Study of Comparison of Mechanical Properties of Al7075 with Al7075 Reinforced with Nano and Micro Particles of Al₂O₃ at Varying Percentage via Stir Casting Route

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Abstract: Al7075-Al₂O₃ materials are formed by adopting stir casting technique on Al7075 by adding reinforcements of Al₂O₃ in the form of nano and micro particles at varying wt. %. In present study Al7075-Al₂O₃ metal matrix composite developed in three different compositions of micro and nano particles. The Fabrication of composite are carried out by liquid metallurgy route via stir casting technique. Casted composites machined to make the samples for mechanical testing. Tensile strength test and Hardness Test are conducted on different machines. Improved results are found after testing. Future scope is also given for research scholar.

Keywords: Metal Matrix Composite, Aluminum, Alumina.

Introduction:
In the recent years, the demand for light weight, low cost and high quality performance materials has increased. Many researchers have tried to develop new materials that meet these requirements. One of the newly developed materials is Aluminium metal-matrix composites (Al-MMCs). Basically, there are three types of MMCs: particle reinforced, whisker reinforced and continuous fiber MMCs. Metal-matrix composite (MMCs) are widely used in industry because of their excellent mechanical properties. Nowadays, there are various MMCs used especially for automotive and engineering applications. This is because of their high strength, high elastic modulus, low co-efficient of thermal expansion, light weight, low thermal shock, good wear resistance and many more advantages. These combinations of these properties are not available in a conventional material. These mechanical properties also depend on the composite particles for the reinforcement of the Aluminium. Most of the alloys that are used as matrices are light alloys, particularly those based on Aluminium alloys.

Aluminium Alloys
Aluminium became a common structural material because of its attractive properties like its light weight, ease of fabrication and machinability, high resistance to atmospheric corrosion, good thermal conductivity, high metallic luster and non-magnetic and non-sparking properties. Selecting the right alloy for a given application entails consideration of its tensile strength, density, ductility, formability, workability, weldability and corrosion resistance. Aluminium alloys are alloys in which Aluminium (Al) is the predominant metal. The typical alloying elements are Copper, Magnesium, Manganese, Silicon and Zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of Aluminium is used for wrought products, for example, rolled plate, foil and extrusions. Cast Aluminium alloys yield cost effective products due to its low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast Aluminium alloy system is Al-Si, where the high levels of Silicon (4.0% to 13%) contribute to good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Wrought Aluminium alloys are used in the shaping processes: rolling, forging, extrusion, pressing, stamping. Cast Aluminium alloys are come after sand casting, permanent mould casting, die casting, investment casting, centrifugal casting, squeeze casting and continuous casting. Aluminium alloys are classified as shown in Figure 1.

Figure 1 Classification of Aluminium Alloy

Aluminium Alloys

Wrought Alloys

Cast Alloys
Physical and thermal properties of Aluminium alloy 7075

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting Point</td>
<td>Approx. 635°C</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>70-80 GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Density</td>
<td>2.81 gm/cm³</td>
</tr>
</tbody>
</table>

Thermal properties

Co-efficient of Thermal Expansion (250°C) is 25.2µm/m°C
Thermal Conductivity: 130W/mK

Stir casting

Stir casting set-up mainly consists a furnace and a stirring assembly as shown in Figure 2. In general, the solidification synthesis of metal matrix composites involves melting of the selected matrix material followed by the introduction of a reinforcement material into the melt, obtaining a suitable dispersion. The next step is the solidification of the melt containing suspended dispersions under selected conditions to obtain the desired distribution of the dispersed phase in the cast matrix. In preparing metal matrix composites by the stir casting method, there are several factors that need considerable attention, including the difficulty in achieving a uniform distribution of the reinforcement material.

- Wettability between the two main substances.
- Porosity in the cast metal matrix composites.
- Chemical reactions between the reinforcement material and the matrix alloy.

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix must be uniform and the wettability or bonding between these substances should be optimized. The porosity levels need to be minimized.

Objective:

- Study the Mechanical Properties of Al7075 with Al7075 Reinforced with Nano and Micro Particles of Al₂O₃ at Varying Percentage Via Stir Casting Route.

Methodology:

Preparation of samples

In this study, Al7075 Aluminium alloy is used as the matrix material while micro and nano particles of Al₂O₃ (alumina) 1.5wt%, 3wt% and 4.5 wt. % of each are used as the reinforcements. The average size of micro and nano Al₂O₃ particles are supplied by nanoshellare 40µm and less than 70nm respectively. For manufacturing of the MMCs, 1.5wt%, 3wt% and 4.5 wt. % of micro and nano Al₂O₃ particles are used. The stir casting furnace is used for producing the MMC composites. Initially, Al7075 alloy charges
into the crucible and heated to about 900°C, which is above the liquidus temperature of the Al alloy. Then, the mixer is lowered into the melt slowly to stir the molten metal. The micro and nano Al₂O₃ particles are preheated in a muffle furnace at a temperature of 900°C for a period of 1 to 3 hours before being mixed with the Al alloy melt. The reinforcement particles feed into the molten metal manually by a spoon. After the completion of particle feeding, the mixing is too continued for further 15 min. Then the molten mixture is poured in the pre-heated mould. The casting billets are of 120 mm height and φ12 mm diameter.

**Mechanical Testing:**

**Tensile Strength**

The tensile test is generally performed on flat specimens. The dimension of the specimen is φ12 mm diameter and 30 mm length and a uniaxial load is applied through both ends.

In the present work, this test is performed on the universal testing machine Hounsfield H25KS (Figure 4) at a crosshead speed 5 mm/min and the results are used to calculate the tensile strength of composites materials. The test is repeated three times on each composites type and the mean value is reported as the tensile strength of that composites.

**Tensile strength test**

The tensile tests are used to assess the mechanical behavior of the composites and matrix alloy. The composite and matrix alloy rods are machined into tensile specimens with a diameter of φ12 mm and gauge length of 60 mm and 50 mm clamping length. Ultimate Tensile Strength (UTS) is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract.

<table>
<thead>
<tr>
<th>Composite composition</th>
<th>UTS (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al7075</td>
<td>220</td>
<td>6.21</td>
</tr>
<tr>
<td>Al7075 + 1.5% Al₂O₃ (Micro)</td>
<td>225</td>
<td>5.34</td>
</tr>
<tr>
<td>Al7075 + 3% Al₂O₃ (Micro)</td>
<td>241</td>
<td>4.81</td>
</tr>
<tr>
<td>Composite Type</td>
<td>Tensile Strength (MPa)</td>
<td>Tensile Strength (% Al₂O₃)</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>------------------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Al7075 + 4.5% Al₂O₃ (Micro)</td>
<td>253</td>
<td>3.97</td>
</tr>
<tr>
<td>Al7075 + 1.5% Al₂O₃ (Nano)</td>
<td>233</td>
<td>5.07</td>
</tr>
<tr>
<td>Al7075 + 3% Al₂O₃ (Nano)</td>
<td>242</td>
<td>4.71</td>
</tr>
<tr>
<td>Al7075 + 4.5% Al₂O₃ (Nano)</td>
<td>240</td>
<td>4.02</td>
</tr>
</tbody>
</table>

Figure 5 Tensile strength of composite with wt. % variation of micro Al₂O₃

Figure 5 Tensile strength of composite with wt. % variation of nano Al₂O₃
Figure 6: %Elongation of composite with wt. % variation of Micro Al₂O₃

Figure 7: %Elongation of composite with wt. % variation of nanoAl₂O₃
Figure 8 Comparison of ultimate tensile strength micro and nano composites

Figure 9 Comparison of %age elongation formicro and nano composites

Figure 4, 5 show variation of tensile strength with increase in percentage of Al₂O₃ particulates. Tensile strength of the micro composite material increases as the content of Alumina particulates increase from 0 to 4.5 wt. %. It is observed that the tensile strength of the micro composites are higher than that of their base matrix it is also observed that the increase in the filler content contributes in increasing the tensile strength of the composite. Also from the Figure 8 it is observed that the tensile strength of the Al7075- Al₂O₃ nanocomposites is higher than that of the micro composites up to 3 Wt.% , due agglomeration of the nano particles in the composite occurs at higher Wt. % of the reinforcement results decrease in the tensile strength.

As the percentage of reinforcement increases in Al7075 the tensile strength also increases but ductility decreases. The reduction in ductility can be attributed to the presence of a hard ceramic phase that is prone to localized crack initiation and increased embrittlement effect due to local stress concentration sites at the reinforcement matrix interface.

**Rockwell 574 Hardness Tester**

The Rockwell 574 Hardness Tester is used for checking of the hardness of the composite samples are made of minimum
thickness of $\phi$12mm diameter. And Rockwell 574 hardness tester is used for hardness calculations, 100kgf is indentation load used with 1/16 inch diameter (1.588mm) of indenter and tests conducted with steel sphere indenter. LCD display showed the harness results.

Figure 10 Wilson hardness tester

Hardness test

Hardness is considered as one of the most important factors that govern the wear resistance of any material. The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load. The minor load establishes the zero position. The major load is applied, then removed while still maintaining the minor load. The depth of penetration from the zero datum is measured from a dial, on which a harder material gives a smaller number. That is, the penetration depth and hardness are inversely proportional. The chief advantage of Rockwell 574 hardness tester is its ability to display hardness values directly. Rockwell 574 Hardness Tester was used for checking of the hardness of the composite samples and values are directly shown on LCD in HRB scale.

Table 3 Comparison of Hardness

<table>
<thead>
<tr>
<th>Composite composition</th>
<th>HRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al7075</td>
<td>46.50</td>
</tr>
<tr>
<td>Al7075 + 1.5% Al2O3 (Micro)</td>
<td>52.72</td>
</tr>
<tr>
<td>Al7075 + 3% Al2O3 (Micro)</td>
<td>55.53</td>
</tr>
<tr>
<td>Al7075 + 4.5% Al2O3 (Micro)</td>
<td>57.61</td>
</tr>
<tr>
<td>Al7075 + 1.5% Al2O3 (Nano)</td>
<td>53.33</td>
</tr>
<tr>
<td>Al7075 + 3% Al2O3 (Nano)</td>
<td>57.64</td>
</tr>
<tr>
<td>Al7075 + 4.5% Al2O3 (Nano)</td>
<td>58.81</td>
</tr>
</tbody>
</table>

Figure 11 Hardness of Micro composite
It is observed that the hardness of the composite is greater than that of its cast matrix alloy. The composites containing higher filler content exhibit higher hardness. Hardness of the Al7075–Al2O3 composite material increases as the content of Al2O3 increases from 0 to 4.5 wt. %. The improvement in the hardness can be attributed to the fact that the Al2O3 possess higher hardness and its presence in the matrix improves the hardness of the composite.

**Conclusions:**

1. Hardness & Tensile strength of the composites are found to be higher than that of base matrix while % age elongation decreases as the weight percentage of reinforcement increases.
2. It has been concluded that nano composites are better in hardness, tensile strength and specific wear rate. It is also observed that micro and nano composites have better wear resistance than Al7075.

**Scope for Future Works**

1. Some MMCs can be manufactured by using other manufacturing techniques like powder metallurgy etc. and particles
size can be further varied and then results can be compared with stir casting technique.

References: