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Fatigue Life Analysis of Aluminium Matrix Composite for Varying Al_2O_3 Particle Size and Weight Fractions

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Abstract: *The contemporary engineering requirements cannot be met by conventional monolithic materials. The opportunity to make composite materials comes from combining two or more different, chemically non-reactive, and easily producible ingredients to satisfy the demand of the always changing requirements. Fatigue behavior of metal matrix composites is vital in many applications as the material fails well within the safe working limits. The loading conditions and material characteristics plays significant role in the failure of the component and hence the analysis becomes even more important to predict the early failure. Hence among many modes of failure, fatigue and fracture related behavior is considered as most important. This work is focused on the fatigue behaviour of the aluminium matrix reinforced with varying sizes of Al_2O_3particles with concentrations of varies weight percentages. R R Moore fatigue analysis is carried out for the ASTM standard specimens for varying loads, it is observed that the fatigue life is optimum for the maximum particle size with lower concentration. Fatigue life decreases with increasing loads irrespective of particle size and concentrations..*

Keywords: Metal matrix composites, Al_2O_3 particles, weight percentages

I. INTRODUCTION

Development of new materials for emerging technologies require practically viable, lightweight materials which offers better mechanical properties. The conventional monolithic materials cannot meet the current requirement of the industry. Combining two or more distinct elements which are chemically non-reactive with ease of production to meet the ever-challenging requirements, finds a way in the development the composite materials. The strength of the composites relies not only on the matrix and reinforcement materials but also on the bonding between them. The combination of such elements tends to have mechanical properties which differ from individual elements or any other monolithic materials. These materials are superior in mechanical and physical properties such as fatigue, fracture, stiffness and wear resistance. Besides, these materials offer better design flexibility. Nowadays, these materials find its applications in building aircraft structures, automobiles, bridges, and other structures. etc. [1].Homogeneity is the average macroscopic material behavior linked to the model scale or characteristic volume. On a microscopic scale, all materials are more or less homogeneous; nevertheless, depending on their size, materials can be categorized as homogeneous, quasi-homogeneous, or inhomogeneous [2].The thermal and electrical conductivity and the melting point of magnesium are comparable to those of aluminum. It can be shaped into a net-like form. Magnesium's primary purpose in a magnesium metal matrix composites (MMMCs) is to construct the matrix. Aluminum and its alloys are best suited to be used as composites. Lightweight, chemically inert, flexible in getting molded, low melting temperature, and uniform mechanical properties make the manufacturing industry's best choice. It has a very high strength-to-weight ratio [3].The addition of secondary phase particles to the surface of magnesium improves its resistance to wear and fatigue. [4-6] Recent advancements in particulate-reinforced metal matrix composites have established a new method for producing materials with exceptional strength and wear resistance [7].Among many materials, aluminum suits most applications because of its agility to take different forms, lightweight, low melting temperature, good mechanical properties, availability, and ease of handling. Al 6065 gained significant importance in the manufacturing of its chemical compositions.

Table 1: Composition of 6065-Aluminium alloy [7]

% Al	% Bi	% Si	% Fe	% Cu	% Zn
94.4-98.5	0.5-1.2	0.4-0.8	0-0.7	0.15-0.4	0-0.25

The chemical compositions of the aluminium 6065 alloy are shown in table 1. It has a very high strength to weight ratio. Aluminium metal matrix composites are extremely used in automobiles, aircraft and aerospace industries, medical and agriculture sectors. Below table 2 shows the mechanical properties of the aluminium 6065 alloy.

Table 2: Aluminium-6065 Mechanical Properties [7]

Property	**Value**
Density (g/cm^3)	2.8
Poisson's ratio	0.033
Elastic Modulus (GPa)	71
Tensile strength (MPa)	280-380
Yield strength (MPa)	250

However, the constituent material and contact qualities, morphological parameters like volume form, fraction, volume size, form, and spatial distribution of the reinforcements influence the degree of property enhancement. According to several experimental and numerical investigations, the damages and deformation behavior of multi-phase materials can be very sensitive to local morphology [8]. It is paramount to consider appropriate production techniques for MMCs. Powder metallurgy is one route; it utilizes high energy for compaction and is relatively expensive; it provides uniform distribution of reinforcements and reduces the porosity in the component. Its operating parameters make it uneconomical and often known for fracturing the reinforcement and intermetallic inclusions during the process [9]. On the other hand, Spray forming often attracts less attention because of its complex working nature. It is expensive, and not all materials and shapes can be produced by this method [10].Stir casting method is most suited for all applications which is most economical and ease of use, in this work stir casting method is used to prepared the specimens as per the standards.

II. SPECIMEN PREPARATION AND EXPERIMENTATION

To conduct the experimentation, specimens are prepared after melting the aluminium with various weight percentages of Al_2O_3 particles and machined as per the standards.

2.1 Specimen fabrication

Figure 1: Specimen preparation

Lathe turning is widely used and economical method of producing cylindrical surfaces. Stir casting method is used to prepare the casting, the casting thus produced is machined in lathe machine for given dimensions. Figure 1 shows the lathe turning operation for producing the fatigue specimens as per the ASTM standards All specimens with

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varying concentrations of alumina particles are produced in similar manner and machined for testing at different loading.

2.2 Fatigue testing

Fatigue testing is carried out for the specimen prepared with required dimensions as per ASTM standards. Initial load of 5kg is applied on the pan and the machine is turned on the counter shows the number of cycles. The rotating beam testing method is used to conduct the fatigue testing . After the specimen fails the machine automatically stops and the number of cycles for failure can be directly taken from the digital counter.The above steps are repeated for 10Kg and 15 Kg loads, varying reinforcement concentration and particle size for alumina reinforcement materials

III. RESULTS AND DISCUSSIONS

The results for varying weight percentages of Al_2O_3 reinforcement with variable load for each specimen and its behavior is discussed and necessary conclusions were drawn

3.1 Effect of loading on fatigue life of Al_2O_3 for 30 micron particles composite

The fatigue tests are conducted for standard specimens with alumina particles as the reinforcements. It is observed that the number of fatigue cycles is increased as the loading is decreased form 5 kg to 15kg. Below figure 2 shows the cyclic fatigue behavior of the specimen. The number of cycles hasincreased from 21,365 to 27,681 for 5% concentration of the particles, this accounts for around 22% increase in the fatigue limit. Similarly for 10% concentrations the fatigue cycles have increased from 15,321 to 22,698 it accounts for around 32% increase in the fatigue life and similarly for 15% weight fractions it has increased from 14,221 to 19,315 cycles which is about 26% increase in the endurance limit. This increase is due tolower stress developed as the applied load is decreased.

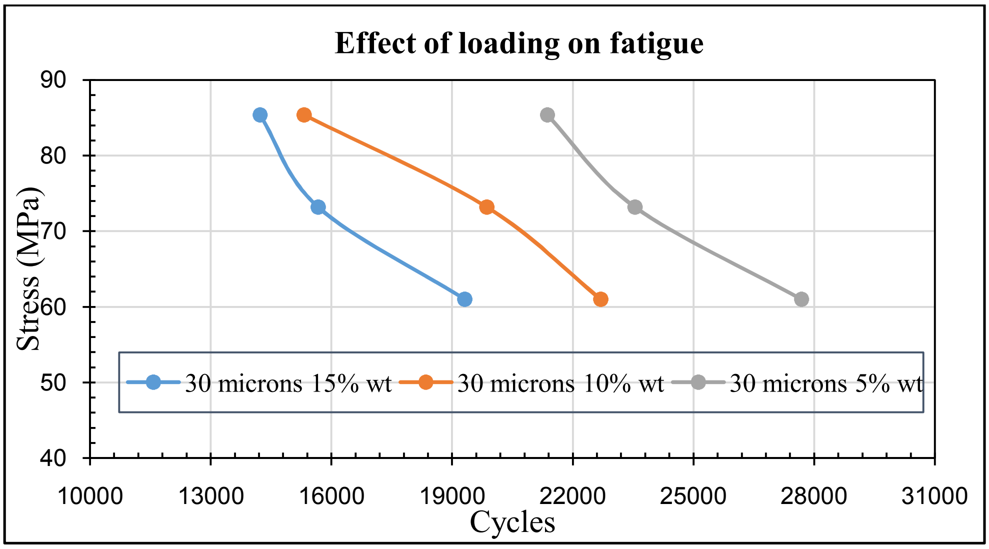

Figure 2: Stress v/s Number of cycles for 30 µ Al_2O_3 particles

The corresponding increase is also due to reduced Al_2O_3 particle concentrations. An improvement in life cycle of about 15%-18% is observed, the lower weight percentage of the Al_2O_3 particles, the higher number of fatigue cycles recorded. The clusters create artificial cracks to lead it for final early failure of the composites. Lack of interfacial interaction between the matrix and the reinforcement creates the artificial cracks at number of locations some may lead to critical length which leads to final failure.

3.2 Effect of loading on fatigue life of Al_2O_3 for60 micron particle composite

To study the effect of increase in the concentration of the alumina particles, tests were further extended for 60 microns particle size. The results of the tests are shown in the below figure 3, for different loading condition the graph has been plotted. Observation reveals that the trend of the previous tests is being maintained. The reinforcement material has improved the cycles to failure in comparison with 30micron particles for the same 5% weight percentage. The 60 micron Al_2O_3 particle with 5%, weight percentage has increased the number of cycles from 29,346 to 43,125 cycles which is about 32% increase. The improvement in the result is accounted for the surface characteristic of the particles.

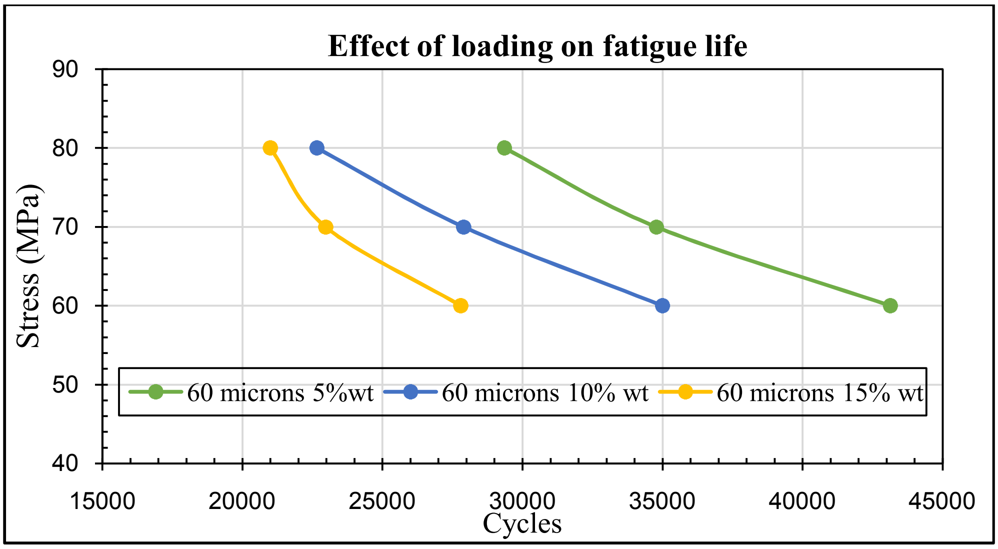

Figure 3: Stress v/s Number of cycles for 60 µ Al_2O_3 particles

Similarly the fatigue limit cycles have increased by 36%, 35% and 31% for 5%, 10% and 15% weight percentages respectively in comparison with 30 micron particle for similar loading conditions. The improvement is found to be the surface texture suits better for good wetting of the matrix material. Mixing of the particles due to density difference may also be a factor for the improvement of the fatigue cycles. Uniform distribution of the Particles can be observed for better results

3.3 Effect of loading on fatigue life of Al_2O_3 120 micron particle composite

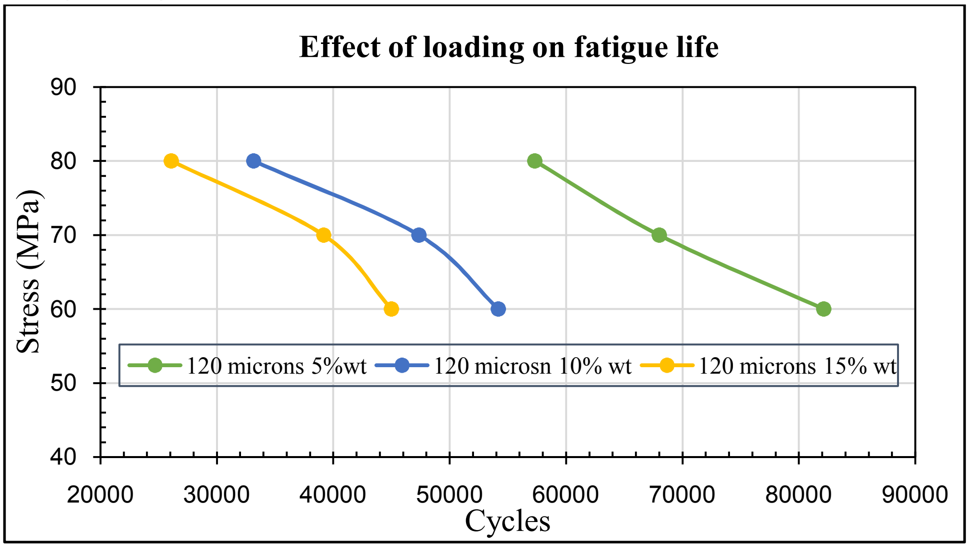

Figure 4: Stress v/s Number of cycles for 120 µ Al_2O_3 particles

Further test for higher particle sizes are conducted and the results reveals that for larger particle size and with lower concentration of the particles, the results are improved with better fatigue life cycles. It is recorded that, 120 microns with 5% concentration has yielded maximum cycles to failure in comparions with all other combination of size and concentration as shown in figure 4. The 5% weight fraction have shown improvement in the fatigue life with an incrase from 43,125 to 82,157 cycles which is nearly 48% significant incrase. Similar improvements has been observed for 10% weight fraction, life cycle increases from 33,142 to 54,180 cycles and for 15% weight fraction 26,078 to 45,0002. Over all improvement about 45% has been observed for 5% in comparision with 15% weight fraction. The improvement in the result is observed to be the increase in the wettability of the reinforcement with the surrounding matrix. The surface interaction between two elements is strong hence the fatigue limit is increased for the same loading conditions for lower particle sixes. Further increase in the particle content, increased the clogging of the particles.

It can be co related between the above two graphs that as the prticle content incrases, the particles are not uniformly distrubuted and they are forming the clusters. These clusters reduces the surface interface bonding between the matrix and reinforcement materials. The shrotage of matrix material around the particle is also the reason for not having the affinity between the two elements. This creates many artificial cracks to initiate and some reach to critical length to reach to the early failure of the component. Hence it can be concluded that the optimum combination is 120 microns with 5% weight fraction for alumina particls have given the maximum fatigue life cycles.

IV. CONCLUSION

It can be concluded that , as the particle concentration is increases, the fatigue life is decreases for all particle sizes of the reinforcements. This is attributed mainly to improper distrubution of the particles in the matrix and this leads to many artificial cracks leading to early failure. The observation reveal that larger particle size with lower concentration of the particles yield highest life cycles. Larger surface area for the particles shows better interaction with the matrix leading to better wettability hence the improvement in the life cycles.

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