Experimental Investigation of Mechanical Properties of Al6061 Reinforced with Iron oxide

S P Shivakumar¹, A S Sharan² and K Sadashivappa³

¹ Department of Mechanical Engineering, SJM Institute of Technology, Chitradurga, India
²,³ Department of Mechanical Engineering, Bapuji Institute of Engineering and Technology, Davangere, India
¹shiv180ct@gmail.com

Abstract. The present work aimed at investigating the mechanical properties of the aluminum matrix composites. The aluminum 6061 alloy as a matrix reinforced with the weight fraction 2, 4 and 6% of particles of iron oxide (Fe₂O₃) of size 40µm is prepared using the stir casting technique. The prepared specimens are tested as per the standards for tensile, bending, impact and hardness properties of the composite. From the results it is observed that the mechanical properties of the said composite have increased with the increment in the weight percentage of iron oxide up to 4% of reinforcement. The significant reaction between the reinforcement and the matrix forms the better bonding between them. The enhanced mechanical properties of the aluminum-iron oxide composites are due to the fine, well bonded and homogeneous distribution of the iron oxide particles in the aluminum matrix. The maximum improvements were observed at 4 wt% of Fe₂O₃.

Keywords: Aluminium alloy, Iron oxide, mechanical properties, MMCs, Stir casting.

1. Introduction
Aluminum matrix composites referred as AMCs are now a day’s attractive for their high strength, stiffness, improved fatigue strength, workability, low density, better thermal stability and improved wear resistance, corrosion etc. [1]. Thus AMCs find their applications in aviation, automobile, structural as well as transportation industries [2]. Composites with Fe₃Al reinforcement exhibits better strength in contrast with the some of the ferrite-austenite steels. Hence these become potential candidates for the applications in high temperature materials. On the other hand, the strength of these materials decreases at higher temperatures which limits their applications [3-4]. Various authors studied the Al-Fe system, and reported that as the Fe content increases the modulus of elasticity and rigidity increases. The poison’s ratio of the Al-Fe system decreases nearly by 0.0023% for every 1% addition of Fe. It has been also reported that the increases in the Fe content increases the creep strength, slight improvement in the machinability and decrement the fatigue strength if the crystals size is course [5]. Wang et al [6] conducted the experimental investigation on the influence of the chemical composition of the alloy prepared using the high pressure die casting technique. The composite has prepared using the 7 wt% and 13 wt% of silicon reinforcement. From the results it is concluded that the
elastic modulus of the alloy has no significant influence by the chemical composition of alloy. On the other hand, the increment in the Fe content by 0.7 to 1.6% has the slight improvement in the elastic modulus. M. Makhlouf [7] worked on the Al–Si alloys and stated that the addition of the Fe, which is insoluble, enhance the strength at elevated temperatures. Authors noted that the adding of elements Fe and Ni reduces the Cu content without reducing the high temperature strength. On the other hand, authors observed that the addition of Fe and Mn holds the crack propagation rate of the alloy. It is also reported that the adding of the Fe in an Al–Si–Mg alloy, have significant influence, improves the hot tearing resistance as it increases the high temperature strength. Maity et al [8] worked on the addition of the CuO particles in the pure aluminum for the production of the Al₂O₃ in situ particle composite. In the reaction, the metal generally reacts with aluminum and forms the intermetallic phases such as Al₂O₃ and Fe₃Al.

Sarkari Khorrami et al [9] examined the influence of the number of FSP passes on the micro-structural and mechanical properties of aluminum matrix reinforced with 4 wt% of Fe particles. The two FSP parameters used are volume fraction of the reinforcing particles and the tool rotation direction. Through this study the effectiveness of the formation of in-situ particles, grain boundaries and other strengthening mechanisms were explored.

Similar works has been carried out by many researchers about the preparation and evaluation of mechanical properties of the Al-matrix composites with Fe as a reinforcement prepared using stir casting technique [10–12], powder metallurgy route [13–16] etc. From the obtained results it is concluded that the presence of Fe in the composite enhances the mechanical properties of the material and that strengthening mechanism is related to the uniform distribution and grain refinement of the Fe particles and the generation of the intermetallic.

Stir casting method of casting the aluminium composites were widely used because of their liquid phase method, economical and ease to conduct. The other methods include the powder metallurgy, die casting, centrifugal casting, pellet method etc. which are expensive, have complex process and methodology and may require the skilled labours. By this way they were limited in application than the stir casting technique.

Various authors studied the aluminium composites produced using the stir casting method. The fabrication of aluminium composites with the iron oxide and multi wall carbon nano tubes(MWCNT) [17] reinforcements, AA6061-redmud composites [18] and AA6061-rutile composites [19] through stir casting techniques. The study of the mechanical properties of aluminium-silicon carbide composites has been carried out using the stir casting techniques [20–23] for varied weight fraction of the silicon carbide.

From the results it is observed that the mechanical properties of the said composite have been increased as the increment in the reinforcement [21–23]. However, authors [22, 27] reported in their work that the addition of SiC particles up to 5 wt% in the aluminium matrix will enhance the mechanical properties of the composites.

From the comprehensive study of literature, it is identified that much work has been carried out on the aluminium matrix Fe reinforcements prepared by the powder metallurgy route. There is a scope for the study of the aluminium-iron oxide composite produced using the stir casting technique. The major objective of this work is to investigate the mechanical properties of the AA6061-Fe₂O₃ particulate composites produced using the stir casting route. The composition considered for the preparation of the composite is 2wt%, 4wt%, and 6 weight fraction of the reinforcement. The tensile, bending, impact and hardness tests of the said composite will be conducted using ASTM standards. Through this work an attempt has been made to compare the AA6061-Fe₂O₃ composites with AA6061-SiC composites.

2. Materials and Preparation

2.1. Material Selection

Aluminum 6061 as matrix material is used in the present work. Its chemical composition is given in the Table 1. AA6061 is selected due to its outstanding properties such as weld ability, light weight, corrosion resistance, etc. which were necessary for the applications in the automobile and aerospace industries. The reinforcement chosen is iron oxide.
Table 1. Chemical Composition of Aluminum 6061

| Element | Mg  | Si  | Cu  | Zn  | Ti  | Mn  | Cr  | Al   |
|---------|-----|-----|-----|-----|-----|-----|-----|------|
| Wt %    | 0.85| 0.68| 0.22| 0.07| 0.05| 0.32| 0.06| Balance |

Figure 1 shows the particles of the iron oxide, which is used as reinforcement, is inorganic compound with chemical name Fe$_2$O$_3$. Iron oxide may available in main three forms such as FeO, which is rare; Fe$_3$O$_4$, occurs naturally; and the Fe$_2$O, which is the main source of iron. The iron oxide is the ferromagnetic material, in appearance dark red in color, ready to react with the acids. Sometimes iron oxide referred as the rust, due to its similar composition and shares many properties as iron.

Figure 1. Iron oxide powder

2.2. Fabrication of composites using stir casting
The techniques used in manufacturing of the metal matrix composite are expensive, complex process and skilled labors are required. Among many methods the liquid phase routes were attract the researcher because of their ease and economical as like conventional casting processes and can produce components of complicated shapes. The most economical, widely used liquid phase route method is the stir casting method which is shown in figure 2.

Figure 2. Stir casting setup [12]
The 2, 4 and 6 wt% of the iron oxide particles were poured, separately, to the super-heated liquid aluminum at the temperature 720°C. The required quantity of the reinforcement is added while stirring at the speed of 550 rpm. The liquid Al6061-Fe2O3 composite then poured to the graphite mold and left to solidify. The parts taken from the mold were now machined to prepare the specimens for different experimental testing.

3. Experimentation

To determine the mechanical properties of the AA6061-Fe2O3 particulate composite different tests were conducted such as tensile, bending, impact and hardness test. For all the three combinations i.e. AA6061-2wt% Fe2O3, AA6061-4wt% Fe2O3 and AA6061-6wt% Fe2O3, specimens were prepared to examine the material properties. All the experiments were carried out as per the ASTM standard testing procedures.

3.1. Tensile test

The tensile tests for all the three compositions have been conducted using universal testing machine (UTM). The specimens prepared are as per the ASTM E08-8 standards. The standard test specimen with dimensions is given in figure 3. The specimen diameter used is 13mm and gauge length used is 57mm, is fitted in a UTM of capacity 200kN. During testing the load applied and the displacements reading were recorded to calculate the stress and strain. From the experiments, yield strength, ultimate tensile strength etc. can be determined. The results were based on the average of three samples.

![Figure 3. Tensile Test Specimen [24]](image)

3.2. Flexural test

The bending test experiment was conducted for all the three compositions. The specimen prepared is as per the ASTM E290 standards. The specimen (shown in figure 4) is prepared for the following dimensions to study the flexural behaviour of the composite.

![Figure 4. Flexural test specimen](image)

3.3. Impact test

Due to the reliability and economical, charpy impact testing is widely used to test the metallic materials. The charpy impact test is conducted, for all the three compositions, to absorb energy required to initiate the crack and continue till the fracture. The specimen (shown in figure 5) is prepared as per ASTM E23 standards.
3.4. Hardness test
The characteristic that resist to the deformation of the solid material is referred as the hardness. Hardness test can be conducted based on the depth of penetration under the application of the external uniform load. For the hardness test, ASTM E23 standards were prescribed for the specimen preparation. Prepared specimens with dimensions were shown in figure 6. The hardness tests were carried out, for all the three compositions, using the diamond indenter in the Brinell hardness testing machine with applied force of 10kgf. For each composition, three specimens were prepared and tested and average value is considered as the hardness of the composite.

4. Results and Discussion

4.1. Tensile Properties
Tensile properties such as elastic modulus, poison’s ratio, tensile strength, yield strength, percentage reduction in area and elongation (which is the measure of ductility) etc. can be determined by the tensile test. Tensile test of AA6061- Fe$_2$O$_3$ particulate composite for 2, 4 and 6 wt% of the reinforcement is conducted, in a room temperature, using universal testing machine with computerized data acquisition units. From the experiments, load and displacement data was recorded for the further analysis.
Test specimens of the composite were tested, for the fracture load, till it reaches ultimate tensile strength. From the recorded data of load and displacement, the stress and the strain values were calculated. The stress-strain graph is plotted to found the elastic modulus, yield strength and ultimate tensile strength as shown in figure 7. From the plot it can be observed that the reinforcement has significant influence on the tensile properties of the AA6061-Fe$_2$O$_3$ composite. As the composition of the reinforcement increases from 2wt% to 4wt%, the increment in the tensile properties of the composite has been observed with the decrement in the strain by 0.1%. Also further increment in the composition from 4wt% to 6wt%, the decrement in the tensile properties has been observed. From the literature, it has been also observed that the mechanical properties of the MMCs were optimum for the composition in the range 3 to 5wt% of reinforcement [12]. The determined values of the tensile properties of the AA6061-Fe$_2$O$_3$ composite have been listed in the Table.2.

Table 2. Tensile properties of Aluminum Iron oxide composites with 40µm particle.

| Sl.No | Specimens          | Yield strength(MPa) | Ultimate tensile strength(MPa) | Young’s modulus(GPa) | Percentage Elongation |
|-------|--------------------|---------------------|--------------------------------|----------------------|-----------------------|
| 1     | AA6061             | 110                 | 152                            | 60                   | 20                    |
| 2     | AA6061+2% Fe$_2$O$_3$ | 175                | 215                            | 64                   | 10                    |
| 3     | AA6061+4% Fe$_2$O$_3$ | 186                | 229                            | 70                   | 9.8                   |
| 4     | AA6061+6% Fe$_2$O$_3$ | 178                | 220                            | 66                   | 8.9                   |

From the table it is also observed that there is little decrement in the percentage elongation for the reinforced composite. This means that AA6061-Fe$_2$O$_3$ composite is able to maintain its ductility even after increasing the weight fraction of the reinforcement. Hence the enhancement in the tensile, yield and elongation of the composite has been observed.

4.2. Bending Properties
The three point bending specimen is used to characterize the flexural strength. Flexural strength is the stress at failure of the material under the flexural load. All the three composition of the composites have been tested as per the standard testing procedures to find the bending properties. During bending test, the applied load and displacement values have been recorded and used to calculate the values of stress and strain. The strain-strain curves were plotted using the calculated values of stress and strain.
The bending curves of AA6061-Fe$_2$O$_3$ composite for various weight percentages (2wt%, 4wt% and 6wt%) of reinforcement is shown in the figure 8. From the plot it is clear that as the increment in the composition of iron oxide the bending resistance increases. It is also observed that the bending properties of the AA6061-Fe$_2$O$_3$ composite increases with the weight fraction up to 4 wt% of the reinforcement, further increases of composition decrease the bending properties.

The calculated flexural strength and the percentage elongation are listed in the Table 3. From the outcomes it is clear that addition of iron oxide greatly influences the flexural strength of the composites. The flexural strength of the AA6061-Fe$_2$O$_3$ composite increases as the increment in the percentage reinforcement up to 4 % and the maximum flexural strength obtained is 304 MPa. There is increment of 50% in the flexural strength of the composite for 4 wt% of iron oxide in comparison with the unreinforced aluminium alloy.

![Figure 8. Bending curves of AA6061-Fe$_2$O$_3$ composite for various percentages of iron oxide](image)

**Table 3.** Flexural properties of AA6061-Fe$_2$O$_3$ composites with 40 µm particle.

| Sl.No | Specimens            | Flexural strength (MPa) | Percentage Elongation |
|-------|----------------------|-------------------------|-----------------------|
| 1     | AA6061               | 152                     | 20                    |
| 2     | AA6061+2% Fe$_2$O$_3$| 271                     | 10                    |
| 3     | AA6061+4% Fe$_2$O$_3$| 305                     | 9.8                   |
| 4     | AA6061+6% Fe$_2$O$_3$| 289                     | 8.9                   |

4.3. Impact Properties

Using the charpy impact test, the energy required to break the sample can be determined. Charpy test is the one used to characterize the material under impact loading conditions. The Charpy impact test is conducted for all the compositions of AA6061-Fe$_2$O$_3$ composite specimens to determine its impact strength. The energy absorbed (J), in room temperature, for all the specimens is recorded.
In view of the fact that aluminum 6061 is a tougher material, its energy absorption capacity is higher. Also, since these composites were prepared using the liquid phase route methods, they exhibit higher impact toughness as compared to other methods. From the figure 9 it is clear that, as the weight percentage of iron oxide increases, impact strength increases. This increment in the impact strength is due to the ability of the material to hold its ductility property, against the increased composition, in turn absorbs more energy to fracture. The maximum impact energy absorbed is 32 Nm for the composition 4 wt% of iron oxide.

4.4. Hardness analysis
All the three compositions of the composites were tested for its hardness using the Brinell hardness testing machine at room temperature. The specimen dimensions used are 15mm × Ø25 mm.

At different locations on the surface of the specimen Brinell hardness test is conducted and the average value of the hardness has been calculated. Since the uniform distribution of the iron oxide particles in the aluminum 6061 matrix gives the uniform hardness values in the specimen at any location. The average values of the hardness of the composite for all the compositions are shown in the figure 10. From the figure 10, it is observed that the increment in iron oxide influence the hardness of the AA6061-Fe₂O₃ composite. The maximum value of hardness is obtained at composition 2 wt% of reinforcement.
4.5. Comparison of AA6061- Fe$_2$O$_3$ and AA6061- SiC

The aluminium 6061 composite with silicon carbide particles, with the weight fraction of 0 to 4% [21], 0 to 5% [22] and 0 to 10% [23] of SiC, were fabricated using the stir casting process. The tensile strength of the composite has been investigated. From the results was reported that the addition of reinforcement improves the mechanical properties of the AA6061-SiC composites [21-23]. The Table 4 shows the comparison of the increment in the tensile strength of the composite with respect to the unreinforced aluminium alloy. All the composites were prepared using the stir casting technique.

![Table 4. Comparison of the percentage increment in the tensile strength](image)

From the Table 4 it is clear that adding of reinforcement increases the tensile strength of the composite. The tensile strength obtained by the adding the 4 wt%, 5 wt% and 10 wt% of SiC particles to the aluminium alloy improves the tensile strength by 20.38%, 3.81% and 6.25% respectively in contrast with the unreinforced aluminum alloy. The addition of 4 wt% Fe$_2$O$_3$ to the aluminium alloy improves the tensile strength of the composite by 33.62% in comparison with the unreinforced aluminium alloy. Thus the AA6061-Fe$_2$O$_3$ composite can be utilized for the automobile, aerospace, marine and structural applications where it requires high strength requirements.

5. Conclusion

The influence of the addition of the iron oxide particles in the AA6061 matrix on the mechanical properties is examined in the present work. The AA6061-Fe$_2$O$_3$ composite is processed successfully using stir casting technique for different weight fractions of the iron oxide. Using the different experimentation, the mechanical properties of the AA6061-Fe$_2$O$_3$ composite were determined and the conclusions were summarized as follows.

The addition of iron oxide enhances the tensile properties. The ultimate tensile strength of the composite was increased by 50% for 4 wt% and decrement in the strain by 51% for the 4wt% of the AA6061-Fe$_2$O$_3$ composite has been observed. From the flexural test the adding of iron oxide to aluminium increases the flexural strength from 152MPa to 305 MPa for the 4wt% of the AA6061-Fe$_2$O$_3$ composite. The addition of 4 wt% of Fe$_2$O$_3$ influences more on the impact strength of the AA6061-Fe$_2$O$_3$ composite. Since the material holds the ductility even at 4 wt% of the reinforcement, it absorbs more energy as compared to the 6 wt% of Fe$_2$O$_3$. Since the addition of iron oxide particles have a little impact on the ductility, the composite prepared possess the little decrement in the hardness. Since the ability of giving more tensile strength for the given weight fraction of the reinforcement of the AA6061-Fe$_2$O$_3$ composite is more as compared to the AA6061-SiC composite, it will be used for the automobile, aerospace, marine and structural applications where it requires high strength requirements.

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