The Effect of Cryogenic Treatment on Mechanical and Tribological Properties of Aluminium Metal Matrix Composites - Al7075 Reinforced with Silicon Carbide

Prashanth. H. M\textsuperscript{1}, Shadakshari. R\textsuperscript{2}
PG Student\textsuperscript{1}, Assistant Professor\textsuperscript{2}
Department of Mechanical Engineering
Acharya Institute of Technology, Bangalore, India

Abstract:
Metal matrix composites are important class of materials containing metal or alloy as matrix and a ceramic particle or fiber or whisker as reinforcements. Aluminum-based metal matrix composites display enhanced wear and mechanical characteristics and these characteristics will be improved after being subjected to cryogenic temperature circumstances owing to higher bonding between the matrix and reinforcement. Especially for automotive and aviation applications, Al-based materials are essential. The primary objective of the job is to explore the impact of cryogenic treatment on the mechanical & tribological characteristics of the products. The samples were prepared in accordance with ASTM standards. Tensile and hardness tests were carried out and the characteristics investigated. Result showed that wear and other mechanical characteristics increase as a proportion of strengthening and even higher owing to the impact of cryogenic therapy.

Keywords: Metal matrix composites, stir casting, Al7075, SiC, cryogenic treatment, wear loss, optical microscopy.

I. INTRODUCTION
Aluminum alloys strengthened with whiskers, fibers and particulates show a substantial enhancement in strength even at very elevated temperatures with very low thermal expansion and co-efficient friction along with higher wear conduct and stiffness and strength relative to other alloys. However, owing to its important mechanical characteristics such as stiffness, hardness, strength, wear conduct, thermal conductivity besides being the structural material, the SiC has acquired the one among the highest attention. Al-SiC has discovered a wider implementation in the automotive, transportation and aviation sectors. Table 2.1 shows the composition of aluminum 7075.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mg</th>
<th>Mn</th>
<th>Zn</th>
<th>Ti</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>% by Weight</td>
<td>0.068</td>
<td>0.14</td>
<td>2.9</td>
<td>1.89</td>
<td>0.18</td>
<td>5.54</td>
<td>0.049</td>
<td>0.13</td>
<td>Bal</td>
</tr>
</tbody>
</table>

Table 2.1. AL7075 chemical composition table

II. OBJECTIVE
The primary goal of this job is to manufacture Al7075-SiC metal matrix composite by stir casting method and prepare the specimen according to ASTM standards and then investigate the mechanical impact of cryogenic treatment and tribological characteristics of the composites for the different weight fraction of SiC samples through mechanical exams and to study the microstructure of the samples.

III. MATERIAL AND METHODS
From literature survey it shows that there is wide scope to studies on the tribological behavior of Al7075-SiC metal matrix composites, so aluminium-7075 is chosen as matrix material, silicon carbide as reinforcement materials (Fig 4.2). Table 2 shows the different weight fraction of SiC in Al7075 for specimen preparation (Fig 4.4).

The silicon carbide is taken in a crucible and heated to a temperature of 250º C for 15 mins. Al 7075 (Fig 4.1) was heated in the furnace at a temperature of 800º C. The molten material was stirred with a stirrer at a speed of 220 rpm to create vortex, then the heated reinforcements were added and stirred. The composites were cast using conventional methods. The specimens are casted in 5 different weight fractions of SiC which is shown below in table 4.1, Fig 4.3 shows the stir casting apparatus required to fabricate specimens.

Stir casting is a two stage mixing process. In this process, the matrix material is heated to above its liquids temperature so that the metal is melted. The melt is then cooled down to a temperature between the liquids and solids points and kept in a semi-solid state. At this stage, the preheated particles will be mixed. The slurry will be again be heated to a liquid state to mix thoroughly. The two stage mixing process has been used in the fabrication of aluminium.

IV. TEST DETAILS

4.1 Hardness Test
Hardness test is carried out on a standard Brinell Hardness Testing Machine according to ASTM E10 standards. Brinell hardness test is accomplished for the examination of hardness of Al SiC with various percentage (0%, 5%, 10%, 15% & 20%). The Brinell hardness testing method was the first hardness testing method to be used in the industry. Usually, this testing process takes between 10 to 30 seconds.

The Brinell hardness test was one of the most widely used hardness tests. For measuring, a rod or plate hardness the test is usually conducted by pressing a diamond sphere of 2.5mm in diameter into the test surface for 10 seconds with a load of 60kg, then measuring the diameter of the resulting impression.

\[
BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}
\]
Where, BHN = Brinell Hardness number, D = Diameter of the Indenter (5mm), d = Diameter of indentation, P = Load applied (60kg), Holding time = 30sec

4.2 Tensile Test

Tensile test is carried out on a standard computerized UTM Machine according to ASTM E8 standards. A tensile specimen is a standardized sample cross-section, it has two shoulders and a gauge in between. A specimen is prepared in a round section along the gauge length, depending on the standards used. Both ends of the specimen should have sufficient length and a surface condition such that they are firmly gripped during testing. The initial gauge length L₀ is standardized (in several countries) and varies with the diameter (D₀) or the cross-sectional area (A₀) of the specimen.

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0}$$

Where, $\Delta L$ is the difference in gauge length, $L_0$ is initial gauge length, and L is final length.

4.3 Wear Testing

Wear test was done on a standard Pin on Disc Testing Machine according to ASTM G99 standards. In this test the specimens are machined to a required size to so that the specimens to mounted on apparatus easily. These specimens are weighed before and after the wear test to under the amount of wear loss in the specimens. Test is actually carried out by keeping speed, time and load as constant.

$$\text{Sliding speed m/sec} = \frac{\pi D N T}{60000}$$

Where, $D = \text{Track diameter (106mm)}, N = \text{Speed of disc in rpm (500 rpm)}, T = \text{time in seconds. (5 min)}$

Weight Loss = Initial Weight - Final Weight

Wear rate = Sliding distance / weight loss

4.4 Microstructure Studies

Metallurgical Microscopic Analysis

Optical microscopy used for characterizing the effects of processing to get the material properties, Characterization of grain boundaries, phase structures are found out by optical microscopy. Samples such as metals, composites, ceramics and geological material can be tested on the specimens, which are tested under microscope under the visible light, which provides magnified images of microstructure & macrostructure.

During testing the specimens are polished to get the flat surface and etched the surfaces, micro structural features of the specimens are captured. Optical microscope apparatus is shown below. Microstructure study is done with metallurgical microscope, performed on the polished specimen.

The specimen microstructure is observed before and after wear test by applying etchant (1g of sodium hydroxide solution/100ml of water)

V. RESULTS AND DISCUSSIONS

5.1 Brinell Hardness Test results

Tests are carried out for different weight fraction of SiC reinforcement (0%, 5%, 10%, 15% and 20%) at ambient temperature. Tests were conducted on As Cast & Cryogenic treated samples. Good hardness values obtained for cryogenic treated specimens. Brinell hardness number can determine the Hardness of composites. The diameter of the indenter is 5mm which is used during test. Applied load on the specimens is 60kg & dwell time set for 30 seconds. BHN is calculated for specimens & the reading is tabulated in below table.

![BHN test specimens](image1.jpg)

![BHN test results](image2.jpg)

<table>
<thead>
<tr>
<th>Weight % of SiC</th>
<th>BHN</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>195.8</td>
</tr>
<tr>
<td>5</td>
<td>254.5</td>
</tr>
<tr>
<td>10</td>
<td>296.2</td>
</tr>
<tr>
<td>15</td>
<td>296.2</td>
</tr>
<tr>
<td>20</td>
<td>322.5</td>
</tr>
</tbody>
</table>

Table 5.1.1: BHN test results

Above Hardness test results reveals that the percentage of reinforcement increases the Brinell hardness number (BHN) and it is maximum at 20% of reinforcement.

![BHN test results](image3.jpg)

Figure 5.1.2: BHN test results

![BHN test results](image4.jpg)

Figure 5.1.2: BHN test results

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5.2 Tensile test results

Table.5.2.1. Tensile strength test results comparison

<table>
<thead>
<tr>
<th>Weight % of SiC</th>
<th>As Cast (TS in N/mm²)</th>
<th>Cryogenic (TS in N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>129.6</td>
<td>143.3</td>
</tr>
<tr>
<td>5</td>
<td>145.2</td>
<td>164.7</td>
</tr>
<tr>
<td>10</td>
<td>141.5</td>
<td>172.4</td>
</tr>
<tr>
<td>15</td>
<td>175.9</td>
<td>212</td>
</tr>
<tr>
<td>20</td>
<td>150.5</td>
<td>262.7</td>
</tr>
</tbody>
</table>

Above tensile test results reveal that the percentage of silicon carbide increases the tensile strength, this is due to the greater bonding between matrix and reinforcement thereby specimen will become stronger.

Figure.5.2.1: As Cast specimen  
Figure.5.2.2. Cryogenic specimen  
Figure.5.2.3. Tensile strength results comparison

5.3 Wear Test results

Pin-on-disk dry sliding machine conducts wear tests on samples to understand the wear features of strengthened composites Al7075 & SiC. Wear experiments carried out by taking into account material, sliding distance, velocity and load parameters. Al7075 blended with SiC components was the material used. Considering 106mm track diameter, steady load 10N with 500-rpm steady velocity and about 5min. Wear properties of Al7075 were analysed in terms of loss in weight.

Dry sliding wear behaviours

In present work, dry-sliding characters of Al7075 composite samples are analysed: The inverse weight loss magnitude of composite gives wear resistance of material. The loading effects on composite at constant sliding distance for Al7075 are tabulated below.

Table.5.3.1. Wear test Attributes

<table>
<thead>
<tr>
<th>Weight % of SiC</th>
<th>Load in N</th>
<th>Time (min)</th>
<th>Speed (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>5</td>
<td>500</td>
</tr>
</tbody>
</table>

Table.5.3.2. Wear test results

<table>
<thead>
<tr>
<th>Weight % of SiC</th>
<th>Weight loss - gm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As Cast</td>
</tr>
<tr>
<td>0</td>
<td>0.0042</td>
</tr>
<tr>
<td>5</td>
<td>0.0038</td>
</tr>
<tr>
<td>10</td>
<td>0.0031</td>
</tr>
<tr>
<td>15</td>
<td>0.0023</td>
</tr>
<tr>
<td>20</td>
<td>0.0021</td>
</tr>
</tbody>
</table>
Wear tests conducted on both as cast and cryogenic specimens. Sliding wear techniques are used to evaluate the wear behaviours from both samples.

The weight percentage of SiC varies from 0% to 20%, wear test with constant sliding distance of 250 mts is evaluated keeping load of 10 N and speed constant of 500 rpm respectively. By observation, the graphs which show that wear loss is more in As Cast specimens when compared with cryogenic treated specimens, as the specimens are cryogenic treated the bonding between the molecules will be strong, hence makes the specimens harder and results in less wear.

6.4 Optical microstructure results
Optical microstructure gives clear details about surface features by which we know the clear distribution of reinforced particles in base metal. This test shows structures of phases, grain boundaries of samples. The following images are the results of optical-microstructure study, the specimens which are As Cast, named as A1, A2, A3, A4 and A5 as in the below fig 6.4.1

Below fig 6.4.2 shows the optical results of W1-W5 As Cast specimen microstructure after the wear testing which contains 0 to 20 wt% of SiC
Figure 5.4.2. Microstructure results of (W1- W5) As Cast specimens after wear test

Below fig 6.4.3 shows the optical microstructure of (C1-C5) cryogenic specimens, which contains 0 to 20 wt% of SiC.

Figure 5.4.3. Microstructure results of (C1-C5) cryogenic specimens

Below fig 6.4.4 shows the optical microstructure results of C1-C5 cryogenic specimens after the wear test, which contains 0 to 20 wt% of SiC.
6. CONCLUSION

Aluminium composites (Al7075-SiC) are manufactured using a stir cast method and SiC-reinforced composites have important potential for structural applications owing to their elevated specific strength and rigidity and low density. The mechanical and tribological characteristics are considerably enhanced as a result of cryogenic treatment. The composites hardness and tensile strength improves considerably by raising SiC's weight percentage and improves further owing to cryogenic treatment. Wear loss is also found to decline with rise in wt percentage of SiC and tend to decline further owing to cryogenic treatment. The micro-structural research also demonstrates that owing to cryogenic treatment the wear loss of the composites reduces.

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