Experimental Investigation by Cryogenic Treatment of Aluminium 6063 and 8011 and NiCoW Coating to Improve Hardness and Wear

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1. INTRODUCTION

The word, “Cryogenics” is taken from two Greek words-“klyros” which means “frost” or freezing, and “genic” meaning to “produce” or generated. Technologically, it means the study and use of materials (or other requirements) at very low temperatures. The use of cryogenic treatment to improve mechanical properties of materials has been developed from the end of the Sixties. A cryogenic treatment is the process of treating work pieces to cryogenic temperatures (i.e. below −190°C (−310°F)) to remove residual stresses and improve wear resistance on steels. Cryogenic treatment is a low temperature treatment process widely used in recent years to enhance the material properties without sacrificing other properties at the same time. Cryogenics plays a significant role in enhancing the mechanical properties of alloys. It also increases the resistance to stress corrosion which is of prime concern in wind engineering application.

Cryogenic hardening is a cryogenic heat treating process where the material is cooled to approximately −185 C (−301 F), usually using liquid nitrogen. It can have a profound effect on the mechanical properties of aluminium and other metals. Silicon is the most important single alloying element used in majority of Aluminium casting alloys. D. Salehi Doolabi et al. [1], in his article has explained microstructure of silicon coating on aluminium. In [2], Yuan et al. explains the three dimensional modelling of surface defects. The composition alone does not affect the property but also the grain size as discussed by Fabio et al. [3] in his paper where the impact of Al-Si combination is discussed. Attarchi et al. [4], has used electrodeposition to give spherical nickel coating. Multilayer coating is
dealt in [5] by Azadi et al. Yi et al. [6], talks about the effect of zirconium on Aluminium properties. Improvement of fatigue characteristics by adding it with aluminium is discussed by Zuqi Hu et al. [7]. Hardness is an important parameter needed in mechanical applications, hardness property is increased by adding copper and magnesium with aluminium by Nafsin et al. [8] and the paper also discusses the impact of hardness on the deformation of objects. Dunia Abdul Saheb et al. [9], in his paper demonstrates the aluminium silicon carbide and aluminium graphite to increase the hardness significantly. In order to increase the UTS, hardness, torsional strength and impact strength Al 6061 alloy/ TiO$_2$ is used by Kataiah et al. [10]. In all the above journals the mechanical property improvement of aluminium is brought about by using metal composites. But, the same property improvement could be brought about by treatment of aluminium cryogenically.

It is found that CHT affects the residual stress, mechanical properties, and precipitation of the Al 6061 alloy in his paper Dae-Hoon Ko et al. [11]. K. N. Pande et al. [12] in his paper has explained the The cryogenic treatment of Polyamide at different temperatures (-80, -140 and -185 °C) for stipulated time period (4, 8, 12, 16, 20 and 24 h) in the cryostat. Mechanical properties like wear performance and tensile properties are evaluated and found to have significant improvements.

The cryogenic treatments are given to improve the mechanical properties. This paper by P. Nageswara rao et al. [13], discusses about the hot rolling and cold rolling after cryogenic treatment. D. Frolich et al. [14], in his paper explains the impact of applying cryogenic cooling, in bringing about deformation-induced α’-martensite in the (−196°C) on microstructure and mechanical properties of AZ91 magnesium alloy. Dry sliding wear tests were also applied and the wear resistance of the alloy improved remarkably after deep cryogenic treatment. Kaveh et al. [12], in his paper explains the deep cryogenic treatment of Thornton et al. [13], The results indicate an improvement in the wear rate of grey cast iron of 9.1–81.4% due to deep cryogenic treatment where significant wear has occurred, although there was no significant surface layer increases the wear resistance, compared to dry turned AISI 347. change in the bulk hardness, matrix hardness or in the microstructure of the material under optical observation.

2. EXPERIMENTAL SETUP AND SEQUENCE

2.1. Material Properties

The following materials were taken for studies Aluminium 8011 and Aluminium 6063. Apart from iron, aluminium is currently the next most widely used metal in the world. This is due to the fact that aluminium has a unique combination of attractive properties such as its low weight, corrosion resistance, and easy maintenance of final product, have ensured that this metal and its alloys will be in use for a very long time. Many studies have been done on the mechanism of cryogenic treatment of non-ferrous metals such as aluminum alloys [15, 16].

The chart shown in Figure 1 gives the sequence in which the experimental process was carried out. The raw material was received and hardness tests were conducted for both the specimens and the softest specimens.

![Figure 1. Experimental Process Sequence](image-url)
The specimen with the lesser hardness was taken and coated with NiCoW and wear test conducted. The Table 1, below gives the properties of both the specimens of aluminum.

The hardness test of the above standard specimen was taken at 500 g load with a 10 mm ball. The composition of AA 6063-T6 consists of Al(97.5%), Cr(0.1), Cu(0.1), Fe(0.35), Mg(0.45-0.9), Mn(0.1), Si(0.2-0.6), Ti(0.1), Zn(0.1). Al 8011 alloy(UNS A98011), Al(97.3-98.3), Fe(0.6-0.1), Si(0.5-0.9), Mn(0.2), Zn(0.1), Cu(0.1), Ti(0.08), Cr, Mg(0.05).

2.2. Sample Preparation

The raw materials employed in this study are two grades of aluminium Al 6063-AA-T6 and Al 8011 with a specimen diameter of 20mm as shown in Figure 2(a), 2(b). These specimens were used for hardness testing.

The Samples powders in Figures 3(a), 3(b), 3(c) are then cryogenically treated and hardness tests taken for the above specimens. The coated samples are given in Figure 3(d) and the EDAX test for results is shown in Figure 3(e).

<table>
<thead>
<tr>
<th>TABLE 1. Properties of Al 6063 and Al 8011</th>
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<tbody>
<tr>
<td>Properties</td>
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<tr>
<td>Hardness Brinell</td>
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<tr>
<td>Hardness Vicker</td>
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<tr>
<td>Ultimate Tensile strength</td>
</tr>
<tr>
<td>Ultimate Bearing Strength</td>
</tr>
<tr>
<td>Fatigue Strength</td>
</tr>
<tr>
<td>Shear Strength</td>
</tr>
</tbody>
</table>

Figure 2(a). Al 6063

Figure 2(b). Al 8011

Figure 3(a). Nickel

Figure 3(b). Cobalt

Figure 3(c). Tungsten

Figure 3(d). Aluminium Specimens used for coating Ni Co W

Figure 3(e). EDAX testing of Ni Co W and Wear Test
2.3 Cryogenic Treatment of Materials

The cryogenic cooling approaches in material machining can be classified into four groups according to application of the cooling, indirect cryogenic cooling or cryogenic tool back cooling or conductive remote cooling and cryogenic jet or flood cooling by injecting the cryogenic fluid into the cutting zone. After cryogenic treatment, alloys showed lower tool wear rate Table 2.

The liquid nitrogen was collected in a container of 20 litres capacity and a pressure pump of 2 l/min capacity was fitted to the container. The nozzle of 3 mm diameter tip was connected to the half inch size plastic pipe and the other end of this pipe was fitted to the time was recorded for machining of 50mm length by a precision stop watch. Cryogenic pre cooling of the workpiece or cutting tool, cryogenic chip. The pressure pump as shown in Figure 4.

3. RESULT AND DISCUSSIONS

3.1 Hardness Test

The hardness tests of the material are an important property that affects the wear strength of the materials. The cryogenic treatment increases the hardness around 10 -15% for every increase in eight hours (Figure 5(a), 5(b), 5(c)). The increased hardness is attributed to the presence of hard ceramic particles, which act as barrier to the movement of the dislocation with the matrix. Brinell hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness.

<table>
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<tr>
<th>TABLE 2. properties of liquid nitrogen</th>
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<tr>
<td>Density</td>
</tr>
<tr>
<td>Melting temperature</td>
</tr>
<tr>
<td>Boiling temperature</td>
</tr>
<tr>
<td>Specific heat</td>
</tr>
<tr>
<td>Thermal conductivity</td>
</tr>
<tr>
<td>Coefficient of heat transfer</td>
</tr>
</tbody>
</table>

Figure 4. Cryogenic Treatment Machine

Figure 5(a). Hardness value of Al 6063 and 8011 without Cryogenic Treatment

Figure 5(b). Hardness value of Al 6063 with cryogenic treatment

Figure 5(c). Hardness value of 8011 with cryogenic treatment

Load applied was 750 kgs and indenter was a steel ball of 5 mm diameter.

The hardness test results of aluminium alloy 6063, 8011 and various time interval cryogenic treated are represented in a bar chart format. From the above result we have concluded that hardness value have been increased by increasing the cryogenic time. Property improvements by cryogenic treatment is dealt with in [17-19].
The last hardness value obtained in Al-8011 (48 hours) cryogenic treated is 96BHN.

3. 2. Wear Test
The usage of cryogenic treatment in improving mechanical properties of materials, especially wear resistance, has prevailed in recent years. Strengthening mechanism of Aluminium alloy is talked about in [20] by Janghorban et al. Brinnel hardness measurements were carried out on the base metal and composite samples by using standard Brinnel hardness test. Brinnel hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Load applied was 750kgs and indenter was a steel ball of 5 mm diameter.

3. 2. 1. Pin On Disc Wear Test
Dry sliding wear test the amount of wear in any component will, in general, depend upon a number of factors such as applied load, testing machine characteristics, sliding speed, sliding distance, environment and material properties. In this test, materials are tested in pairs under nominally non-abrasive conditions. Prior to testing, the surface of the specimens was polished by using 1000 grit paper. Care was taken and the test sample surfaces were flat and polished metallographically prior to testing. The size of the pin is 10 mm in diameter and 30 mm long whereas the disk is 165 mm in diameter (En 31 disc 58-60 HRC) and thickness of 10 mm. The case depth of 1 mm is given for both the test specimen. The pin is positioned perpendicular and forced against the revolving disk specimen with a required load. So the wear track on the disk is a circle, involving multiple wear passes on the same track. The variable speed motor in the machine (Figure 6), causes the disk specimen to revolve about the disk center and the plane of the disk is held horizontally.

However, the worn surface becomes rough at the heavy load of 30 N, that is, obvious plastic deformation and delamination accompanied with plenty of cracks and fractured layers. As the loads increase, the composite coatings bear higher contact stress and result in plastic deformation as given in Table 3.

### Table 3. Wear Rate under 300,600 and 800 rpm conducted at different loads for various duration

<table>
<thead>
<tr>
<th>RPM</th>
<th>300</th>
<th>300</th>
<th>600</th>
<th>600</th>
<th>800</th>
<th>800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>8</td>
<td>8</td>
<td>24</td>
<td>24</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Load 1</td>
<td>5.85</td>
<td>50</td>
<td>52</td>
<td>45</td>
<td>46.6</td>
<td>40</td>
</tr>
<tr>
<td>Load 2</td>
<td>73</td>
<td>68</td>
<td>72</td>
<td>61</td>
<td>64</td>
<td>55</td>
</tr>
<tr>
<td>Load 3</td>
<td>83</td>
<td>72</td>
<td>87</td>
<td>75</td>
<td>98</td>
<td>85</td>
</tr>
</tbody>
</table>

4. MICROSTRUCTURAL INVESTIGATION
The Aluminium specimen of two grades Al 6063 and Al 8011 were cryogenically treated for 8 hrs, 24 hrs and 48 hrs, hardness and wear tested at loads of 1, 2, 3 kg at speeds of 300, 600, 800 rpm.

The microstructures of the Scanning Electron Microscope (SEM) of the specimen in Figure 7(a), 7(b), 7(c), 7(d) gives the microstructure of the cryogenically treated aluminium specimen with and without coating. The treated surface Worn surface was analyzed by a scanning electron microscope (SEM) with energy dispersive X-ray (EDX) spectrometer.

The All composite with coating experiences micro-cutting wear due to the abrasion among asperities of the friction surfaces.
6. CONCLUSIONS

1. The influence of cryogenic treatment on the hardness of Aluminium alloy was studied in the present paper. The hardness increases around 10 to 15% for every increase of eight hours of cryogenic treatment. This increase in hardness is mainly caused due to dislocation in atoms and increase in density due to cooling at -196°C at three different temperatures.

2. During the cryogenic treatment the lower the temperature and longer the soaking time, the results indicate an increase in hardness with increase in the cryogenic treatment hours.

3. The wear mechanism of NiCoW alloy treated cryogenically against aluminium was studied in the present paper.

4. The improvement in wear resistance and reduction in wear rate can be attributed to the formation of high dislocation density that can resist the formation of cracks on the surface, which improves the wear resistance of aluminium coated with NiCoW treated cryogenically.

7. REFERENCES


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