101	5.84
2	223450	5.35	698001	5.84	998451	6.00
3	201779	5.30	232901	5.37	434012	5.64
4	356001	5.55	412053	5.61	891231	5.95
5	678321	5.83	512075	5.71	534670	5.73
6	254672	5.41	871451	5.94	854012	5.93
7	-	-	-	-	890129	5.95
8	-	-	-	-	756012	5.88
Average	349521	5.5	522961	5.68	756328	5.86
Std. Deviation	161237	0.178	208611	0.183	180767	0.116

COV (log basis)	-	0.0226	-	0.0322	-	0.0198
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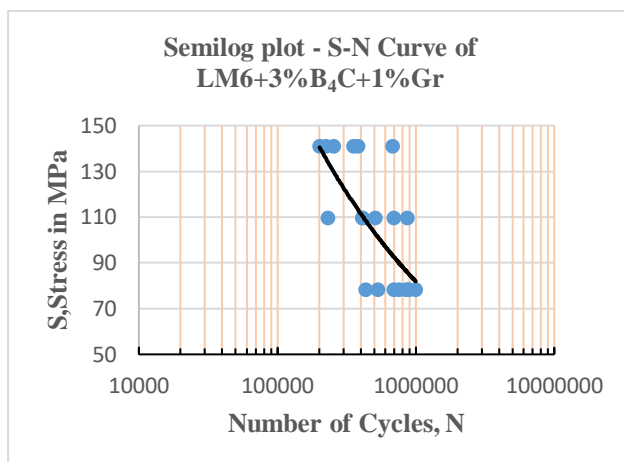


FIGURE 13: SCATTER OF FATIGUE LIFE AND AVERAGE S-N CURVE FOR LM6, 3%B₄C, 1%GR COMPOSITES

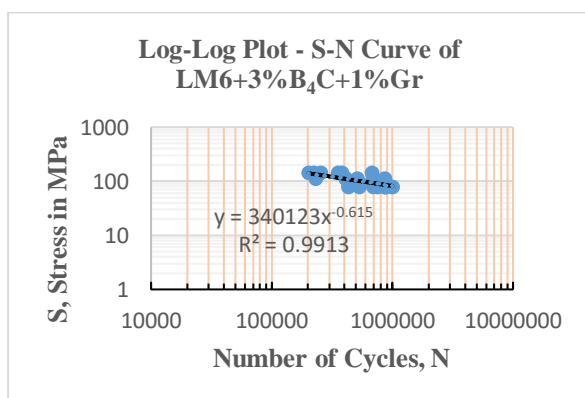


FIGURE 14. STRESS LIFE RELATION FOR LM6, 3%B₄C, 1%GR COMPOSITES USING POWER REGRESSION
 The values of a and b were used in Equation 8 with a values between 78.23 MPa to 140.81 MPa. The predicted number of cycles from the best fit equation are shown in Table 11. It can be observed that the experimental and estimated values are in good agreement with error values less than 15%.

TABLE 11. PREDICTION OF NUMBER OF CYCLES BETWEEN CHOSEN STRESS LEVELS FROM POWER REGRESSION FOR LM6, 3% B₄C, 1% GR COMPOSITES

Stress Level (MPa)	Average fatigue life (cycles)		Error (%)
	From Power Regression	From Experimental data	
78.23	823900	756328	8.20
90	655994	-	-
100	552710	-	-
109.52	476739	522961	9.70
120	410911	-	-
130	360765	-	-
140.81	316823	349521	10.32

Fatigue test results of Aluminium LM6, 4%B₄C, 1%Gr Composites:

The specimens of LM6, 4% B₄C, 1%Gr Composites undergone a fatigue test. The fatigue life test results of all the specimens from the three different stress levels are shown in the Table 12. The variation in life for all three stress levels is lower than the anticipated 4%, 5%, and 7%, with observed values of 3.31%, 3.26%, and 1.42% respectively. Because of this, there is no need to carry out further tests on additional test specimens.

S-N Curve in semi-log coordinates and log-log coordinates for this composition is as shown in Figure 15 and 16.

TABLE 12. FATIGUE TEST RESULTS OF LM6, 4% B₄C, 1% GR COMPOSITES WITHIN 5% ERROR AND 90% CONFIDENCE

Sample No.	Stress Level 1 (151.41 MPa)		Stress Level 2 (117.76 MPa)		Stress Level 3 (84.12 MPa)	
	Cycles	Log life	Cycles	Cycles	Log life	Cycles
1	209354	5.32	554321	5.74	801786	5.90
2	356701	5.55	798601	5.90	612042	5.79
3	289341	5.46	231894	5.37	801832	5.90
4	476012	5.68	622015	5.79	897001	5.95
5	671201	5.83	870939	5.94	545084	5.74
6	673219	5.83	506982	5.70	998732	6.00
7	-	-	-	-	921801	5.96
8	-	-	-	-	786230	5.90
Average	445972	5.61	597459	5.74	795564	5.89
Std. Deviation	178775	0.186	207982	0.187	143216	0.0837
COV (log basis)	-	0.0331	-	0.0326	-	0.0142

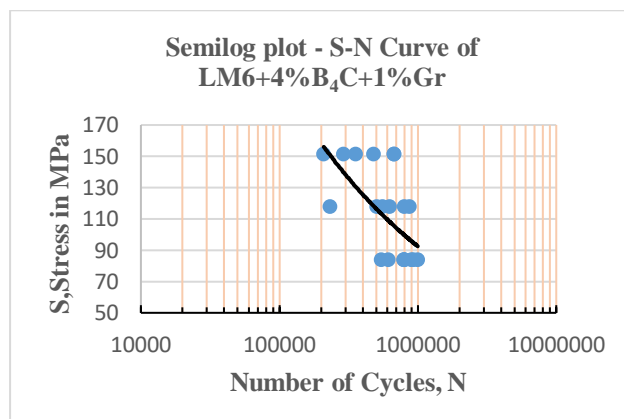


FIGURE 15: SCATTER OF FATIGUE LIFE AND AVERAGE S-N CURVE FOR LM6, 4%B₄C, 1%GR COMPOSITES

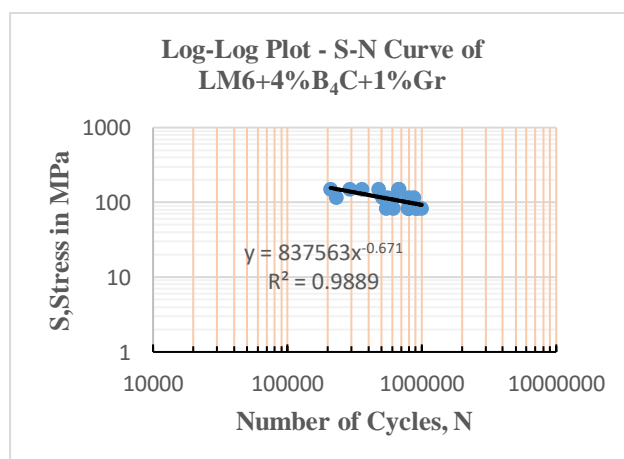


FIGURE 16. STRESS LIFE RELATION FOR LM6, 4%B₄C, 1%GR COMPOSITES USING POWER REGRESSION

The values of a and b were used in Equation 8 with a values between 84.12 MPa to 151.41 MPa. The predicted number of cycles from the best fit equation are shown in Table 13. It can be observed that the experimental and predicted values are in good agreement with error values less than 15%.

TABLE 13. PREDICTION OF NUMBER OF CYCLES BETWEEN CHOSEN STRESS LEVELS FROM POWER REGRESSION FOR LM6, 4% B₄C, 1% GR COMPOSITES

Stress Level (MPa)	Average fatigue life (cycles)		Error (%)
	From Power Regression	From Experimental data	
84.12	927557	795564	14.23
95	773568	-	-
105	666230	-	-
117.76	561414	597459	6.42
130	484379	-	-
140	433659	-	-
151.41	385800	445972	15.01

Fatigue test results of Aluminium LM6, 5%B₄C, 1%Gr Composites:

The specimens of LM6, 5% B₄C, 1%Gr Composites undergone a fatigue test. The fatigue life test results of all the specimens from the three different stress levels are shown in the Table 14. The variation in life for all three stress levels is lower than the anticipated 4%, 5%, and 7%, with observed values of 1.67%, 3.12%, and 3.31% respectively. Because of this, there is no need to carry out further tests on additional test specimens.

S-N Curve in semi-log coordinates and log-log coordinates for this composition is as shown in Figure 17 and 18.

TABLE 14. FATIGUE TEST RESULTS OF LM6, 5% B₄C, 1% GR COMPOSITES WITHIN 5% ERROR AND 90% CONFIDENCE

Sample No.	Stress Level 1 (153.88 MPa)		Stress Level 2 (119.69 MPa)		Stress Level 3 (85.49 MPa)	
	Cycles	Log life	Cycles	Cycles	Log life	Cycles
1	237601	5.38	587631	5.77	876231	5.94
2	456921	5.66	390873	5.59	799023	5.90
3	301291	5.48	305094	5.48	998210	6.00
4	250874	5.40	763043	5.88	354611	5.55
5	299054	5.48	250967	5.40	324319	5.51
6	286701	5.46	650340	5.81	756920	5.88
7	-	-	-	-	887083	5.95
8	-	-	-	-	376441	5.58
Average	305407	5.47	491325	5.66	671605	5.79
Std. Deviation	71805	0.0913	187500	0.177	256589	0.192
COV (log basis)	-	0.0167	-	0.0312	-	0.0331

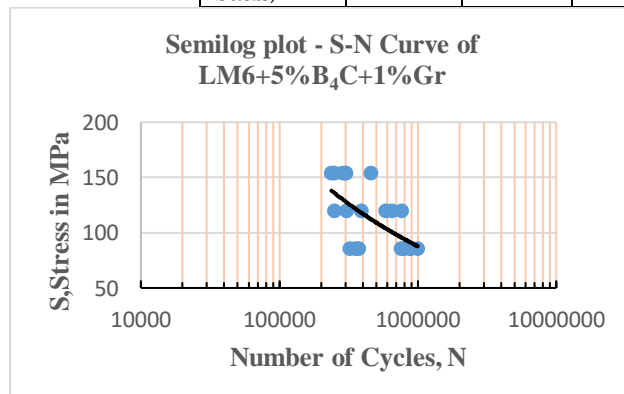


FIGURE 17: SCATTER OF FATIGUE LIFE AND AVERAGE S-N CURVE FOR LM6, 5%B₄C, 1%GR COMPOSITES

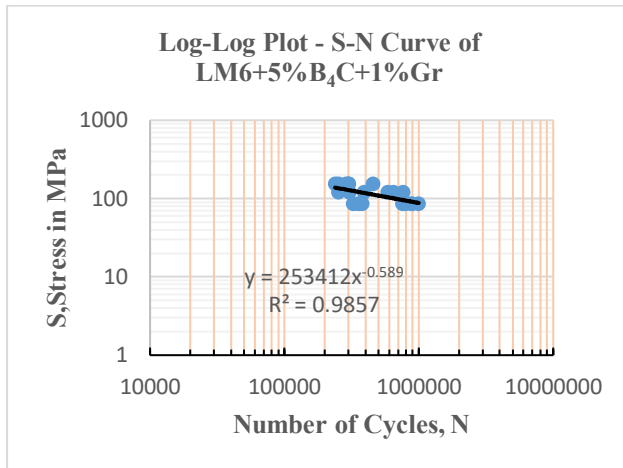


FIGURE 18. STRESS LIFE RELATION FOR LM6, 5%B₄C, 1%GR COMPOSITES USING POWER REGRESSION
 The values of a and b were used in Equation 8 with a values between 85.49 MPa to 153.80 MPa. The predicted number of cycles from the best fit equation are shown in Table 15. It can be observed that the experimental and predicted values are in good agreement with error values less than 15%.

TABLE 15. PREDICTION OF NUMBER OF CYCLES BETWEEN CHOSEN STRESS LEVELS FROM POWER REGRESSION FOR LM6, 5% B₄C, 1% GR COMPOSITES

Stress Level (MPa)	Average fatigue life (cycles)		Error (%)
	From Power Regression	From Experimental data	
85.49	784490	756328	3.59
95	655865	-	-
105	553374	-	-
119.69	490321	522961	6.66
130	411224	-	-
140	362606	-	-
153.80	320327	349521	9.11

Comparison of Fatigue characteristics of Aluminium LM6-Boron Carbide-Graphite Hybrid Composites:

Figure 19 shows the S-N Curves of Aluminium LM6- Boron Carbide- Graphite hybrid composites with a percentage reinforcement of Boron Carbide ranging from 1% to 5% and a fixed Graphite of 1% compared with S-N Curve of base alloy LM6.

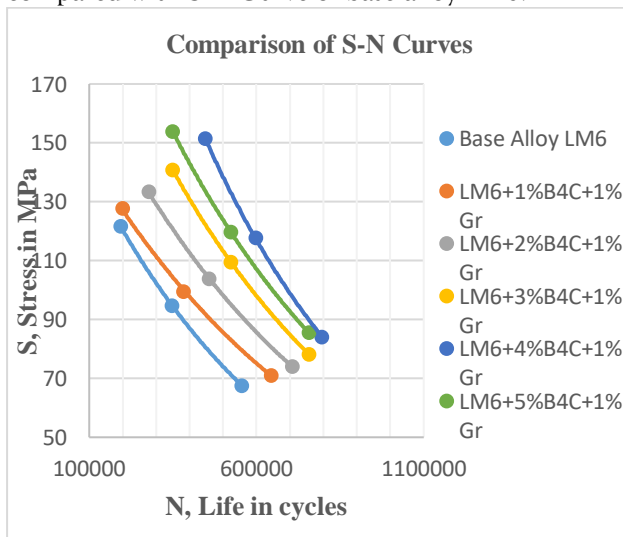


FIGURE 19. COMPARISON OF S-N CURVES FOR ALUMINIUM LM6 - BORON CARBIDE - GRAPHITE COMPOSITES WITH MATRIX ALLOY LM 6

The above results correspond to a given life where the fatigue strength of these composites increases with increasing the percentage of Boron Carbide reinforcement. These effects are very much true up to the 5% addition of reinforcements, yet not withstanding over 5% addition of reinforcements there is no improvement in fatigue strength. The fatigue strength of Aluminium -Boron Carbide - Graphite composite increased with increasing the reinforcement content only as long as the composite is capable of providing enough ductility to achieve full strength.

Table 16 Lists the tensile strength and fatigue strength values at 500000 cycles of Aluminium-Boron Carbide-Graphite composites varying in percentage Boron carbide and fixed proportion of Graphite reinforcements. Figure 20 shows dependence of the tensile strength and fatigue strength on percentage Boron Carbide reinforcement.

TABLE 16. COMPARISON OF TENSILE AND FATIGUE STRENGTH FOR ALUMINIUM LM6 -BORON CARBIDE - GRAPHITE COMPOSITE WITH MATRIX ALLOY LM6

Composition	Ultimate Tensile strength (MPa)	Fatigue strength @ 500,000 Cycles (MPa)	Ratio of fatigue to tensile strength
Al LM6 Base alloy	135.20	74.37	0.55
Al LM6-1% B ₄ C-1%Gr	142.01	83.45	0.59
Al LM6-2% B ₄ C-1%Gr	148.20	77.17	0.52
Al LM6 -3% B ₄ C-1%Gr	156.45	106.35	0.68
Al LM6 -4% B ₄ C-1%Gr	168.23	125.60	0.75
Al LM6 -5% B ₄ C-1%Gr	170.98	111.46	0.65

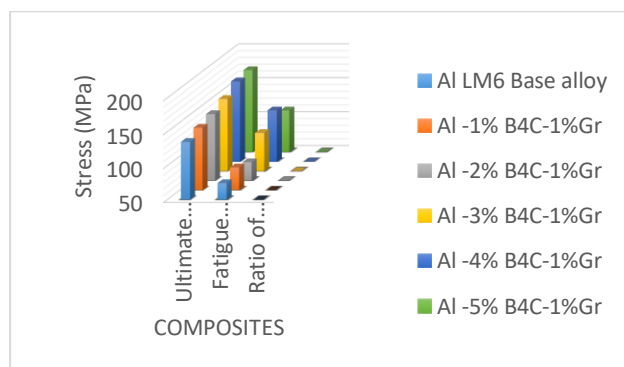


FIGURE 20. COMPARISON OF TENSILE STRENGTH AND FATIGUE STRENGTH OF ALUMINIUM LM6 - BORON CARBIDE - GRAPHITE HYBRID COMPOSITE WITH MATRIX ALLOY LM6

CONCLUSION

The principal conclusions and findings derived from the above research are given below:

Statistical experimental design was utilized to decide how many samples are to be tested at every stress level in rotating bending fatigue tests. The results were further used to calculate average fatigue life with 5% error and 90% confidence. It was observed that life increase varies with decrease in stress level. At increasing the percentage reinforcement from 2 to 5 on the scale of matrix alloy LM6, fatigue resistance improves, but does not improve at 6% reinforcement when compared to reinforcement of 5%.

Mathematical models have been set up for all the compositions and power regression model has been utilized to predict the fatigue among the selected stress levels. From the results we can see that the tensile

strength of composites and fatigue strength of composites were increases up to 5 % reinforcement and not much increase beyond 5 %.

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