EFFECT OF DEEP CRYOGENIC TREATMENT ON MECHANICAL PROPERTIES OF 7075 ALUMINUM ALLOY

Shirish Patil

Mechanical Engineering, CSSMS, M.S, India

Vinay Lomte

Department of Chemical Technology, Dr. BAMU, M.S, India

ABSTRACT

Aluminum alloys in various compositions displays different set of properties owing to its complex precipitation behavior during aging. Significant work has been performed by investigating the effects on various properties of ferrous metals like tool steels at cryogenic temperatures. As for Al alloys, the effects of cryogenic treatment on properties of age hardenable alloys like 7075 are not reported extensively in current literature. This work consists of application of DCT at -185°C to 7075 aluminum alloy for various time durations. The cryogenic treatment was incorporated between the solutionizing and artificial aging of conventional T6 temper of Al alloy. This treatment sequence has been referred earlier in the literature for CT to 6061 Aluminum Alloy with significant improvements. The behavior of this alloy to the treatment was identified by measuring hardness, electrical conductivity and surface roughness. These measurement parameters were found to be significantly affected at specific cryogenic soaking duration and statistical analysis of experimental data supported the claim.

Keywords: Aging; Hardness; Conductivity; Roughness; Cryogenic.

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1. INTRODUCTION

Aluminum alloy have long been of prime interest due to its high strength to weight ratio and increased performance when compared to ferrous alloys. They display different set of properties in various compositions and are the major candidates in the aerospace community due to modest specific strength, manufacture ease and low cost. Aerospace industry demands improved performance and high specific properties [1]. The effects of cryogenic treatment (CT) to large

extent on various ferrous alloys especially on tool steels and to some extent nonferrous alloys like Copper, Magnesium, Aluminum alloys, polymers and composites have been well under research. Cryogenic temperatures effects on properties of materials have been examined extensively in terms of mechanical, thermal and electrical properties [2, 3]. Positive effects of low temperatures on this type of materials properties have led to the cold/sub-zero and cryogenic treatments of different variety of cutting tools and mechanic parts for increasing hardness, strength and wear resistance in automotive and manufacturing industry [3].

The sequential stages of basic CT consist of a gradual cooling of the component up to the defined temperature, holding for a given time (Soaking time) and progressively leading back to the room temperature to obtain an improvement of mechanical properties, specifically like hardness and wear resistance [4]. So, enhancement of metallurgical properties is obtained by CT to most of the metals, in turn improving several strengths of the treated parts [5]

As for aluminum alloys, formation of coherent precipitates in aging is mainly responsible for increase in strength and hardness. These coherent precipitates form from supersaturated solid solution after solutionising and quenching of age hardenable aluminum alloys like 2XXX, 6XXX and 7XXX series. So, material strengthening in these alloys is based on a precipitation hardening process. For 7xxx Al alloys, generally accepted precipitation sequence is like,

Where, GP zones are ordered solute-rich clusters of atoms responsible for appreciable elastic strains in the surrounding matrix [6]. So, if these alloys are treated at cryogenic temperatures there could be change in microstructure and subsequently in properties like the same way as “conditioning” of the matrix of the tool steels when subjected to the CT [6, 7]. As precipitation is closely associated with dispersion and dissolution of solute particles in matrix of the alloy and changes due to CT are correlated to this precipitation behavior.

The important part here is when and how the CT should be incorporated in conventional heat treatment cycle of ferrous or nonferrous alloys. As for the ferrous alloys like steels and nonferrous alloys like Aluminum alloys, heat treatment comprising of austenitizing /solutionising and tempering / aging associated with dissolution and dispersion of precipitates can cause change in microstructure and properties. Inclusion of CT between quenching (after solutionising) and aging could affect the changes in the alloy and matrix “conditioning”. It was evident by influential changes in some properties like hardness and surface roughness of Al 6061 when CT was given between quenching and aging [6]. As for 7075 AL alloy, this initiated the present work for the following treatment cycle which investigates the response of this alloy to the CT.

As per available literature hold time over 36 hours at cryogenic temperatures does not bring significant improvements but in most cases 24 hours are enough to obtain results [4], so 20h, 24h and 28h were taken as cryogenic soaking durations.

The work comprises characterization by measuring the properties such as hardness, electrical conductivity and surface roughness. The response of the alloy to CT with respect to different properties under various treatment parameters is presented here.

2. EXPERIMENTAL PROCEDURE

The alloy used for the experimentation was an as-received commercial 7075 Al alloy with a block of 250 by 250 mm with 30 mm thickness confirming to the composition by spectrometric analysis using ASTM B 209-01 (as shown in Table 1) from which two coupons each were prepared for different material/condition tested. It has undergone treatment of T6 and cryogenic cycle (SQCA – Solutionising + Quenching + Cryogenic Soaking + Artificial Aging). The heat treatment and cryogenic cycle are listed in Table 2.

Table 1 Composition of the AA 7075 used in the work

Element	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt.%	0.05	0.16	1.67	0.45	2.13	0.12	6.08	0.03	89.3

Table 2 Various heat treatment cycles applied to AA 7075 alloy

Treatment Cycle	Process
T6	Solution-treatment at 475°C for 1 h, quenching in cold water at room temperature, and aging at 120 °C for 24 h
SQCA (CT Cycle)	Solution-treatment at 475°C for 1 h, quenching in cold water at room temperature, Cryogenic soaking at -185°C for 20,24,28h and aging at 120 °C for 24 h,

The hardness at various stages of the treatment was measured as per ASTM E18-03 on the Rockwell hardness tester on B scale, with 1/16th inch ball diameter and 100 kg load.

Electrical conductivity measurement (ASTM E1004-99) at various stages of the treatment was carried out by Techno four- Indian make electrical conductivity meter (type 979) for nonferrous metals in % IACS. (International Annealed Copper Standard) The conductivity was measured in at random surfaces on each sample of cube and then averaged to obtain a conductivity number for the whole specimen.

The surface roughness was measured by a Mitutoyo make, Surf test SJ210 (stylus tip radius 5 mm). Samples were machined on a vertical grinder with 0.25mm depth of cut before the measurement of roughness (Ra value) after the treatments given.

Figure 1 A Line chart shows different CT soaking periods for the hardness of AA 7075 compared to T6

Figure 2 A Line chart shows different CT soaking periods for the electrical conductivity of AA 7075 compared to T6

Figure 3 Surface Roughness for different CT soaking periods of AA 7075 compared with T6

3 EXPERIMENTAL: PROPERTIES MEASUREMENT

3.1 Hardness

Hardness measurements which were taken at subsequent intervals of treatment like after quenching, after cryogenic treatment and after aging to observe changes and effect of treatment on hardness. The treatment has exhibited increase in hardness for each subsequent treatment stage. 24 h cryogenically soaked (SQCA) sample had maximum hardness followed by 20h after treatment compared T6 coupons Maximum increase in hardness was 7% for 24 h followed by about 6% for 20h while reduction of 3% to 28h. Fine precipitation and optimum precipitate distribution contributed to improved hardness in cryogenically soaked (SQCA) samples over T6. The average and % change in hardness of SQCA cube specimens is depicted in the chart 1 28 h

The effect of the treatment was checked for its consistency over longer duration. This was done by hardness measurements at periodic intervals to determine long-term (up to 6 months/180 days) stability of the properties on T6 and SQCA treated coupons. It was observed that the values of all coupons in T6 and 20, 24 and 28 h SQCA were fairly stable over the entire period. Increase in hardness after 180 days was approximately by 8 % for T6 and 24Hrs samples. This graph shows that effect of treatment is consistent over longer duration.

Figure 4

3.2 Electrical Conductivity

Measurements of electrical conductivity are helpful in heat treatment monitoring of aluminum alloys. Detection of flaws, micro structural changes are evident with change in the material conductivity. Also, for heat treated aluminum alloys higher values of electrical conductivity are indicative of good corrosion resistance.

Electrical conductivity at different treatment stages of T6 and SQCA samples displayed in graph 6.2 showed that readings of all samples after aging are consequently less than the initial stages of treatment (quenching and cryogenic soaking). Conductivity decreases for each sample in each treatment stage, which is in accordance with ascending hardness values for respective samples in respective treatment stage for T6 and SQCA. So low electrical conductivity at higher hardness depicts dissolution of some precipitates which is attributed to the dissolution and re-precipitation phenomenon due to CT [7]. Maximum % reduction is (approximately 3%) for 24h followed by for 20 h but for 28 h increased by 7% approximately,

The highest average value (35.8) was for 28 Hrs SQCA sample which had lowest hardness (73.9HRB) among all samples which is in accordance with earlier hardness, conductivity readings. There was no major fluctuation in conductivity readings at each time interval and all samples had constant conductivity over entire duration as shown in the graph. Variability in precipitate formation in microstructure for treated samples could be influential in electrical conductivity

Figure 5

3.3 Surface Roughness

Roughness is a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. Surface roughness measurements were taken by surface roughness tester after treatment i.e., T6 and Cryogenic treatment (SQCA). The R_a values of roughness were measured in at least five random locations on single sample surface and then averaged to obtain a roughness value for the whole specimen. The measurement showed surface roughness R_a (μm) of T6 and SQCA treated samples on the single surface with small machining cut of 0.25 mm. % reduction compared to T6 was maximum for 28hrs (4%) followed by 20hrs (0.84%) while for 24hrs roughness increased (0.28%). Lower R_a values for the sample of 24 h and to a small extent for 20h indicate that cryogenic soaking after quenching and before aging could have helped to reduce roughness variably. Roughness reduction could be due to formation of large number of fine precipitates which helps in “filling up” of the gaps between coarser precipitates and uniform precipitate distribution [7].

The effect of the cryogenic treatment on the basic mechanical properties viz. hardness was significant, electrical conductivity was small as compared to the other treatments and the CT gave the additional benefit of improved surface roughness as observed for the sample of 24 h and 20h.

All the quantitative data collected from different tests and treatments at various conditions mentioned earlier was required to be analyzed on some statistical terms to find and establish co-relations between the sets of data so that some inferences could be drawn which would be helpful to gauge the effect of various treatments on properties and changes on the material. To determine whether the difference was a result of actual changes in the material or whether the observed differences were due to normal data variation (not a real difference), statistical

t -tests were performed. The t -test method performed for analyzing two sets of data to determine whether the difference in measured averages is real or a byproduct of chance variation some properties, albeit small. that there is about a 90-95% confidence level ($t > 1.75$);

that there was a difference in hardness ,electrical conductivity as a result of 48-h cryogenic treatment.

The SEM images show the Vacant lattice sites appearance after quenching which become more dominant due to CT, leading to formation of large number of vacancies, which ultimately forms fine precipitates in large quantities helping to increase hardness.

Figure 6 T6

Figure 7 20h

Figure 8 24 h

Figure 9 28 h

4. CONCLUSIONS

When Aluminum alloy 7075 was cryogenically treated between solutionising and artificial aging (SQCA) for 20, 24 and 28h and compared to T6 and as-received condition, changes were observed for different properties which can be summarized and following conclusions can be drawn.

- There was considerable increase in hardness compared to T6 for all tested specimens for 20,24h SQCA but for 28h SQCA small increase in hardness observed for EXCO and tensile specimens while reduction for cube specimens. Fine precipitation from large number of vacancies due to CT helped to increase hardness.
- Electrical conductivity (EC) decreased compared to T6 for cube specimens for 20, 24h SCCA but for 28h SQCA there was substantial increase.
- Incoherent relationship between hardness & EC was observed for different groups of test specimens such as for cube specimens inverse relationship was seen between hardness and EC (like increase in hardness, decrease in EC)
- As-received specimens showed inferior results than T6 and SQCA treated conditions for hardness, and EC
- Some of the above mentioned improved properties of SQCA samples over T6 appears to be a function of material itself in terms of chemical composition, cryogenic treatment and precipitate formation
- A high probability that 24h CT could have a real effect on hardness, and to some extent by 20 ,28 h CT to hardness and surface roughness.

FUTURE SCOPE

- More tests required to confirm that 24h CT indeed influences material properties of AA7075
- Effect of CT on fatigue and stress corrosion behavior could be tested
- Quantitative relationship between different processing parameters by CT can be found out
- Effect of CT on micro structural changes and characterization in 7XXX series Al alloys need to be investigated

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