Carbon – Science and Technology

ISSN 0974 – 0546

http://www.applied-science-innovations.com

RESEARCH ARTICLE Received:10/07/2016, Accepted:24/09/2016

Experimental wear behaviour of cryogenically treated aluminium 6063 and 8011 materials

K. K. Padmanabhan (1) and R. Bharathbalaji (2)

Department of Automobile Engineering, Karpagam University, Coimbatore, Tamilnadu, India.
Email: (1) kkpadmanabhan2012@rediffmail.com, (2) 26.balaji@gmail.com

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 wear behaviour has shown improvement with aluminium grades being treated cryogenically on the specimens. To conduct wear test Aluminium experimental investigation has been carried out on aluminium alloys with cryogenic coolants. The cryogenic coolant has increased the wear resistance properties of aluminium upto 25% when compared to wear of non-cryogenically treated aluminium. The cryogenic treatment was carried out under three different timings for three different rpm's under varying loads. The paper also studies the micro structural changes under these varying conditions. The experimental investigation of the paper concludes that cryogenically treated aluminium shows increase in wear resistance of nearly 25%.

Keywords: Cryogenic, Wear, Microstructure.

---

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 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 materialproperties 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. Yuan-Zhi ZHU **[1]**, in his article has explained how AlFeSi particle is distributed on near the aluminium surfaces heterogeneously. It shows how these clusters of hard particles induce fracture. The composition alone does not affect the property but also the grain size as discussed by Fabio **[2]** in his paper where the impact of Al-Si combination is discussed. Effect of aluminium with Zirconium is discussed by Yi Meng **[3]**, where it increases the Ultimate tensile strength of the alloy. Magnesium is an alloying material of aluminium. Improvement of fatigue characteristics by adding it with aluminium is discussed by Zuqi Hu **[4]**. Hardness is an important parameter needed in mechanical applications, hardness property is increased by adding copper and magnesium with aluminium by Nafsin [5] and the paper also discusses the impact of hardness on the deformation of objects. Dunia Abdul Saheb [6], 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 [7]. 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 Cryogenic Heat Treatment (CHT) affects the residual stress, mechanical properties, and precipitation of the Al 6061 alloy in his paper Dae-Hoon Ko [8]. K. N. Pande [9] in his paper has explained the cryogenic treatment of Polyamide at different temperatures (-80, -140 and -185 ^{o}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 [10], discusses about the hot rolling and cold rolling after cryogenic treatment. D. Frolich [11], 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 [12], in his paper explains the deep cryogenic treatment of Thornton [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. Many studies have been done on the mechanism of cryogenic treatment of non-ferrous metals such as aluminium alloys [14, 15].

Though multiple works have been carried out previously on various other materials, this paper deals with Aluminium 8011 and Aluminium 6063. These materials were taken into considerations and analysed the wear properties keeping in mind the applications of wear and tear that happens in automobile parts in dynamic conditions. 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. Hence, a cryogenic analysis has been carried out in this paper for these two grades of aluminium.

2. Experimental Procedure:

2.1 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.

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 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 50 mm length by a precision stop watch. Cryogenic pre cooling of the workpiece or cutting tool, cryogenic chip. The pressure pump as shown in Figure (1).

Table 2. Properties of Liquid Nitrogen

Density	1.25 g/cm^3
Melting Temperature	- 210 °C
Boiling Temperature	- 196 °C
Specific Heat	1.04 KJ/Kg K
Thermal Conductivity	25.9 W/m K
Coefficient of heat transfer	32 W/m^{2}K

Fig 1: Cryogenic Treatment Machine

3. Experimental Result and Discussions

3.1 Wear Test: The usage of cryogenic treatment in improving mechanical properties of materials, especially wear resistance, has prevailed in recent years (Das et al., 2010a; Tyshchenko et al., 2010; Mohan Lal et al., 2001; Vimal et al., 2008).

3.1.1 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 causes the disk specimen to revolve about the disk center and the plane of the disk is held horizontally.

Table 1**:** Wear Rate under 300,600 and 800 rpm conducted at different loads for various duration.

RPM	**300**	**300**	**600**	**600**	**800**	**800**
	With Cryogenic Treatment	**Without Cryogenic Treatment**	**With Cryogenic Treatment**	**Without Cryogenic Treatment**	**With Cryogenic Treatment**	**Without Cryogenic Treatment**
Hrs	*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

The dry test was conducted for the samples in three different loads [Table 1] for specimens treated with and without cryogenically treated pieces. The speed and load ranges were determined taking into account the capacity of the wear testing machine and the minimum amount of wear loss which could be measured using the weighing balance. The maximum capacity of the weighing balance used for measuring the wear loss is 250 g with an accuracy of 0.001 g. After each test the mass loss of pin was considered as the wear. During the test the temperature of the pin and disk interface was increased considerably. Based on the preliminary investigations on the machine, wear test parameters were arrived, which are wear track diameter 10–140 mm, sliding speed range 0.26–12 m/s, disk rotation speed

100 – 2000 rpm, and normal load up to 200 N. Hence tests were carried out for three different loads (10, 20, and 30 N), for four different specimens conditions all cryogenically treated [Al 6063, Al 8011] at three different rpm's (300, 600, 800). Wear results are obtained by conducting test for a selected rpm and load. Each specimen was tested for duration of 600 s before arriving at the weight loss. The wear rate of each pin was calculated from the weight loss during this test duration. The amount of wear is determined by measuring the specimen length before and after the tests.

A cylindrical specimen of size 10 mm diameter and 30 mm length was prepared and loaded in a computer interfaced pin- on - disc wear testing rig. Prior to testing, the surface of the specimens was polished metallographically by using 1000 grit paper prior to testing. Care was taken that the test sample's end surfaces were flat. The rotating disc was made of EN 31 steel and hardness of 58-60 HRC. Wear tests were carried out at 25 °C room temperature and 60 % relative humidity for 10 minutes. Wear loss was measured by using software.

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact. Wear is progressive damage, involving material loss, occurs on the surface as a result of relative motion between the surfaces. As the wear is a surface removal phenomenon and occurs mostly at outer surfaces, it is more appropriate and economical to make surface modification of existing alloys than using the wear resistant alloys. Dry sliding wear tests for different number of specimens were conducted by using a pin-on-disc machine [Figure 2].

Figure (2): Pin-on disc machine.

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. In particular, the worn surface shows high hardness compared with the unworn surface indicating work hardening. As the loads increase, the composite bear higher contact stress and result in plastic deformation.

3.1.2 Wear rate: The wear rate is one of the most important factors that control the life of a material in many engineering applications. In the Pin on disc wear test, wear rate can be defined as the average thickness removed per cycle from the beginning of the test to a certain number of cycles. That is, the hardness of the both alloy and composites is influenced by the dislocation movement in the substructure due to cryogenic treatment. The higher vacancy concentration is obtained by lowering the temperature. This promotes the clustering process and results in a finer scale of precipitation. The load and rpm chosen was highest among the three samples considered.

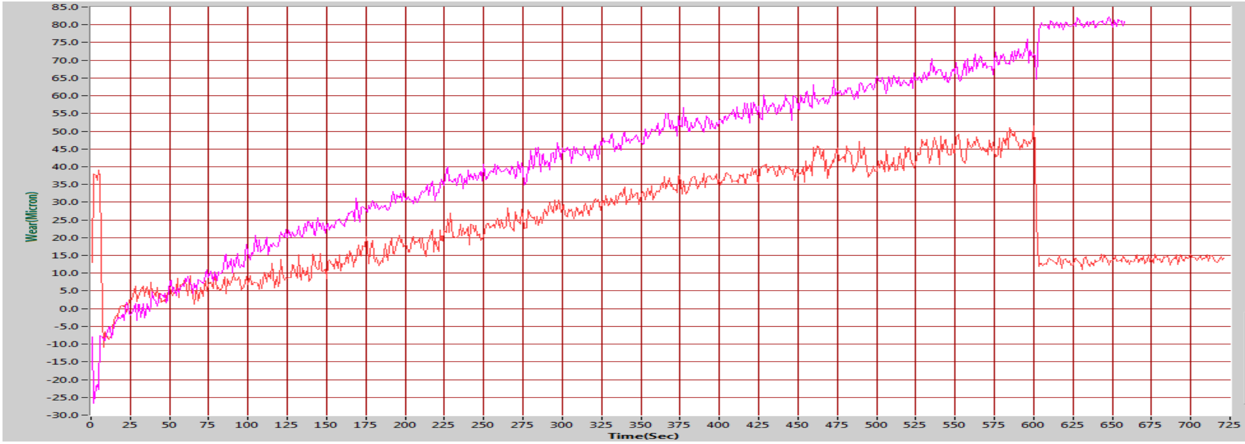

Fig 3(a): Wear test results taken for Al 6063 specimen with and without cryogenic treatment.

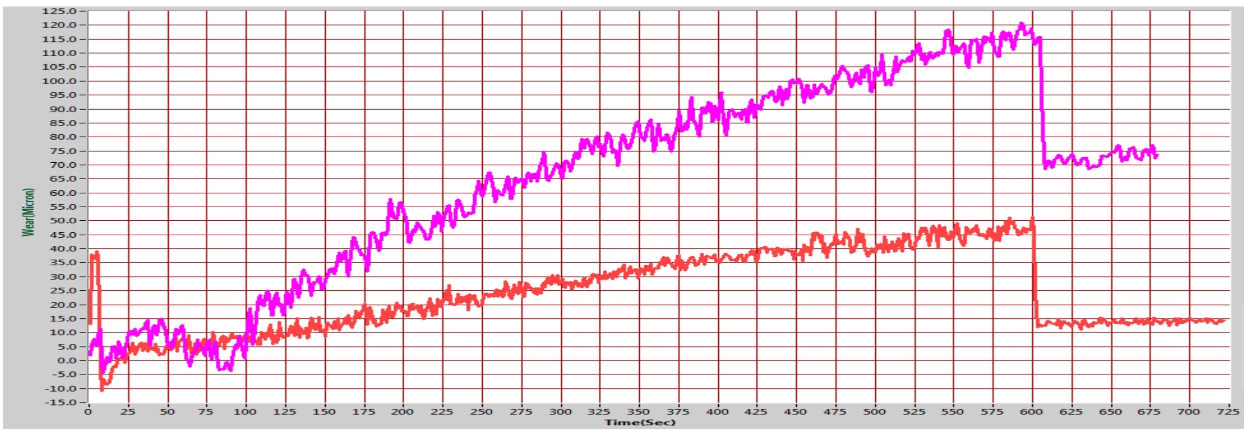

Fig 3(b): Wear test results taken for Al 6063 specimen with and without cryogenic treatment.

One of the reading among the several reading and its shows a reduction in wear if the specimen is coated as in Figure (3a). At 600th Second the max wear is 70 microns for a specimen treated cryogenically. But, the wear is 40 microns for a specimen coated with NiCoW. The results due to cryogenic treatment shows a wear reduction of nearly 42% of wear. Figure (3b) shows the wear results compared with specimens without cryogenic treatment that gives a wear result of of 120 microns. The improvement in wear rate is far higher than in cryogenic treatment. Impact of wear on bearings is dealt with in the papers **[16 - 19]**.

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 (4a-d) gives the microstructure of the cryogenically treated aluminium specimen. The treated surface worn surface was analyzed by a scanning electron microscope (SEM) with energy dispersive X-ray (EDX) spectrometer.

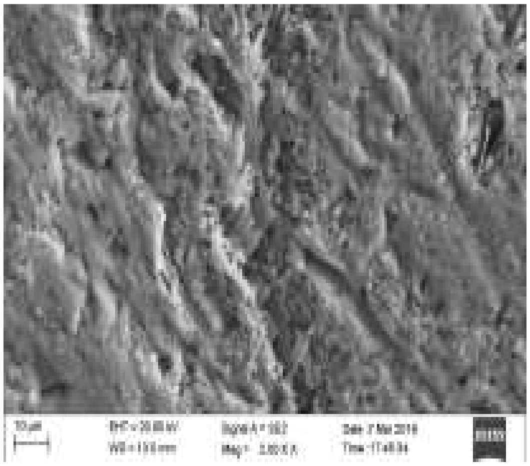

Fig 4(a): Al 6063 without cryogenic treatment

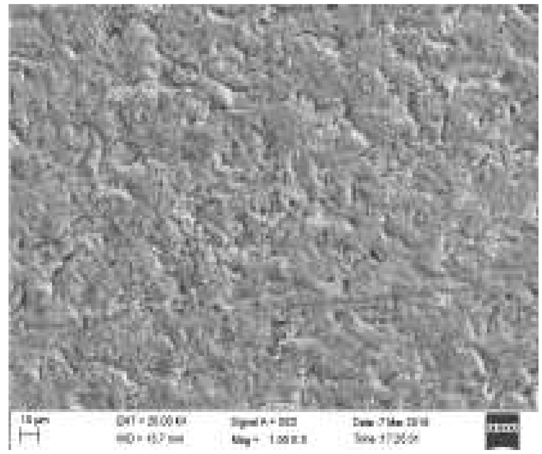

Fig 4(b): Al 6063 with cryogenic treatment

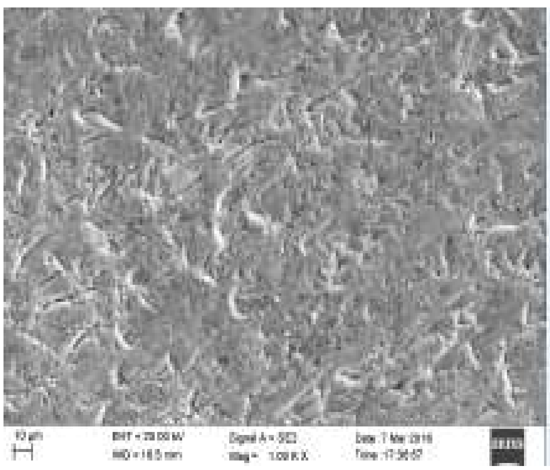

Fig 4(c): Al 8011 without cryogenic treatment

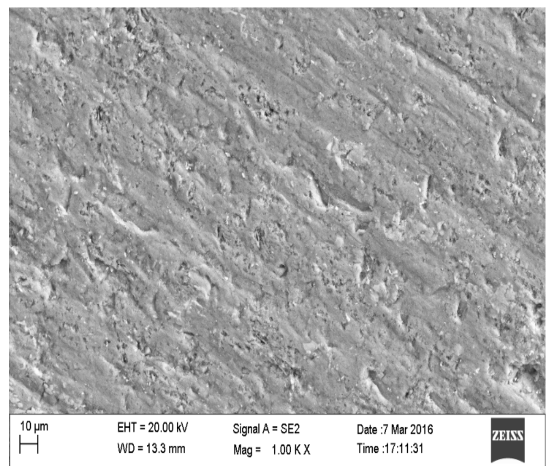

Fig 4(d): Al 8011 with cryogenic treatment

The Al composite with cryogenic experiences micro-cutting wear due to the abrasion among asperities of the friction surfaces. From the Images of SEM for 6063 and 8011 it is found that the cryogenically treated aluminium samples show the material with greater compactness and hence better surface finish. It is more organized and perfect because the molecules get rearranged during cryogenic treatment.

5. Conclusions:

1. The influence of cryogenic treatment on the hardness of Aluminium alloy was studied in the present paper. The wear improvement is observed for every increase of eight hours of cryogenic treatment. This increase in wear resistance is mainly caused due to dislocation in atoms and increase in density due to cooling at -196 ^{o}C.
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 and better wear resistance properties.

6. Acknowledgements: I would like to thank Karpagam University (Karpagam Academy of Higher Education) in establishing the lab facility for Pin on Disc friction equipment for carrying out this research to find the wear behaviour of the materials. The cryogenic treatment was carried out at Commando Engineer’s Laboratory, Coimbatore, India.

7. References:

[1] Yuan-zhi Zhu, Qiang Wan, Bing-liang Li, Feng Zhou, Ya-feng Zhang, Transactions of Non Ferrous Metals Society of China, 24/2 (2014) 477 - 483.
[2] Fabio Grosselle, Giulio Timelli, Franco Bonollo, Material Science and Engineering A, 527/15 (2010) 3536 – 3545.
[3] Yi Meng, Jianzhong Cui, Zhihao Zhao, Lizi He, Materials Characterization 92 (2014) 138 - 148.
[4] Zuqi Hu, Li Wan, Shusen Wu, Han Wu, Xueqiang Liu, Materials & Design 46 (2013) 451 - 456.
[5] N. Nafsin, H. M. M. A. Rashed, International Journal of Engineering and Advanced Technology *(IJEAT)* ISSN: 2249-8958, 2/5 (2013).
[6] Dunia Abdul Saheb, ARPN Journal of Engineering and Applied Sciences 6/10 (2011).
[7] G. S. Kataiah, D. P.Girish, International Journal of Pharmaceutical Studies and Research IJPSR/Vol. I/ Issue I/July-September, (2010) 17 – 25.
[8] Dae-Hoon Ko, Dae-Cheol Ko, Hak-Jin Lim, Jung-Min Lee, Byung-Min Kim, Journal of Mechanical Science and Technology, 27/7 (2013) 1949 – 1955.
[9] K. N. Pande, D. R. Peshwe, Anupama Kumar, Trans. Indian Inst. Met. 65/3 (2012) 313 – 319.
[10] P. Nageswara rao, R. Jayaganthan, Materials & Design 39 (2012) 226 – 233.
[11] D. Frölich, B. Magyar, B. Sauer, P. Mayer, B. Kirsch, J. C. Aurich, R. Skorupski, M. Smaga, T. Beck, D. Eifler, Wear 328–329 (2015) 123 – 131.
[12] Kaveh Meshinchi Asl, Alireza Tari, Farzad Khomamizadeh, Materials Science and Engineering A 523/1–2 (2009) 27 – 31.
[13] R. Thornton, T. Slatter, A. H. Jones, R. Lewis, Wear 271/9-10 (2011) 2386 – 2395.
[14] J. J. Wang, X. X. Xue, Z. Q. Yang, H. Zhang, Y. Zhou, Adv. Mat. Res. 1646 (2011) 1646 – 1650.
[15] Q. C. Wang, Y. L. Ke, J. Zhejiang Univ. Sci. A. 37 (2003) 748 – 754.
[16] S. G. Simranpreet, S. Jagdev, Mater. Manuf. Process. 25 (2010) 378 – 385.
[17] M. V. Chernets, Journal of Friction and Wear 36/2 (2015) 163 – 169.
[18] V. M. Aleksandrov, E. A. Gubareva, Journal of Friction and Wear, 28/3 (2007) 239 – 245.
[19] M. V. Zernin, A. V. Mishin, N. N. Rybkin, S. V. Shil'ko, Journal of Friction and Wear 35/5 (2014) 396 - 406.

*****