Experimental investigation on mechanical properties of Al 7075/Al₂O₃/Mg NMMC's by stir casting method

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Abstract. There is an increasing demand for light-weight, affordable and rapidly processed products as a result of their significant level of superiority these days. In the present research, the effect of mechanical stir casting on 7075 based lightweight aluminium alloy established together with nano-Al₂O₃ with average particle size (20–30) nanometre and wt.% of (1.0, 2.0, 3.0, and 4.0) has been studied. Several scientists exposed that non-consistent distribution of nanoparticles possessing high porosity in the matrix. Electric stir casting could protect against the difficulties encountered with mechanical stir casting. By infusing Al₂O₃ particulates right into aluminium alloy the aluminium 7075/1% Wt. Al₂O₃ is giving area to nanocomposite. By including 1%, micro magnesium powder improved the wettability of the reinforcement. Optical microscope, SEM, studies carried out for the evaluation of composites. SEM micrographs reported that the nanoparticles were consistently distributed throughout the matrix and the active grain microstructure studies were preformed. The hardness, tensile strength, and impact results of Al7075/1% Wt. Al₂O₃ nanocomposites have been improved as compared with the Al7075 base alloy.

Keywords. AA 7075; nano-Al₂O₃; Mg; stir casting.

1. Introduction

In the recent days, lightweight aluminium alloys are preferred as design material for aerospace, vehicle and marine industries because of their extraordinary physical and thermal properties. Among various groups of aluminium alloys, the Al7075 alloy is very corrosion resistance and qualitative one and reveals excellent strength and finds a lot of applications in the areas of automotive, structure and commercial applications. The metal matrix composites produced from aluminium alloys are of a broad concern because of their high strength, crack strength, rigidity and wear resistance. Moreover, these kinds of MMNCs' are remarkable while reinforced with nano-ceramic particles [1]. Fabrication of Al 7075 MMNCs' has been limited in specific applications such as aerospace in addition to armed force weapons as a result of high handling expense. In the present days, Al alloy matrix nanocomposites have been used for the production of auto parts such as disc brake, engine piston, cylinder lining and more [2]. There is a classification of the production approaches for Al MMNCs' into three types such as (a) solid-state procedure, (b) liquid state procedure and also (c) powder metallurgy [3, 4]. By the approach of the fluid state, the procedure strengthened

the reinforcement of Al MMNCs' and refined more. Dhanalakshmi *et al* [5] studied metal matrix composites and also examined the mechanical characterisation of stir cast hybrid Al 7075–Al₂O₃–B₄C metal matrix composites.

Senthilvelan *et al* [6] investigated fabrication as well as characterisation of SiC, Al₂O₃, and B₄C reinforced Al–Zn–Mg–Cu Alloy (AA 7075) metal matrix composites. Al₂O₃ and B₄C are the common reinforcement materials used in lightweight aluminium matrix composites. Rajmohan *et al* [7] revealed evaluation of mechanical and wear properties of hybrid aluminium matrix composites. A few research studies were carried out on SiC composites as a result of the higher expense of SiC powders. Mechanical stir casting is an attractive technique since it is rather less priced and used for a wide choice of materials. Umanath *et al* [8] made analysis of dry sliding wear behaviour of Al6061/SiC/Al₂O₃ hybrid metal matrix composites. The rate of passion in MMC's for usage in the aerospace, auto sectors as well as various other commercial applications has increased over the previous 30 years. Karthikeyan *et al* [9] investigated mechanical properties and wear behaviour of Al–Si–SiC–Graphite composite utilising SEM. Hybrid composites are those composites which have a combination of two or even more reinforcements. Ceramic Nanoparticles reinforce the durability of lightweight aluminium by this there is a significant improvement in the toughness of light-weight

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Table 1. Chemical composition of aluminum Al7075.

Element	Fe	Si	Mn	Cr	Cu	Ti	Zn	Mg	Others	Al
% of weight	0.198	0.052	0.055	0.195	1.458	0.047	5.989	2.151	0.025	Remainder

Table 2. Mechanical properties of aluminium Al7075.

Density (gm./cm ³)	Poisson ratio	Hardness (BHN)	Tensile strength (MPa)
2.7	0.33	60	220

Table 3. Properties of aluminium oxide.

Density (gm./cm ³)	Poisson ratio	Hardness (BHN)	Elastic modulus (MPa)
3.86	0.22	1500	375

aluminum [10, 11]. Currently, there are several producing methods of MMNCs' consisting of in-situ technique [12, 13]. Yuan *et al* [14] researched the mechanical properties and tribological properties of lightweight aluminium matrix compound enhanced with in situ AlB₂ bits. The circumstances of a rising in fragment enhanced metal matrix MMCs have been researched long-ago; however, the needed approval was not there for its beginning. Creating dislocation designs for diffusion of toughened alloys are specially made to represent reinforcing products [15, 16]. MMCs reinforced with Nano-ceramic bits, fibres or whiskers have increased the interest. As a result of their higher crack durability as well as strength [17, 18], particle enhanced aluminium metal matrix composites find possible applications, particularly in auto engine components such as cylindrical tubes, brake rotators, piston and in space applications [19].

The primary objective of this study is to prepare the MMNCs of Al 7075 reinforced with Al₂O₃ nano ceramic

powder with a dimension size (20–30 nm) and also study its mechanical characteristics.

2. Selection of materials

While selecting a product, one needs to be very cautious and also take one of the most exceptional care to make sure that it matches the defined application. That integrates a selection of the matrix and reinforcement materials.

2.1 Matrix material

There is a choice of Aluminium 7075 alloy as a matrix product as a result of their outstanding strength-to-volume proportion, unique mechanical properties, high thermal conductivity, cost-efficient and also better wear characteristics. It includes zinc, magnesium, and copper as its significant alloying elements as shown in table 1. The mechanical properties of Al 7075 are presented in table 2.

The primary purpose of alloying 7075 Al alloy is to enhance toughness, corrosion resistance, machinability, and weldability. Mechanical Properties of 7075 Al-alloy are given in table 2.

2.2 Reinforcement material

There is an increasing use of alumina which is nothing but Aluminium oxide (Al₂O₃) nanoparticles as the reinforcement product with an average dimension of (20–30 nm). High wear resistance, extreme hardness, and low density

Figure 1. (a) Electric stir casting, (b) Stir casting layout.

Table 4. Composition of the test specimens.

Weight of Al7075 (in gm)	Weight of Al7075 (in %)	Weight of Al ₂ O ₃ (in gm)	Weight of Al ₂ O ₃ (in %)	Weight of Mg (in gm)	Weight of Mg (in %)
1000	100	0	0	0	0
608	99	6.08	1	6.08	1
580	98	11.8	2	5.8	1
572	97	18	3	5.8	1
583	96	24.7	4	5.9	1

Table 5. Final composition of the test specimens (Wt.% of reinforcement).

Sample no.	Weight of Al 7075 (in %)	Wt.% of the reinforcement
1	100	Pure Al7075
2	99	Al7075 + 1% Al ₂ O ₃ + 1% Mg
3	98	Al7075 + 2% Al ₂ O ₃ + 1% Mg
4	97	Al7075 + 3% Al ₂ O ₃ + 1% Mg
5	96	Al7075 + 4% Al ₂ O ₃ + 1% Mg

are the features of aluminium oxide fragments. Table 3 reveals the mechanical properties of aluminium oxide.

3. Experimental procedure

The manufacturing of the metal matrix composites by using the electrical stir casting method was done. Electrical stir Casting is a liquid state technique of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibres) is blended with a molten matrix metal using mechanical stirring. The liquid composite product is after

that cast by conventional casting methods as well as could additionally be processed by standard metal forming innovations shown in figure 1(a) and 1(b), which is the finest and also economical from all the conveniently available methods for generating metal matrix composites in vast quantities. In this technique, the raw product of Al7075 which remains in the form of the rectangle-shaped bar is melted in an electric heating furnace in a graphite crucible and also heated up to 900°C. Afterwards, the incorporated nano aluminium oxide (Al₂O₃) which is wholly combined with 1% of magnesium to improve the wettability is pre-heated at 650°C and poured into the molten matrix. Next, the combination is mixed using a stainless steel stirrer coated with alumina to avoid the reaction between stainless steel and Al alloys at higher temperatures. The coating of alumina to the stirrer is essential to prevent the migration of ferrous ions from the stirrer into the molten metal. Due to this reason, there is no possibility of erosion of stainless steel stirrer and Fe pickup in the melt. Lastly, there is a launch of the solidified composites with the aid of air to lessen the settling time of particles. There is a cutting of solidified compound of similar dimensions and cut as per ASTM requirements for

Figure 2. Density values for different compositions.

conduction of experimental tests. The composition of the test specimens is shown in tables 4 and 5.

3.1 Heat treatment

T6 heat treatment is used for aluminium alloys to improve their mechanical properties. T6 heat treatment of nano Al_2O_3 reinforced Al7075 composite samplings, where heat treatment is done at 530°C for 2 h, followed by water quenching, as well as ageing treatment did at 200°C for 6 h. Before heat

treatment, cast specimens initially cut as per ASTM dimensions by using Wire cut Electric discharge machine.

3.2 Metallographic analysis

Microstructures of as-cast, as well as heat treated aluminium composite specimens were examined for metallographic ally. After that, the specimens were ground, polished and etched with Keller solution which has 1%HF, 1.5%HCl, 2.5% HNO_3 , and 95% H_2O .

Figure 3. (a) Pure Al 7075, (b) 1% Al_2O_3 + 1% Mg, (c) 2% Al_2O_3 + 1% Mg, (d) 3% Al_2O_3 + 1% Mg, (e) 3% Al_2O_3 + 1% Mg.

3.3 SEM analysis

To get indoor structures of aluminium samples, SEM studies were executed. Specifically, the precipitates that need to develop after heat treatment were examined. The portions of alloying elements were discussed, and also their charts were obtained.

4. Results and discussions

The Al7075 alloy/ Al_2O_3 Metal matrix nanocomposite produced by stir casting process and adhering to examination like hardness, tensile, and toughness tests to provide their mechanical properties.

Figure 4. As cast tensile test specimen for different wt.% compositions.

Figure 5. Heat treated tensile test specimen for different wt.% compositions.

4.1 Density measurement

Density is one of the important properties that reveal characteristics of composites. There was a resolution of the speculative density values of the composites by using Archimedes principle, and also the theoretical values are calculated making use of the formula listed below. Al 7075 alloy density value is 2.7 gm/cm^3 , and density of Al_2O_3 is 3.7 gm/cm^3 . The experimental and theoretical density values are shown in figure 2.

Figure 2 shows the variation of theoretical and the experimental density concerning the weight portion of reinforcement. It is clear from the graph that the density values reduced with increasing weight % of Nano Al_2O_3 particles when compared to the base metal (Al 7075).

4.2 Microstructure evaluation

There was a cutting of the microstructure of the samplings according to the standard metallographic procedure, and the surface area of samples were ground with 600 grit papers. After using Keller reagent microstructures, the unreinforced and reinforced composite specimens were observed by using the microscopic optical lens.

Optical microscopic photos show the Microstructure of the specimen. In my work, four different samplings are considered with 500X magnifying's. Depending on the weight percentage of included nano-reinforcements the crystalline structure has changed. The nanocomposite images are shown in figure 3(a)–(e).

5. Mechanical testings

5.1 Tensile strength test (ASTM E8)

The tensile test was carried out on the computerised universal testing machine of greater than 1000 KN load

ability. The Main purpose of this analysis was to determine tensile, toughness, and the per cent of elongation. The increase in yield and UTS with four different weight % of Nano Al_2O_3 are shown in figures 4 and 5. From the graphs, it is clear that an increase in the yield and ultimate

Figure 6. % elongation of different compositions.

Figure 7. As-cast hardness versus wt.% of reinforcement of composites.

Figure 8. Heat treated hardness versus wt.% of reinforcement of composites.

Figure 9. As cast impact strength for different compositions.

Figure 10. Heat treated impact strength for different compositions.

strength of heat-treated samples over un-heat treated samples and also the samples with 4 wt.% of Al₂O₃ had increased yield and ultimate strength over samples with 0 wt.% of Al 7075.

As shown in figure 6 by adding nano-Al₂O₃ to the base metal, the percentage elongation of the nanocomposite is decreased. That shows a decline inflexibility of the composite.

5.2 Microhardness (ASTM E92-17)

Microhardness examination is performed on the Vickers hardness testing machine to find the hardness values in the Al 7075/Al₂O₃ composite according to ASTM E 92-17 requirements. In this experiment, a diamond intended having a diameter of 10 mm and load carrying capacity of 50 N applied to the composite specimen for 10 s.

Hardness examinations were accomplished to observe the impacts of heat treatment as well as results of wt.% enhancement of aluminium oxide on lightweight

Figure 11. (a) Pure Al 7075, (b) 1% Al_2O_3 + 1% Mg, (c) 2% Al_2O_3 + 1% Mg, (d) 3% Al_2O_3 + 1% Mg, (e) 4% Al_2O_3 + 1% Mg.

aluminium alloy matrix because hardness is an indication of a product's resistance to plastic contortion. Figures 7 and 8 reveal the variant of hardness values with wt.% aluminium oxide. It is observed that the hardness values enhanced with the enhancement of aluminium oxide. Aluminium oxide particulates are ceramic products that are more difficult compare with the aluminium matrix alloy. They attach the misplacement activity and also consequently a rise in pressure setting. Heat treatment likewise takes on the hardness values of aluminium matrix alloy. By precipitation, heat treatment was added and solidification was acquired. The lightweight aluminium matrix composites were option heat treated with at 530°C for 1 h. From figures 7 and 8, a contrast in between hardness values of as-cast as well as heat treated with aluminium oxide enhanced aluminium matrix composites could additionally be observed. It is seen that heat treatment increased the hardness values.

5.3 Impact strength (ASTM E23-12C)

Toughness is the capability of a product to withstand heavy load without failure; it is also called Impact strength. The Charpy examination was done on the Al7075/Al₂O₃ testing according to ASTM E23-12C. Figures 9 and 10 showed an increase in the toughness value of heat treated specimens over as-cast specimens and also the composite with 4 wt% of Al₂O₃ had improved significantly the impact strength over samples with 0 wt.% of Al 7075.

From figure 10 it was observed that there was considerable progress in the toughness of the composite when contrasted with the unreinforced alloy, an increase of 26.1% is found in from the chart.

6. Scanning Electron Microscopy

SEM Analysis provides valuable details for the metallurgical exam, micro evaluation, as well as failure assessment. Scanning electron microscopy is performed at extremely high magnification to generate high-resolution images.

From figure 11(a)–(e), we found that nano reinforcement particles evenly dispersed in the matrix. From this, we could state that the composite is uniform. Since the distribution of reinforcement is homogeneous, it has improved the mechanical characteristics of the composite.

7. Conclusions

In the present investigation, aluminium alloy 7075 was enhanced by 1.0, 2.0, 3.0, and 4.0 Weight % of Al₂O₃ nanoparticles fabricated by stir casting method. From the experimental results, the following conclusions are drawn.

- Aluminium matrix (1, 2, 3 and 4 Weight %) of Al₂O₃ nanocomposites have efficiently been made by the electrical stir casting procedure.
- Heat treatment process increased the mechanical properties of nano aluminium oxide composites when compared to as-cast.
- By increasing the wt.% of nano-reinforcement the density decreased when compared to base alloy.
- The Tensile strength, hardness, and toughness gradually improved by increasing Weight % of Al₂O₃.
- Optical micrographs, and SEM photos revealed that the Al₂O₃ fragments were well dispersed in the Aluminium matrix.

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