Influence of $\text{Al}_2\text{O}_3$ Nanoparticles Addition to AA6082-T6 on Mechanical Properties by Stir Casting Technique

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Abstract. The work aims at investigating the effects of the addition of $\text{Al}_2\text{O}_3$ nanoparticle as an enhancer on the mechanical characteristics of AA6082-T6 Metal Matrix Nano Composites (MMNCs) compounds. During the experiment, different weight fractions of $\text{Al}_2\text{O}_3$ nanoparticles (5, 10, 15, 20, 25, and 30 %) were added to molten AA6082-T6 using stir casting technique (SCT). Samples were formed at solidification and tested for mechanical properties, including the ultimate tensile strength (UTS), hardness (BHN), and density ($\rho$). Furthermore, the samples were evaluated for Young's coefficient (E) and yield strength (YS). From the results of the investigations, the developed method was found successful in ensuring the homogenous dispersion of the nanoparticles in the MMNCs. Increases in the proportion of the nanoparticles were found to increase the hardness (18.48%), density (15.89%), UTS (22.95%), Youngs modulus (27%), and YS (19.86%) while decreased were observed in the ductility (57.14%) as the proportion of the nanoparticles increases. Finally, Nano $\text{Al}_2\text{O}_3$ molecules were found to be a good material for the promotion of AA6082-T6 compounds.

1. Introduction
AA6082-T6 is a cast aluminium alloy that enables aging ad exhibits good corrosion resistance against salt spray and exposure to alkali; hence, it is ideal for military application [1]. Its dimensional stability is also good at elevated temperatures; this makes it good for use in welding structures [2, 3]. Regardless of these interesting properties, their mechanical properties need reinforcement for better engineering applications. To achieve this, ceramic materials must be used to reinforce alloys to improve their mechanical characteristics [4, 5].

Metal matrix composite materials are designed with the aim of combining the interesting features of ceramics and metals. Molecules of high strength & high refractive index are normally added to an elongated metal matrix and the outcome has mechanical properties in-between those of the ceramic and the matrix alloy. A study by Thangarasu et al. [6], focused on the fabrication of titanium carbide particulates-reinforced aluminium (6082-T6) matrix composites (AMCs) via stir casting. The study reported a successful fabrication of the composite with the incorporation of TiC particles at the proportion of 5 & 10 %. Investigations using scanning electron microscope showed uniform distribution of the TiC nanoparticles within the matrix. There were also improvements in the TS, microhardness, and wear resistance with increases in wt. % of TiC particles in the matrix.

Verma et al. [7] investigated the effect of B4C and RHA on Al-7075. SEM analysis was performed and increases in hardness were found with an increase in the wt% of B4C and RHA molecules. Kandpal & Singh [8] proposed a method using stir casting technique in which fabricated aluminium alloy 6061 reinforced with different $\text{Al}_2\text{O}_3$ particles wt% (5%, 10%, 15% and 20%) was
used. SEM technique was used to study the microstructure of the AMMC and the increase in wt. % of Al2O3 was found to increase the micro-hardness, tensile, and compression strength of the composite. Al-Alkawi et al. [9] fabricated nanomaterials with good mechanical properties from 6061AA-alloy. Five wt.% of nanoparticles (Al2O3) (20-30 nm grain size) were used during the study (1, 1.5, 2, 2.5 and 3wt% Al2O3). The nanocomposites were manufactured by stir casting technique. Also, it was obtained that all the mechanical properties of the nanocomposites were higher than that of the metal matrix.

In another study, Verma & Rao [10] reviewed the effect of various reinforcements on Al 6061. They concluded that fuss casting is the best method of fabrication. It increases mechanical properties by adding various reinforcements in Al 6061.

Ashwath et al. [11] studied the fabrication of aluminium alloy AA-SiC and AA- Al2O3 with different weight percentages (3, 6 and 9) of SiC and Al2O3 of 10 μm average particle size. Aluminium alloy 2024 reinforced with 6% wt. of Al2O3 specimens showed improved hardness results, stress-strain, and strength behaviour while aluminium alloy 2900 reinforced with 6 wt. % Al2O3 showed good formability and ductility properties closer to AA 2024.

Massoud et al. [12] fabricated MMC via a geometric 34 “combination of metal (matrix) and enhanced ceramic solid particles for designed properties,” MCMO is used in prototypes of space shuttle, commercial and electronic aircraft, pedestal, bicycles, cars, golf clubs, and a variety of other applications. Arumugam et al. [13] reinforced zirconium diboride particles of three different weight percentage (0, 3, 6 and 9 %) with aluminium alloy (AA6082) using the stir casting technique. Hardness, tensile and compression tests were conducted to evaluate the mechanical behaviour. The SEM microphotographs proved the successful dispersion of ZrB2 particles into the aluminium matrix and a tremendous improvement in the mechanical properties of the AMCs.

Samuel & Satish [14] noted differences in the mechanical characteristics of composites that are identical to each other superficially but varied in synthesis method. The study by Ramkumar & Natarajan [15] focused on the influence of TiO2 NPs with different microstructural modifications (0 to 3 wt. %) and reinforcement of pure Al developed using ARB technique. The outcome of the microstructural studies showed that the achievement of a uniform distribution of the “reinforcement particulates, ultrafine matrix grains and dislocations, as well as elongated grains are respectively due to rolling after eight passes.”

According to the literature review described in the previous section, the works were concerned with the following fields:

1. Different reinforcement (particle, Nano) with different percentage used in aluminium alloy.
2. Different grades of aluminium alloy used as metal matrix composite.
3. Multiple methods to manufacturing alloy.
4. The effect of reinforcement on mechanical properties, corrosion-fatigue behaviour, and weldability.

These properties can be improved by strict control of the distribution and quantity of the constituents of the compound and the processing conditions. Hence, the aim of this study is to fabricate and investigate the mechanical characteristics of AA6082-T6 reinforced with different proportions of Al2O3 nanoparticles.

2. Experimental work
Experimental work includes the following:

2.1. Materials
In this study, the raw materials used include AA6082-T6 Al alloy, Al2O3 powder, distilled water, coal and generating efficacy used in dissolving aluminium alloy scrap. The utilized AA6082-T6 is a 6000-series Al with a significant amount “of Mg and Si; the alloy is formulated for primary forming into wrought products.” This material is designated 6082 by the aluminium association (AA) while the European standards designated it as EN AW-6082. “ISO: AlSi/MgMn is the EN chemical designation. It is designated as H30 by the British Standard (BS) while the UNS number is A96082 [16]. Chemical analysis of the AA6082-T6 was performed at the “State Company for Inspection & Engineering
Rehabilitation (SIER), Formerly (The Specialized Institute for Engineering Industries.” Table 1 shows the chemical composition of the base metal while Table 2 provides the mechanical and physical properties of AA6082.

**Table 1.** Chemical compositions of AA6082-T6.

| Wt. % Max. | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
|------------|----|----|----|----|----|----|----|----|----|
| Measured (SIER) | 0.9 | 0.4 | 0.1 | 0.8 | 0.9 | 0.2 | 0.15 | 0.08 | Balance |

**Table 2.** Mechanical and Physical Properties of (AA 6082-T6)

| Material | Density (gm/cm³) | Hardness (BHN) | UTS (MPa) | YS (MPa) | Poisson's Ratio (v) | EL (%) | E (GPa) | Melting Point (°C) |
|----------|------------------|----------------|-----------|----------|-------------------|-------|---------|-------------------|
| AA6082-T6 | 2.7 | 75 | 262 | 230 | 0.3 | 14 | 70 | 650 |
| Measured (SIER) | | | | | | | | |

Al₂O₃ is among the commonly used and cost-effective materials in engineering ceramics (Figure 1). It is made from readily available materials and reasonably priced, thereby ensuring good value for the cost of the fabrication into shapes. With its excellent characteristics and good price, it has a wide range of industrial applications (Abdulhadi et al., 2017; Ghusoon et al., 2019). Table 3 shows the chemical composition of Al₂O₃ while Table 4 shows its mechanical and physical properties.

**Figure 1.** Al₂O₃ powder

**Table 3.** Chemical compositions of Al₂O₃

| Chemical compositions | SiO₂ | Fe₂O₃ | TiO₂ | Na₂O | Al₂O₃ |
|-----------------------|------|-------|------|------|-------|
| Wt. % | 0.15 | 0.05 | 0.15 | 0.45 | Rem. |

**Table 4.** Mechanical and Physical Properties of Al₂O₃

| Mechanical and Physical Properties | Value |
|-----------------------------------|-------|
| Hardness (VHN)                    | 1365  |
| Ultimate Tensile Strength (MPa)   | 300   |
| Modulus of Elasticity (GPa)       | 370   |
| Poisson's Ratio (v)               | 0.22  |
| Shear Modulus (GPa)               | 150   |
| Bulk Modulus (GPa)                | 228   |
| Flexural Strength (MPa)           | 400   |
| Fracture Toughness (MPa.m⁰⁵)      | 4     |
| Compressive strength (MPa)        | 3000  |
| Density (gm/cm³)                  | 3.69  |
| Melting Point (°C)                | 2054  |
| Boiling Point (°C)                | 3000  |
| Particle size (nm)                | 20-40 |
2.1. Stir Casting Technique (SCT)

Stir-casting technique (SCT) or Vortex Technique (VT) is one of the simple and common ways of fabricating metal matrix Nano composites; it involves the incorporation of the reinforcement particles into the molten metal matrix metal, such as Al. Then, a stirrer is introduced into the molten metal to mechanically stir the matrix in order to achieve a homogenous particles distribution within the molten metal. This is a common process for the incorporation of ceramic, graphene, metal oxide, and carbon nanotubes particles to both Mg and Al matrices [19]. However, this technique is associated with the following challenges:

(i) The tendency of nanoparticles to cluster due to high surface area and resulting high van der Waals forces between them;

(ii) Poor wettability of the solid nanoparticles with the molten metal; and

(iii) High density of porosity due to possible entrapment of the air induced by the rotating stirrer.

The stir casting process is depicted in Figure 2 [20]. The fabrication of AA6082-T6/(Al₂O₃) NPs of 20–40 nm average size at a specific stirring rate of 500 rpm and a temperature of 850°C was performed to ensure a great exploitation of the mechanical properties. In the production of other composites, the molten Al alloy is first removed from the gases, after which different weight ratios of Al₂O₃ molecules (5%, 10%, 15%, 20%, 25%, & 30%) were introduced to a specific volume of the molten Al alloy via STC at 7500°C; the combination is mechanically stirred to achieve a uniform particles distribution in the molten matrix. The mixture is allowed for 45 minutes at 700°C before being poured into molds & heated. The samples are removed after solidification, formed and prepared for different mechanical evaluations.

![Figure 2. Stir Casting Technique (SCT) (Rajan Verma, 2017)](image)

2.2. Percentage of Mixture

Table 5 shows the amount of based metal and the nanoparticles in weight percentage.

| AA6082-T6 (g) | Al₂O₃ (g) | Total weight (g) | Al₂O₃ wt. (%) |
|---------------|-----------|----------------|--------------|
| 950           | 50        | 1000           | 5            |
| 900           | 100       | 1000           | 10           |
| 850           | 150       | 1000           | 15           |
| 800           | 200       | 1000           | 20           |
| 750           | 250       | 1000           | 25           |
| 700           | 300       | 1000           | 30           |
3. Results and Discussion

AA6082-T6 reinforced ceramic formations containing different percentages of Al₂O₃ particles were performed by SCT. Table 6 and Figures (from 3 to 8) present the results of the investigations on the mechanical properties of the tested materials.

Table 6. Mechanical properties of AA6082-T6 & AA6082-T6/Al₂O₃ composites.

| MMNCs | AA6082-T6 | +5 wt% Al₂O₃ | +10 wt% Al₂O₃ | +15 wt% Al₂O₃ | +20 wt% Al₂O₃ | +25 wt% Al₂O₃ | +30 wt% Al₂O₃ | SIF |
|-------|-----------|--------------|--------------|--------------|--------------|--------------|--------------|-----|
|        | AA6082-T6 | +5 wt% Al₂O₃ | +10 wt% Al₂O₃ | +15 wt% Al₂O₃ | +20 wt% Al₂O₃ | +25 wt% Al₂O₃ | +30 wt% Al₂O₃ |     |
| Ductility (%EL) | 14        | 12           | 10           | 9            | 7            | 6            | 4             | 57.14 |
| YS(MPa) | 230       | 242          | 253          | 264          | 275          | 287          | 280           | 19.86 |
| UTS(MPa) | 262       | 270          | 286          | 307          | 320          | 340          | 323           | 22.95 |
| E(GPa) | 70         | 82           | 84           | 87           | 90           | 96           | 89            | 27   |
| Hardness (BHN) | 75        | 81           | 83           | 88           | 89           | 92           | 87            | 18.48 |
| Density ρ(g/cm³) | 2.7       | 2.78         | 2.82         | 2.91         | 2.98         | 3.21         | 3.1           | 15.89 |

The effect of Al₂O₃ incorporation on the compounds’ ductility is presented in Figure 3. This figure showed that increases in the wt. % of the reinforcement materials caused decreases in the materials’ ductility (57.14%), implying a significant reduction in the extent of elongation of the compound as a result of the presence of the reinforcement material. This could be due to the fragile and harsh nature of the Al₂O₃ particles. Being that Al₂O₃ is resistant to heat and with high fragility, it fills the pores when dispersed in an Al alloy matrix and exposes its fragile nature, thereby reducing the compounds’ ductility.

![Ductility of (AA6082-T6 + wt.% Al₂O₃)](image)

Figure 3. Effect of different wt. % of Al₂O₃ Nano particles on the ductility of AA6082-T6/Al₂O₃

The incorporation of Al₂O₃ particles into the Al alloy also causes an increase in the YS, UTS, E, BHN, and ρ as depicted in Figures (4, 5, 6, 7, and 8), respectively. Figures (4, 5, 6&7) respectively showed increases in YS (19.86%), UTS (22.95%), E (27%), and hardness (18.48%) with increasing percentages of Al₂O₃ NPs until the critical reinforcement percentage is reached. This observation is due to the high mechanical characteristics of Al₂O₃ NPs in terms of its high YS, high Young’s modulus, etc. These features are expected to add positively to the mechanical characteristics of AA6082-T6/ Al₂O₃ nanocomposites upon then homogenous dispersal of Al₂O₃ NPs as a reinforcement material. However, there is a specific concentration of Al₂O₃ NPs that will be added to the matrix before observing reduction in the maximum values of these mechanical properties. Based on this study, this specific concentration corresponds to 25% plus nanoparticles as Al₂O₃ groups are formed in compounds beyond this value, and these groups degrade the mechanical properties of compounds by decreasing their values as can be seen in Figures 4-7.
Figure 4. Effect of different wt. % of Al₂O₃ Nano particles on yield strength of AA6082-T6 / Al₂O₃ composite.

Figure 5. Effect of different wt. % of Al₂O₃ Nano particles on ultimate tensile strength of AA6082-T6 / Al₂O₃ composite.

Figure 6. Effect of different wt. % of Al₂O₃ Nano particles on Young’s modulus of AA6082-T6 / Al₂O₃ composite.
Regarding the Al₂O₃ NPs-reinforced compounds, the addition of about 25% of the NPs provides better improvements on the tensile strength, yield strength, Young's modulus, & stiffness, while the mechanical properties of compounds that contain more than one value were degraded due to the formation of Al₂O₃ clusters in the compounds.

Figure 8 clearly showed that the reinforcement materials were smaller in size than the molecules of the matrix; hence, they were positioned in-between the matrix molecules and effectively filled the gaps. This results in increased density (15.89%) of the compounds in comparison to AA6082-T6.

Lastly, the findings of this study suggest that Al₂O₃ NPs is a good material for AA6082-T6 reinforcement owing to its capability to improve the mechanical characteristics of the alloys except for the softness due to the increased hardness as depicted in Figure 3. These improvements in mechanical properties of the compounds are due to the homogenous distribution of the Al₂O₃ NPs in the alloy matrix.
4. Conclusion

The following conclusions are drawn from the outcome of this study:

1. AA6082-T6/ (Al2O3) composites containing different weight % of (Al2O3) can be successfully fabricated by a chemical reaction between molten aluminum alloys with (Al2O3) particulates using Stir Casting Technique (SCT).

2. The best improvement in mechanical properties was achieved with a weight gain of 25% (Al2O3) reinforcement compared with non-reinforced base alloys Al6082-T6. The homogenous distribution of the Al2O3 NPs in the matrix increased the Yield strength (19.86%), Young's modulus (27%), maximum tensile strength (22.95%), hardness (18.48%), and density (15.89%) of the compounds when compared with the non-reinforced base alloys Al6082-T6.

3. The addition of Al2O3 molecules reduced the softness of the compounds (57.14%) compared to the non-reinforced base alloy Al6082-T6 due to the fragile and solid nature of Al2O3 particles. When dispersed in Al alloy matrix, they fill the pores and expose its weak nature.

4. Uniform distribution of the nanoparticles within the composite materials enhanced the fabrication of the materials, but the addition of Al2O3 nanoparticles above a critical concentration reduces the mechanical properties of the compound due to the formation of Al2O3 clusters in the compound.

References

[1] Zhang X, Zhou X, and Nilsson J O 2019 Corr. Sci. 150: p. 100-109.
[2] Dubey R R, Velmurugan S, and Jayaganthan R 2018 Mat. T: Proc 5(9): p. 17203-17212.
[3] Sun N and Apelian D 2019 Int. J. Met. 13 (2), 234.
[4] El-Kady O and A Fathy 2014 Mat. & Des. (1980-2015) 54: p. 348-353.
[5] Kumar GV, Rao C, and Selvaraj N 2011 J. min. mat. Char. Eng. 10(01): p. 59.
[6] Thangarasu, A, et al 2014 Emer. Mat. Res. 3(3): p. 123-129.
[7] Verma, N, Rao P, and Vettivel S 2017 Res. J. Eng. Technol. 8(3): p. 179-186.
[8] Kandpal, B C, J kumar S, and Singh H 2017 Mat T: Proc 4(2, Part A): p. 2783-2792.
[9] Alkawi, H J A and Owaid A J 2018 Eng. Technol. J. 36(7 Part Engineering): p. 792-797.
[10] Verma, S. and Rao P S 2018 IOSR J. Mech. Civ. Eng. 15(4 (Ver. III)): p. 16-20.
[11] Ashwath, P, et al 2018 Mat. T.: Proceedings 5(2): p. 7329-7336.
[12] Malaki, M, et al 2019 Met. 9(3): p. 330.
[13] Manikandan A, Omkumar M S, and Mohanavel V 2019 Mat in the 53(3): p. 327-332.
[14] Dayanand S and Babu S 2019 Int. J. Eng. Res. & Technol. 7(9): p. 1-5.
[15] Ramkumar K R and Natarajan S 2019 J. All. Com. 793: p. 526-532.
[16] Baumeister, T. Marks' standard handbook for mechanical engineers. 11th ed. Vol. 1. 2007: McGraw Hill.
[17] Ghusoon, R M, Rawaa H M, and. Basim H A 2019 IOP Conf Ser: Mat. Sci. Eng. 518: p. 032042.
[18] Abdulhadi H, Ahmad S, Ismail I, Ishak M, & Mohammed G 2017, Met. 7(6): p. 191.
[19] Shaikshavali, G, Goud D E V , and Mohan M M 201, Int. J. Eng. Res. Gen. Sci. 4.
[20] Rajan Verma, S S, Dinesh Kumar 2017 Int. J. Eng. Res. & Technol. 6(3).