Fatigue and Facture Behaviour of Al6061-Al2O3 Metal Matrix Composite: Effect of Heat Treatment

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Abstract. Metal matrix composites of 6061Al - Al2O3 matrix are associated as standard materials inside the space of flying, car and marine applications to move forward the physical properties. Particulates of Al2O3 with 40 µm, 60 µm &100 µm were reinforced utilizing Die casting method. Next stage of fortre is being changed from 0-16wt% in steps of 4wt%. Microstructural characterization has been conducted for the composites to check the homogeneous movement of particles. Fatigue and Facture Toughness properties of 6061Al - Al2O3 composite have been inspected. Effect of fortress on the Disintegration, Shortcoming and Facture toughness properties was considered carefully. A considerable enhancement in Fatigue and Facture Toughness properties was observed by the incorporation of particulates. Formation uniformly dispersed particulates in the matrix was observed for the composite up to 12% filler composition.

Keywords: Al6061, Al2O3; Die- Casting; Mechanical Properties; Corrosion test; Fatigue test; Facture Test.

1. Introduction
Immaculate metals of aluminum have slight quality and we cannot utilize with specific reason wherever extreme to twisting and burst is essential extra components are settled to base metals for surge control. The prime mechanical properties of aluminium6061 are achieved in alloying trappings and warm medicines. This invigorates the establishment of small warm rushes through line by signal of relocation and improve its mechanical properties. Commonly utilized aluminum combination for mechanical application is Al6061 due to its ravishing wide-ranging properties those are small thickness, incredible quality, ductility sturdiness and strife to fatigue. It takes remained broadly expended in airplane essential components and extra endlessly focused on basic application.

Al6061 combination is as well defencelessness to push oxidization angry. It is happened by homogeneity of the 6061alloy and natural persevering stresses associated by its innovation approaches. The point of the work are to look at the gear of warm conduct on the microstructure, unbending nature of aluminum 6061metal and aluminum 6061/Al2O3 MMC’s. A blend of Al2O3including to aluminium6061 amalgam and extra reinforcing is accepted by the way of possible reserves of assistant advances the mechanical properties of this 6061alloy primarily for temperature tradition. So, presently this examination on the properties of heat treatment is utilized as a assets of developing the mechanical properties of aluminum 8% Al2O3 alloy. Aluminum 6061 is utilized in a kind of cast and fashioned frameworks and circumstance of heat treatment.
Die casting procedure is a reasonable and low-cost technique to convey MMCs. Other than being essential, versatile, and appealing, as compared with other strategies, it licenses the era of components in broad sum. Other than, this sort of planning is by commercial utilize for the course of action of particulate Al-based composites Al$_2$O$_3$ alloy. Aluminium 6061 are utilized in a kind of a cast and made systems and circumstance of heat treatment.

The Metal matrix composites ensure a wide choice of orchestrating applications. They have been broadly organized for mechanical devices ask to headway the mechanical, chemical and warm presentation of mechanical components. [1] But, its small break quality [2] limits this one utilization in various applications. Copious effort has been truly in instruction to move forward the facture sturdiness of Al$_2$O$_3$. A curiously approach is to upgrade another fortifying organize they are particles, hairs and strands to the Al6061- Al$_2$O$_3$ system [3–6].

In show disdain toward of the reality that, these managing with offerings certain challenges with troublesome course of action organize, more costs, difficult to urge a typical dissemination of the other organize. The break strength of Al6061- Al$_2$O$_3$ composite materials can be made strides by the combination of metal components by a plastic execution sharp on the Al6061- Al$_2$O$_3$organize [7-11]. In formerinvestigation Al6061- Al$_2$O$_3$composites was organized to recognize extraordinary mechanical properties and awesome break strength. Mishra et al. observed the microstructure of break sturdiness Al6061- Al$_2$O$_3$ system [12].

Mixed mode fatigue crack growth experiments were performed using the compact tension shear specimens made of Al 6061-T6 alloy for mode mixity angles of 30°, 45°, and 60° [13]. Based on the overall performance of the models during the entire crack growth regime, the results of the present investigation clearly show that Irwin’s model and one of the Tanaka’s model were consistently found to predict the mixed mode fatigue life close to the experimental data. Whereas, Richard’s and Yan’s models, again based on the overall performance, are found to be conservative models consistently for the prediction of the mixed mode fatigue life.

The effect of building orientation on the very-high-cycle fatigue (VHCF) response of Ti-6Al-4V specimens produced through selective laser melting (SLM) process with three different building orientations (0°, 45° and 90°) was experimentally assessed [14]. Size of defects induced fatigue failures and the stress intensity factor range decrease with the number of cycles to failure. The building orientation significantly influences both the defect size and the resulting VHCF response.

Crack closure induced by laser peening (LP) and its effect on fatigue life extension of 2024-T351 aluminum alloy with initial fatigue crack was studied [15]. The fatigue life of the LP-treated pre-cracked specimen was 412% and 44.7% higher than the untreated specimen and LP-treated specimen without pre-crack, respectively. The crack closure around the pre-crack resulting from the LP-induced plastic deformation is mainly responsible for fatigue life extension.

The high-temperature fatigue behaviour of a heat treated AlSi7Cu3Mg alloy was reported [16]. Fatigue testing has been performed at room and higher temperatures. The fatigue strength decreases by increasing the testing temperature from 473 to 573 K. The uniform distribution of fine strengthening precipitates in the α-Al matrix is affected by higher test temperature, which promotes coarsening phenomena of the precipitates. The failure mode changes from brittle to ductile at 573 K.

Ceramic coatings were produced on AA7075-T6 alloy by micro-arc oxidation (MAO) [17]. Effects of duty cycle on microstructure and fatigue behavior of the coated samples were investigated. The influence of the residual stress relaxation on the fatigue life at high and low cyclic stresses was explored. Defects on coating surface including pores and cracks decreased the fatigue life of the substrate.
In the present investigation focused on the fatigue properties of Alumina reinforced Al6061 alloy.

2. Material
In Table 1 as shown Composition of matrix metal 6061 Al alloy. In Table 2 and 3 are represented the mechanical and physical properties of matrix metal 6061 Al alloy respectively. The alumina properties are depicted in Table 4.

| Table 1. Chemical composition of 6061 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Mg  | Si  | Fe  | Cu  | Cr  | Mn  | Zn  | Ti  | Al  |
| 0.9 | .62 | 0.33| 0.28| 0.17| 0.06| 0.02| 0.02| Balance |

| Table 2. Mechanical Properties of Al6061 |
|----------------------------------------|
| Property                  | Values  |
| Yield strength (MPa)        | 110     |
| Ultimate strength (MPa)     | 207     |
| Elongation (%)              | 16      |
| Hardness (BHN)              | 75      |
| No of cycle                 | 2000/min|

| Table 3. Mechanical Properties of Al6061 |
|----------------------------------------|
| Property                  | Values  |
| Density                   | 2.7 g/cm³|
| Melting Point             | 580°C    |
| Modulus of Elasticity     | 70-80 GPa|
| Poisson’s Ratio           | 0.33     |

| Table 4. Properties of alumina |
|-------------------------------|
| Property                      | Values  |
| Density (Gm/cc)               | 3.89    |
| Porosity (%)                  | 0       |
| Elastic Modulus (GPa)         | 375     |
| Shear Modulus (GPa)           | 52      |
| Bulk Modulus (GPa)            | 228     |
| Poisson’s ratio               | 0.22    |
| Fracture Toughness (MPa)      | 4       |
| Hardness                      | 1440    |
| Compressive strength (MPa)    | 2600    |

3. Experimental

3.1 Die Casting
Die casting method, the stable die and it is constructed with steel. The molten metal pouring into mould cavity with high pressure and high speed. It takes duplet upright platens on which boosts are situated
which add the die shares. In duel platen, one die platen is fixed and additional die platen is employed for released and locked die. Inserted the necessary metal into the shot sleeve and then presented into the casting die by a hydraulically-driven piston. When the metal has hardened, the mould cavity is opened, and removes the casted metal. Thus, Al6061/Al₂O₃ composite with frequent dissimilar compositions (0, 4, 8, 12 and 16wt %) was attained rectangular solid shaped bars with dimension of 25mm and a length of 150mm.

3.2 Facture Toughness Test

The facture toughness testing of the composite material models were prepared according to ASTM E8 standard, through the using of three point bending machine in figure 2. The dimension of the models was 10mm width and 4mm thickness and length 80mm as exposed in below figure 1. Facture test were examined in Raghavendra Metallurgical centre peenya, Bangalore.

![Figure 1. Facture test specimen according to ASTM standard.](image)

![Figure 2. 3-Point Bending test.](image)

3.3 Fatigue Test

The fatigue testing of the MMC samples were prepared as per the ASTM E446 standard, with the use of digital testing rotating bending fatigue test machine. The samples with dimension of diameter 10mm and 6mm and measure length 100mm are shown in Figures 3. The samples were introduced for test with a speed of 1500rpm and temperature range from 100 to 300. Fatigue test was investigated in Dr. Ambedkar Institute of Technology, Bangalore.
4. Results and Discussion

4.1 Without Heat Treatment of Facture Test

Table 5. Facture Test Result of Al6061/Al$_2$O$_3$ composite.

| Microns | Reinforcement (%) | Facture stress in MPa | % of Elongation |
|---------|-------------------|-----------------------|-----------------|
|         | 0                 | 118.25                | 12              |
| 40      | 4                 | 146.45                | 23              |
|         | 8                 | 173.28                | 62              |
|         | 12                | 198.32                | 125             |
|         | 16                | 182.46                | 112             |
|         | 4                 | 132.26                | 17              |
| 60      | 8                 | 158.45                | 53              |
|         | 12                | 179.21                | 118             |
|         | 16                | 167.52                | 103             |
|         | 4                 | 118.85                | 13              |
| 100     | 8                 | 142.12                | 46              |
|         | 12                | 169.23                | 112             |
|         | 16                | 150.82                | 97              |

Figure 3. Fatigue test specimen according to ASTM standard.

Figure 4. Ultimate Tensile Strength V/S Reinforcement of Al6061/Al$_2$O$_3$ composite.
Above plot provides the details about the Facture toughness of prepared composite material. There is substantial modify in the graph for composite materials differentiate to pure base material. Increase in all the fatigue properties can be obviously looking in the figure 4&5. Adding of particulates enhance the stability of base material. A reduction in elongation at break is observed by the adding of particulates. This is due to the interaction developed between matrix and filler.

Facture toughness properties such as shown in Table 5. The values are improved step by step up to 12 % of particulates in the aluminum matrix. Further, the values found to be reduced. Agglomeration of particulates or reduction in the consistency of dispersal reduces the Facture toughness properties of the composites at higher loading stage. From result we can conclude 12% of 40 microns particle has a good facture toughness properties compare to other two particles such as 60 and 100. Here we can select 12% of 40 microns particles aircraft and automobile application.

4.2 With Heat Treatment of Facture Test

| Microns | Reinforcement (%) | Facture stress in MPa | % of Elongation |
|---------|-------------------|-----------------------|-----------------|
| 0       | 142.45            | 23                    |
| 4       | 170.52            | 35                    |
| 8       | 197.52            | 73                    |
| 12      | 221.82            | 138                   |
| 16      | 203.65            | 121                   |
| 4       | 155.42            | 29                    |
| 8       | 182.24            | 68                    |
| 12      | 200.54            | 132                   |
| 16      | 189.32            | 115                   |
| 4       | 145.32            | 25                    |
| 8       | 167.28            | 62                    |
| 12      | 188.44            | 124                   |
| 16      | 172.38            | 110                   |
Figure 6. Ultimate Tensile Strength V/S Reinforcement of Al6061/Al₃O₃ composite

![Graph showing Ultimate Tensile Strength vs Reinforcement percentage for 40, 60, and 100 microns particles.]

After Hear treatment above plot provides the details about the Fracture toughness of prepared composite material. There is substantial modify in the graph for composite materials differentiate to without heat treatment of the Al6061/Al₃O₃ Composite. Increase in all the fatigue properties can be obviously looking in the figure 6 &7. Addition of Heat increases the stability of Al6061/Al₃O₃ Composite. A reduction in elongation at break is observed by the addition of heat. Addition of heat increases the bonding between matrix and filler.

Facture properties such as shown in Table 6. From result we can conclude 12% of 40 microns particle has a good Facture toughness properties compare to other two particles such as 60 and 100. Here we can select 12% of 40 microns particles aircraft and automobile application.
4.3 **Without Heat Treatment of Fatigue Test**

**Table 7.** Fatigue Test Result of Al6061/Al₂O₃ composite.

| Microns | Reinforcement (%) | Fatigue stress in MPa | Number of Failure Cycle X 10⁴ |
|---------|-------------------|-----------------------|-------------------------------|
|         | 0                 | 118.25                | 12                            |
| 40      | 4                 | 146.45                | 23                            |
|         | 8                 | 173.28                | 62                            |
|         | 12                | 198.32                | 125                           |
|         | 16                | 182.46                | 112                           |
|         | 4                 | 132.26                | 17                            |
|         | 8                 | 158.45                | 53                            |
| 60      | 12                | 179.21                | 118                           |
|         | 16                | 167.52                | 103                           |
|         | 4                 | 118.85                | 13                            |
|         | 8                 | 142.12                | 46                            |
| 100     | 12                | 169.23                | 112                           |
|         | 16                | 150.82                | 97                            |

**Figure 8.** Fatigue stress V/S Reinforcement of Al6061/Al₂O₃ composite
Figure 9: No of failure cycle V/S Reinforcement of Al6061/Al₂O₃ composite

Figure 10: Fatigue Stress V/S No of failure cycle of Al6061/Al₂O₃ composite

Above plot provides the details about the fatigue properties of prepared composite material. There is substantial modify in the graph for composite materials differentiate to pure base material. Increase in all the fatigue properties can be obviously looking in the figure 8, 9 & 10. Adding of particulates enhance the stability of base material. A reduction in elongation at break is observed by the adding of particulates. This is due to the interaction developed between matrix and filler.

Fatigue properties such as shown in Table 6. The values are improved step by step up to 12 % of particulates in the aluminum matrix. Further, the values found to be reduced. Agglomeration of particulates or reduction in the consistency of dispersal reduces the Fatigue properties of the composites at higher loading stage. From result we can conclude 12% of 40 microns particle has a good fracture toughness properties compare to other two particles such as 60 and 100. Here we can select 12% of 40 microns particles aircraft and automobile application.
4.4 With Heat Treatment of Fatigue Test

Table 8. Fatigue Test Result of Al6061/Al₂O₃ composite

| Microns | Reinforcement (%) | Fatigue stress in MPa | Number of Failure Cycle X 10⁴ |
|---------|-------------------|-----------------------|--------------------------------|
| 0       |                   | 142.45                | 23                             |
| 4       |                   | 170.52                | 35                             |
| 8       |                   | 197.52                | 73                             |
| 12      |                   | 221.82                | 138                            |
| 16      |                   | 203.65                | 121                            |
| 4       |                   | 155.42                | 29                             |
| 8       |                   | 182.24                | 68                             |
| 12      |                   | 200.54                | 132                            |
| 16      |                   | 189.32                | 115                            |
| 4       |                   | 145.32                | 25                             |
| 8       |                   | 167.28                | 62                             |
| 12      |                   | 188.44                | 124                            |
| 16      |                   | 172.38                | 110                            |

Figure 11. Fatigue Stress V/S No Reinforcement of Al6061/Al₂O₃ composite
After Heat treatment above plot provides the details about the fatigue properties of prepared composite material. There is substantial modify in the graph for composite materials differentiate to pure base material. Increase in all the fatigue properties can be obviously looking in the figure 11, 12 & 13. Addition of Heat increases the stability of Al6061/Al\textsubscript{2}O\textsubscript{3} Composite. A reduction in elongation at break is observed by the addition of heat. Addition of heat increases the bonding between matrix and filler.

Fatigue properties such as shown in Table 8. From result we can conclude 12% of 40 microns particle has a good Fatigue properties compare to other two particles such as 60 and 100 Here we can select 12% of 40 microns particles aircraft and automobile application.

4.5 Microstructure studies by SEM

Figure 14 displays the Fatigue & Facture Test SEM picture of Al60601/Al\textsubscript{2}O\textsubscript{3} metal matrix composite. A well microstructure is seeing in all Al60601/Al\textsubscript{2}O\textsubscript{3} metal matrixes composite and it shows a better scattering of particulates during the matrix.
Figure 14. Fatigue & Facture Test SEM Images (a - e) of Al6061/Al₂O₃ composite

a) Cup cone pattern  b) Trans granular facture  c) Trans granular facture  d) Inter granular facture  e) River pattern

5. Conclusion
Three-point bending test of an aluminum 6061 reinforced particulate Composite impregnated with Al₂O₃ are studied to determine the flexural stress, flexural strain and maximum bending strength. In the present work, aluminum 6061 and Al₂O₃ particles are mixed in different compositions. It is observed that the composite with a composition of 4% Al₂O₃ enhances the Facture and Fatigue properties. The Fatigue property and Facture stress is greatly influenced by Al₂O₃. Aluminum composite material having good mechanical properties on increasing the percentage of alumina. Composites with Al₂O₃ particles up to 12% increase the tensile strength 290MPa and elongation 4.8% in aluminum alloy matrix containing Cu-Zn-Mg. Finally, it can be concluded that the composite material developed in the present investigation found to be good in terms of mechanical properties. SEM microphotographs clearly show the nature of dispersion and it reflects in the mechanical properties. Heat treatment increases the stability of the resulting composites due to the enhanced interaction between filler and matrix phases.
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