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TECHNICAL NOTE

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

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ABSTRACT

The aim of this paper is to focus on the effect of cryogenic treatment on the microstructure, mechanical and wear properties of Al 6061 and Al 8011. The first objective was to understand the degree to which hardness of these aluminium grades have been enhanced by giving cryogenic on the specimens. The second objective is to check the wear resistance property of these two aluminium specimens if coated with NiCoW and then treating it cryogenically. To conduct hardness tests specimens were fabricated from aluminium plates from both these grades and cryogenically treated. To conduct wear test, both the grades of aluminium were coated with NiCoW, and experimental investigation were carried out with cryogenic coolants. The hardness and wear removal rate were studied for both specimens. The cryogenic coolant enhanced the hardenability of aluminium alloys resulting in increased hardness of nearly 15%. The cryogenic coolant has increased the wear resistance properties of aluminium coated with NiCoW by nearly 25% when compared to wear of the non-treated aluminium with the coating materials. The cryogenic treatment was carried out under three different timings of 8, 24 and 48 hours for three different rpm's 300, 600, 800 under varying loads. The paper also studies the microstructural changes under these varying conditions.

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1. INTRODUCTION

The word, "Cryogenics" is taken from two Greek words–"kryos" 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 1960s. A cryogenic treatment is the process of treating workpieces 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 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 their paper where the impact of Al-Si combination is discussed. Attarchi et al. [4], have used electrodeposition to give spherical nickel coating. Multilayer coating is dealt in [5] by Azadi et al. Yi et al. [6], talk about the effect of zirconium on aluminium

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properties. Improvement of fatigue characteristics by adding it to aluminium is discussed by Zuqi Hu et al. [7]. Hardness is an important parameter needed in mechanical applications. This property is increased by adding copper and magnesium to aluminium (Nafsin et al. [8]). This 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 significantly increase the hardness. 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 treating it cryogenically.

Dae-Hoon Ko et al. [11] found that CHT affects the residual stress, mechanical properties, and precipitation of the Al 6061 alloy.. K. N. Pande et al. [12] in their paper have explained 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. The 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 their paper explain 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 their paper explain 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 increase of 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, namely 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 low weight, corrosion resistance, and easy maintenance of final product, ensuring 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 aluminium 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 conducted for both the specimens and the softest specimens.

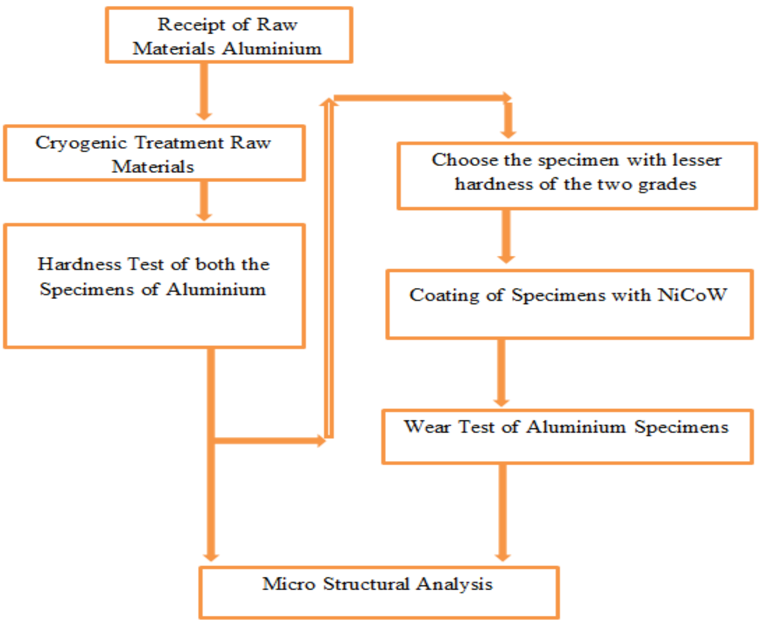

Figure 1. Experimental Process Sequence

The specimen with the lesser hardness was taken and coated with NiCoW and wear test conducted. Table 1 below gives the properties of both specimens of aluminium.

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 is 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 Figures 2(a) and 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 1. Properties of Al 6063 and Al 8011

Properties	**Al 6063**	**Al 8011**
Hardness Brinell	73	150
Hardness Vicker	83	175
Ultimate Tensile strength	241 MPa	572 MPa
Ultimate Bearing Strength	4334 MPa	8665 MPa
Fatigue Strength	68.9 MPa	159 MPa
Shear Strength	152 MPa	331 MPa

Figure 2(a). Al 6063

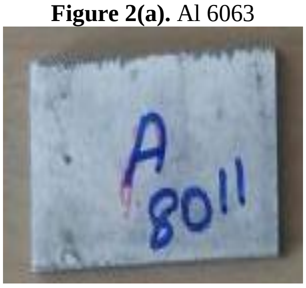

Figure 2(b). Al 8011

Figure 2(c). Electrodeposition Unit

Figure 3(a). Nickel

Figure 3(b). Cobalt

Figure 3(c). Tungsten

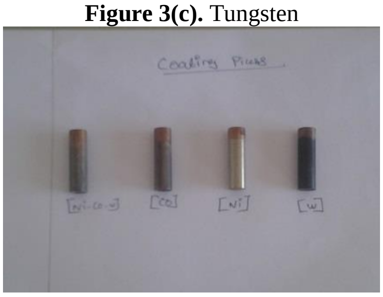

Figure 3(d). Aluminium Specimens used for coating Ni Co W

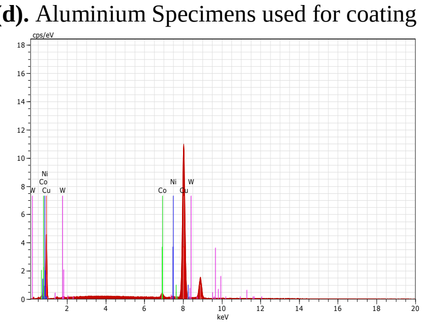

Figure 3(e). EDAX testing of Ni Co W and Wear Test

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 lit/min capacity was fitted to the container. The 3 mm diameter tip nozzle 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 of the material is an important property that affects its wear strength. 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 2. Properties of liquid nitrogen

Density	1.25 g/cm^3
Melting temperature	-210 ºC
Boiling temperature	-196 ºC
Specific heat	1.04 kj/kg.ºk
Thermal conductivity	25.9 W/m.ºk
Coefficient of heat transfer	32 W/m^2.ºk

Figure 4. Cryogenic Treatment Machine

The applied load was 750 kg and indenter was a steel ball of 5 mm diameter.

The hardness test results of aluminium alloy 6063, 8011and various time interval cryogenic treated are represented in a bar chart format. From the above results we can conclude that hardness value have increased by increasing the cryogenic time. Property improvements by cryogenic treatment is dealt with in [17-19].

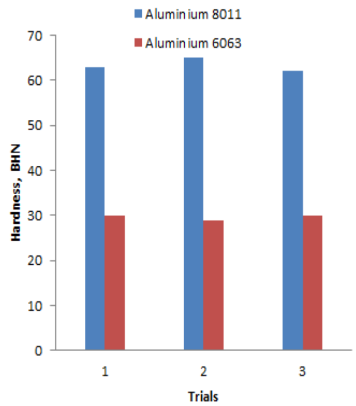

Figure 5(a). Hardness value of Al 6063 and 8011 without Cryogenic Treatment

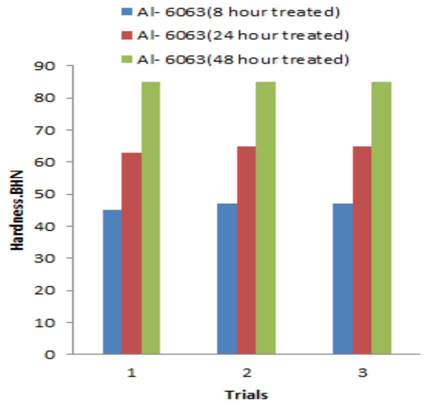

Figure 5(b). Hardness value of Al 6063 with cryogenic treatment

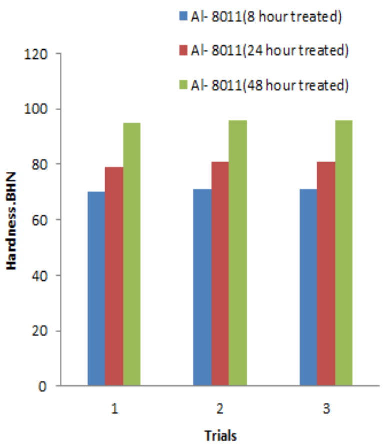

Figure 5(c). Hardness value of 8011 with cryogenic treatment

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 discussed 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. The applied load was 750kgs and indenter was a steel ball of 5 mm diameter.

3. 2. 1. Pin On Disc Wear Test

In 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 were polished by 1000 grit paper. Care was taken and the test sample surfaces were flat and polished metallographically prior to testing. The size of the pin was 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 test specimens. 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.

Figure 6. Pin-on disc machine

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

RPM	**300**	**300**	**600**	**600**	**800**	**800**
Coating	**With Coating**	**Without Coating**	**With Coating**	**Without Coating**	**With Coating**	**Without Coating**
Hours	**8**	**8**	**24**	**24**	**48**	**48**
Load 1	5.85	50	52	45	46.6	40
Load 2	73	68	72	61	64	55
Load 3	83	72	87	75	98	85

4. MICROSTRUCTURAL INVESTIGATION

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

Scanning Electron Microscope (SEM) examination 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.

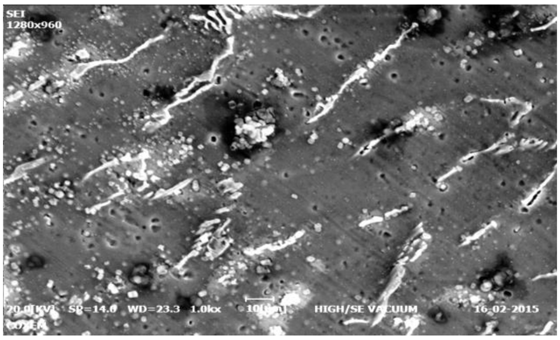

Figure 7(a). Al 6063 with Cryogenic Treatment

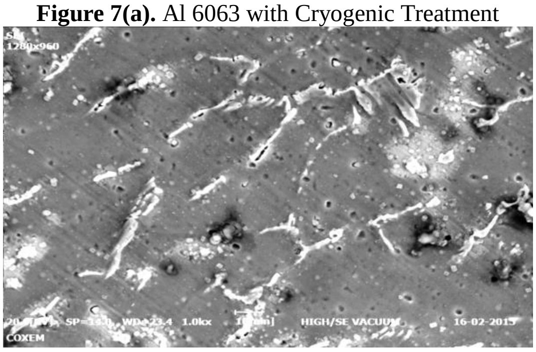

Figure 7(b). Al 6063 with Cryogenic Treatment+NiCoW coating

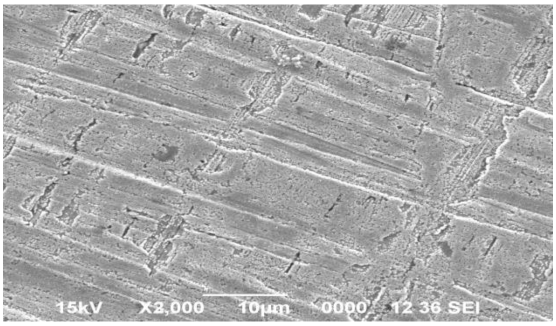

Figure 7(c). Al 8011 with cryogenic treatment(Ni+Co+W) coating

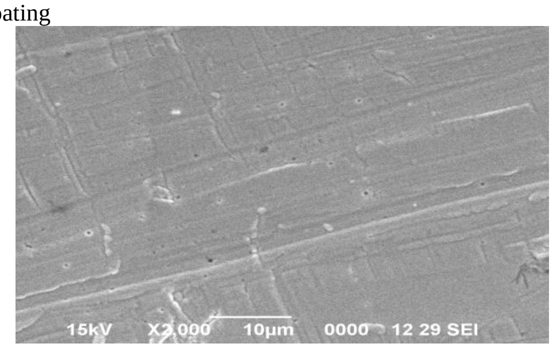

Figure 7(d). Al 8011 with Cryogenic Treatment

6. CONCLUSIONS

1. The influence of cryogenic treatment on 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^{0}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 under the dry sliding condition
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.

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چکیده

هدف از این مقاله تمرکز بر روی اثر درمان برودتی در ساختار، مکانیکی و خواص سایشی آلیاژ Al۶۰۶۱ و ۸۰۱۱ Al است. هدف اول به درک میزان تاثیر شدت برودت بر افزایش سختی این آلیاژهای آلومینیوم برودت یافته است. هدف دوم است که برای بررسی مقاومت به سایش این دو نمونه آلومینیوم پوشش داده شده با NiCoW و سپس برودت یافته است. آزمایش های سختی بر روی نمونه‌های ورقه‌ای از هر دو آلباژ آلومینیوم پس از برودت دهی انجام شد. آزمون سایش نیز بر روی نمونه‌های از هر دو آلباژ آلومینیوم پوشش داده شده با NiCoW پس از برودت دهی با ماده سردکننده انجام شد. سختی و آهنگ سایش هر دو نمونه مورد مطالعه قرار گرفت. خنک کننده برودتی سختی از آلیاژهای آلومینیوم در حدود ۱۵٪ افزایش داده است. خنک کننده برودتی خواص مقاومت در برابر سایش از آلومینیوم پوشش داده شده با NiCoW را در حدود ۲۵٪ در مقایسه با آلیاژهای پوشش داده نشده و برودت نیافته افزایش داده است. عملیات برودت دهی تحت سه زمان مختلف ۸، ۲٤ و ٤۸ ساعت به مدت سه دور در دقیقه مختلف ۳۰۰، ٦۰۰، ۸۰۰ تحت بارهای مختلف انجام شد. این مقاله همچنین به مطالعه تغییرات ریزساختاری تحت این شرایط متفاوت پرداخته است.

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