EFFECT OF CRYOGENIC TREATMENT ON THE MECHANICAL AND MICROSTRUCTURAL PROPERTIES OF ALUMINIUM ALLOYS - A BRIEF STUDY

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Abstract- 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. Cryogenic engineering is a branch of material handling process which has significant commercial applications. Cryogenics not only plays a significant role in enhancing the mechanical properties of Al alloys but also increases the resistance to stress corrosion which is of prime concern in various engineering applications, this has inspired researchers to adopt this technique in enhancing the properties of aerospace alloys and alloys used in the heat exchangers where the material has to withstand severe conditions of temperature and pressure. However the application of cryogenic treatment for the Aluminium alloys is still in the process and very few work has been done in this regard, the present work will provide and a comprehensive insight for the current state of research on the effect of cryo treatment of Aluminium alloys.

Keywords- Cryo-Treatment, Soaking Time, Ultimate Tensile Strength, Stress Corrosion.

I. INTRODUCTION

Aluminium alloy have long been of interest in various industries due to its increased performance in comparison with ferrous alloys. Aluminium alloys plays a significant role in the applications where high strength to weight ratio is necessary. These alloys in its various compositions exhibits different set of properties. Due to this diversification they have various field of applications and very large commercial use. Aluminium alloys are the prime candidates in the aerospace community due to their modest specific strength, ease of manufacture and low cos. Increase in payloads and fuel efficiency of air craft has become a important issue for aerospace industry which requires increased performance above the existing alloys requires the development of more advanced materials with high specific properties. Weight reductions arising from design modifications or enhancements in mechanical properties alone are marginal as compared to what can be achieved by the use of newer materials with lower density. Uses of Titanium alloys and composites have opened the doors for the applications in aerospace industry. But dew to their high cost and unease of manufacture and restrictions in material handling, the extent of application of these are quite restricted. 3102 Aluminium alloy is mainly used in the manufacture of heat exchanging apparatus of air conditioners which require well combined mechanical properties such as high strength, elongation, Erichsen number and deep ironing properties. The properties of hydrophilic and radiating and weather resisting properties are demanded to ensure it can be employed at 173K to 373K.

There is a need to increase the properties of aluminum alloys at elevated temperature for high temperature applications. AA 5XXX series which are used in the manufacture of pressure vessels etc. requires increased performance. In this process there is a need to increase the properties of conventional materials like Aluminium alloys without sacrifice of any property. This has opened the doors for the low temperature treatment of Materials called as cryogenics. Cryogenic treatment is the gradual cooling of the components until the defined temperature, holding it for a given time and then progressively leading it back to the room temperature. The aim is to obtain an improvement of mechanical properties, typically hardness, and wear resistance. But in recent Tests Fatigue limit too, and to achieve optimal ratio between conflicted properties like Hardness and Toughness.

The fundamental distinction among different Cryo treatment process is given by the temperature reached during the cycle as a parameter. Based on this they are categorized as

- SCT: sub-zero cryo treatment is the process in which the samples are placed in a furnace at 193K and then are brought back to room temperature.
- DCT: deep cryo treatment is the process in which the samples are slowly cooled to 77K held down for many hours and gradually warmed to the room temperature.

The graph represented below shows the variation of the temperature during the cryogenic treatment with the time.

The cryo processing of tool steels and HSS steel have increased the wear and hardness by a significant amount and thereby increasing the life and production time. Cryogenics field for Aluminium alloys, that represent a very important class of structural metals for subzero-temperature applications and are used for structural parts for operation at temperatures as low as 77 K. Below 77 K, most Aluminium alloys show little change in properties, yield and tensile strengths may increase, elongation may decrease slightly, impact strength remains approximately constant.Consequently, Aluminium alloys are useful material for many low–temperature applications.

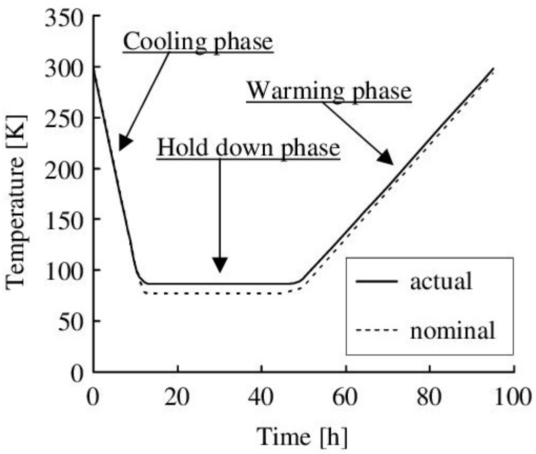

Fig.1.DCT Temperature profile

II. DESCRIPTION

Po Chen studied the effect of cryogenic treatment on the residual stresses and mechanical properties of an aerospace aluminium. In this work the cryogenic treatment was applied to the Al alloy used for aerospace application that had already been heat treated. It was slowly cooled without thermal shocks to approximately 89K, held at this temperature for 24 hours and reheated slowly, it was observed that after the cryogenic treatment the residual stresses was reduced by up to 9ksi in the parent metal, significant enhancement was observed in Stress Corrosion Cracking performance was observed, very small increase in the value of the micro hardness fatigue and tensile properties were noted after the treatment.

The effect of cryogenic thermal treatment on the room temperature strength, hardness, and toughness of aluminium 7075-T651 was investigated by Lulay et al. This is a precipitation-hardened material that is used in applications requiring high strength and good corrosion resistance. Test specimens were received and then deep treated cryogenically. The treatment consisted of placing the test specimens in a commercial cryogenic freezer (−196°C) for two different lengths of time: 2 h and 48 h. The 2-h treatment was conducted to determine whether there were any time-independent effects. The 48-h treatment was conducted to evaluate soaking effects. No processing was performed after the cryogenic treatment. A set of specimens was also tested in the as-received condition to establish a baseline. All testing was performed at room temperature. From this testing, the proportional limit, yield strength (0.2% offset), ultimate tensile strength, and elongation were determined. Hardness testing and Charpy impact testing were also conducted. The effect of 48-h cryogenic treatment on the basic mechanical properties was very small, generally about a 1% difference. The largest percent change was observed in the Charpy impact testing, which was nearly a 12% difference. There was almost no difference between the as- received and the 2-h treatment for any of the properties. Venkateswara rao et al studied on Cryogenic Toughness of Commercial Aluminum-Lithium Alloys: Role of De lamination toughening. Based on a study of the fracture-toughness and tensile behavior of commercial aluminum-lithium alloys, 2090 and 8090 heat treated and cryogenic (77 K) temperatures, the following conclusions were drawn:

All commercial alloys displayed increases in strength, uni-axial tensile-ductility, and strain-hardening rates with decrease in temperature from 298 to 77 K. The observed increase in uni-axial tensile ductility with decrease in temperature also appeared to be associated with loss of constraint from enhanced short-transverse de-lamination at 77 K. Tensile ductility values measured in 2090-T8E41 under more constrained conditions approaching plane strain, accordingly, were found to decrease at lower temperatures. Despite low short-transverse toughness, optimal strength/toughness (longitudinal) properties were found at both 298 and 77 K in the 2090-T8E41 alloy. Such behavior is attributed primarily to the anisotropic, un-recrystallized, and highly elongated grain structure in peak-aged 2090, which leads to poor short-transverse toughness but promotes crack-divider and crack-arrester de-lamination toughening, especially at cryogenic temperatures, in the perpendicular orientations. N Eswara Prasad et al studied Mechanical behavior of aluminium–lithium alloys, Reveals a significant information about the Aluminium Lithium alloys. These alloys are prime candidate materials to replace traditionally used Al alloys. Despite their numerous property advantages, low tensile ductility and inadequate fracture toughness, especially in the through thickness-directions, militate against their acceptability. He showed that Extensive co-planar slip, sensitivity towards the presence of even low contents of alkali metals, hydrogen and some of the impurities are key factors responsible for the property limitations. It is now possible to obtain alloys in different thermal and thermo-mechanical conditions that are suitable for different product forms. However, further efforts are needed to suit- ably modify the microstructure and crystallographic texture in order to improve isotropic mechanical behavior and enhance damage tolerance of these alloys. He also suggested that Understanding of mechanical behavior and the related micro-mechanisms in these alloys has helped to a significant extent the use of Al–Li alloys for certain structural applications. Xian quan Jiang et al investigated the effect of mechanical properties and microstructures of 3102 Al-Alloy. In this work the mechanical and microstructure properties of cryogenic treated Al 3102 H19, H26 or O state, were studied. The outcome of the result was that after deep cryogenic treatment, the strength of H 19 state increased and the elongation to failure decreased but in the O state the yield strength increased but the breaking strength, elongation decreased. For H26 state, the strength and elongation increased. Under Optical Microscopy and transmission electron microscopy it was seen that cryogenic treatment caused by the fibrous grain broken down and many grains with the size of 0.1-0.3 micro meter were formed. These fine equiaxial grains showed improved strength and elongation of the foil, the atomic shrinkage force slips high density dislocations into interface of the grains and forms terraces and fissures in it. This leads to the elongation decrease and the interface been broaden at very low temperature. As a result the synthetic mechanical properties of H26 state improved by the way of cryogenic treatment, but the H19 state and O state shows no improvement at low temperatures.

The effect of cryogenic treatment on the properties of AA 7075 alloys were studied by Saeed Zhirafar et al and following conclusions are made for the cryogenic treatment of Aluminium. In the 7075 alloy the increase of volume fraction of second phases was the main micro- structural effect of the cryogenic treatment, this was found by the results of microscopy, XRD abd EDS microanalysis. As the volume fraction of secondary phase increased after cryo treatment the hardness of cryogenic treated Aluminium alloy 7075 showed slight increase over the one subjected to conventional T6 treatment, there were no noticeable variation in toughness, by Increasing the amount of second phase after cryo processing, the resistance of the Al alloy 7075 to fatigue decreased, most likely by promoting the nucleation of micro cracks. Effect of cryogenic treatment on the mechanical properties of 2A11 aluminium alloy was studied by Junge wang et al. Cryogenic box with program control and electric resistance furnace were employed to perform cryogenic treatment process as well as heat treatment process. Impact tester, tensile tester, three coordinates measuring machine, high precision caliper and standard metallography were used to carry out tests.

The influence of different process parameters on mechanical properties of 2A11 aluminium alloy were compared, and the results showed that cryogenic treatment could improve mechanical properties of 2A11 aluminium alloy. The dimensional stability increases after cryogenic treatment once, and increases further after cryogenic treatment again.

The influence of cryogenic processing after the saturation of the aging process of ALCu4.7 alloy was investigated by stankowiak et al. the outcome of this work was that cryogenic treatment accelerates the process of aging and this influence was studied in the temperature range of 493K to 693K in comparison with conventional alloy, the above work proved that the cryogenic treatment has a great influence on the aging process, the other mechanical properties of the material was also increased after the cryogenic treatment.

III. PROPERITES OF ALUMINIUM ALLOYS AFTER CRYO TRETMENT

In the overall study of the cryogenic treatment of aluminium alloys it was observed that with the increase in commercial usage of cryo treatment the number of research in this field is increasing in a faster pace.

The literature regarding the effect of cryogenic treatment of 7075 T6 Aluminium alloy was done by Lulay. In that work, Aluminium alloy was examined with two different soaking times (2 and 48 hours) at cryogenic temperature (77K) and then at the room temperature they measured the strength, hardness and toughness of the samples(as shown in Table 1). Samples with 2 hours soaking time at cryogenic temperature did not show a change in mechanical properties whereas there was a observable change in those samples soaked at 48 hours(fig 2,3).

The observed changes were 11% increase of charpy impact tough ness and a half point decrease in Rockwell B hardness.

Table.1. Mechanical properties with soaking time

Soaking time	As received	2Hours	48Hours
Proportional limit, Mpa	484	485	491
Yield strength, 0.2% Mpa	530	530	534
Ultimate tensile strength, Mpa	583	583	585
Charpy test, J	8.5	8.8	9.5
Hardness in BHN	91.3 R_b	91.1 R_b	90.8 R_b

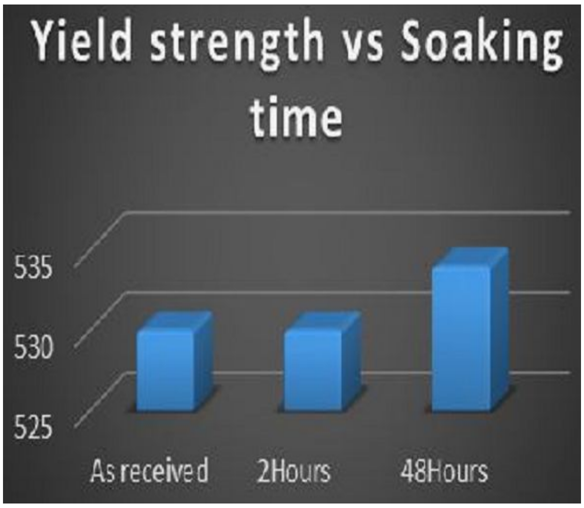

Fig 2. represents yield strength vs soaking time

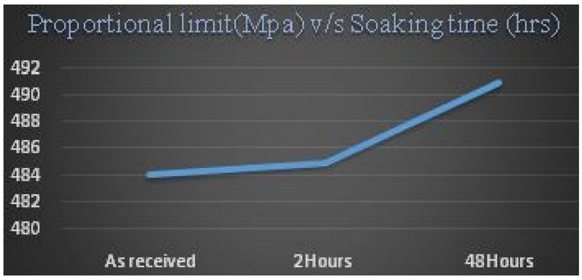

Fig.3. represents proportional limit vs soaking

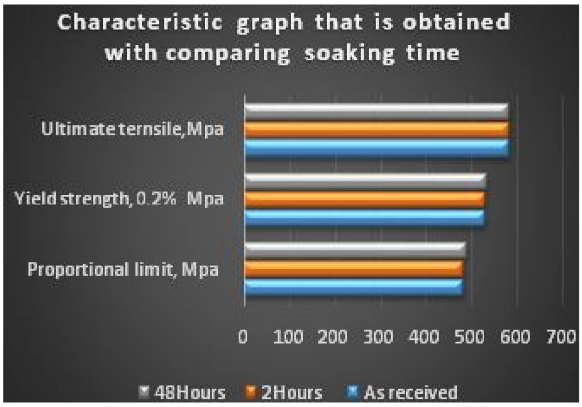

Fig.4. characteristics of UTS, YS, PL with soaking time

Hardness

The hardness tests of the material is an important property that affect the wear strength of the materials. It was observed that the improvement in the properties of aluminium alloy after cryogenic treatment was negligible when compared to the other materials like the tool steels where significant improvement in properties are noticed. The increase in Hardness is approximately within 5% for all the Aluminium alloys after the cryogenic treatment.

Tensile properties

The tensile behavior of the various alloys with and without cryo-genic treatment was studies and following conclusions can be drawn from the table below it can be observed that the increase in the UTS of the Aluminium alloys is not the same for all the alloys and it varies individually with type of the alloy. The increase in the tensile strength is predominant in the alloys used for aerospace or aeronautical applications like 2XXX and 8XXX series alloys. The increase in the tensile strength is marginal after cryo treatment of the other alloys studied in their work.

Table.2.Variation of UTS with different materials

Type of Alloy	UTS for conventional material in Mpa	UTS for cryo-treated material in Mpa	Percentage increase in UTS in %
2091-T8X	481	610	21.1
8090-T351	352	486	27.57
7075-T6	583	585	0.3
2090-T8E41	589	642	5.4
8091-T8X	581	697	16.6

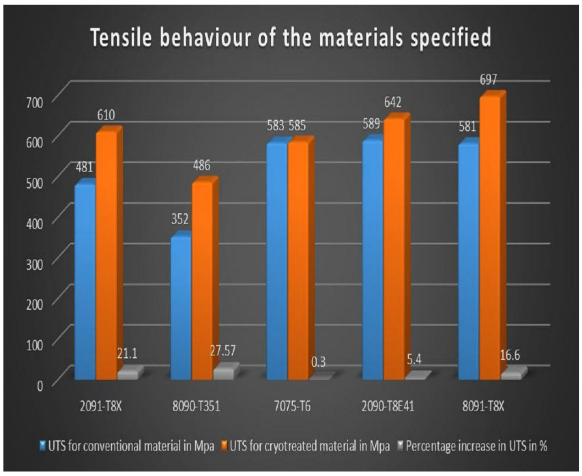

Fig.5. graph of tensile behavior with and without cryo treatment

MICROSTRUCTURE

Comparison between the specimens that underwent the conventional T6 treatment and those that had the cryogenic treatment was performed by microstructural examination according to the typical microstructure of 7XXX series the microstructure consists mainly of Aluminium solid solution as matrix. It was observed that when the content of alloying elements exceeds the solid solubility limit, the alloying element produces the second phase that may consist of either pure alloying ingredient or an inter-metallic compound phase. Visual inspection of these two microstructure, it can be seen that the amount, as well as the distribution of this second phase, have been increased for the specimens which underwent cryogenic treatment, compared to the conventional T6 treated specimen. As from the histogram results it was evident that the cryogenic treatment increases the volume fraction of the alloy and thereby enhancing the mechanical properties of the cryo treated alloy.

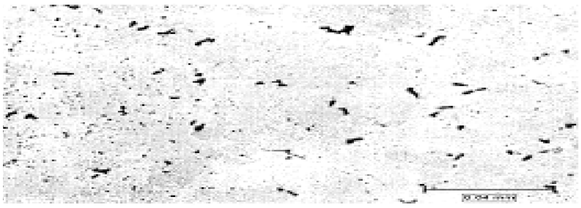

Fig.6.optical micrograph of 7075-T6[10]

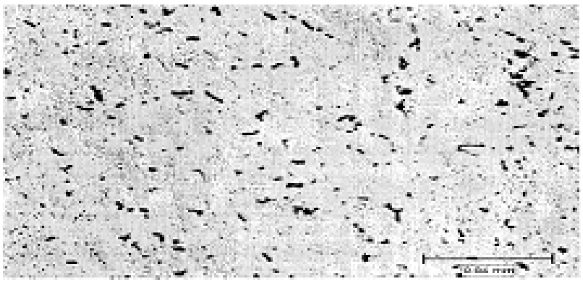

Fig.7.optical micrograph of 7075-T6 cryo-treated

IV. SUMMARY AND OUTLOOK

Cryogenic treatment is a recent tread in the 21st century to enhance the properties of the conventional Alloys. Cryogenic treatment has a wide filed of application in tool making and the manufacture of inserts for the tool. When it comes to the application of this technique for the Aluminium alloys, very little work has been done. Complete information of the properties of these alloys at cryogenic temperature is still not known. In this approach the review on the effect of cryogenic treatment on the mechanical properties of aluminium alloys was done and following were the outcomes. The variation of the behavior of these alloys for cryo treatment is not the same for all alloys of Aluminium. Some alloys shows greater variation and some show very less influence of this treatment.

A marginal improvement in the mechanical properties was observed after cryogenic treatment for most of the alloys. The microstructure depicts reduction of residual stress after cryogenic treatment. Finer grains were observed after subjecting the material to very low temperature which affect the material properties. Hence in this process, the study of the application of cryo treatment for many other Al alloys is strongly recommended to enhance the commercial application of this process.

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