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EFFECT OF HEAT TREATMENT ON STRESS CORROSION CRACKING RESISTANCE OF AL-ZN-MG-CU ALLOY USED IN AEROSPACE ENGINEERING APPLICATIONS

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ABSTRACT

Agehardenable aluminium alloy belonging to the Al-Zn-Mg-Cu family have proved useful as structural materials primarily because of their unique combination of low density, high strength and good corrosion resistance and designated as 7xxx series of alloys. They find wide applications in airframe structures such as aircraft, space vehicles and light armored carriers. Different types of aluminium, steel, titanium alloys are used to manufacture high precision forgings and castings for various parts in aerospace industries which have been proactively developing newer methods of thermo mechanical treatment for various heat treatable aluminium alloys such as the 2XXX, 6XXX and the 7XXX series alloys. Aluminum alloy confirming to AA 7049 specification is a high strength aluminium alloy used extensively in aerospace sectors. These alloys exhibit a very high strength (more than 650 MPa) when subjected to T6 temper heat treatment but they are susceptible to corrosion. Therefore corrosion resistance can be increased by heat treating to T73 temper. However there will be reduction of 10 – 15% in strength but improvement in corrosion resistance could be because of reduction in residual stresses built during heat treatment process. In the present investigation, it is proposed to systematically study the effect of heat treatment on the stress corrosion cracking resistance (SCC) of this alloy. The raw material was in the form of extrusion of 60 mm diameter and 75 mm length and it is subjected to T6 and T73 heat treatment tempers. The SCC resistance was being studied in both the tempers by subjecting the specimens to test as per ASTM G 47 test standard. Also, the mechanical properties viz., Ultimate Tensile Strength, 0.2% proof stress, % elongation and hardness was determined in both T6 and T73 temper conditions. It is found that the stress corrosion cracking resistance was enhanced at T73 temper when compared to T6 temper. The mechanical properties were superior at T6 temper. The specimens at T73 temper exhibited higher resistance to corrosion when subjected to stress corrosion cracking test.

KEYWORDS: Aluminium Alloys, Stress Corrosion Cracking Resistance, Heat Treatment, Temper Conditions, Mechanical Properties

INTRODUCTION

Aluminium alloys play a major role in aerospace sector. They remain as the major materials for civil airframe construction and are used for many applications. In most aircrafts, it is used in manufacturing structural members. Aluminium alloys have an edge over other conventional structural materials owing to their high specific strength (strength/density). The continued effort to reduce the weight thereby cost in aeronautical industries led to the development of several newer aluminium alloys. Aluminium and its alloys exhibit most desirable combination of properties. They can be strengthened to nearly 20 times its original value. Aluminium alloys have good static and fatigue strength, which are the major and dominant requirements for the structural applications to obtain strategic weight benefits. The properties and behavior of the metals and alloys during manufacturing and their performance during their service life depend on their composition, structure and processing history. Important basic properties such as strength, hardness, ductility and toughness as well as resistance to wear and scratching are greatly influenced and modified by the alloying additions, processing conditions and heat treatment conditions.

Aluminium is one of the light metals. The property of light metals translates directly to material property enhancement for many products since by far the greatest reduction in weight is achieved by a decrease in density. This is an obvious reason why light metals are used in transportation, notably aerospace sector.

Table 1: Mechanical Properties of Aluminium with Different Purity Level

Purity %	UTS (MPa)	0.2% PS (MPa)	% EL
99.9	45	10	50
99.8	60	20	45
99.6	70	30	43

The strength of aluminium in compression is same as in tension. The strength of various grades of pure aluminium is increased only by cold work, which reduces ductility. Hot and cold worked metal has a denser and finer grain structure than cast material and in the annealed condition wrought aluminium alloys have a high level of properties than cast [2]. Aluminium is alloyed with number of elements to produce a wide range of materials with particular properties. These are grouped into three categories. These have been subjected to plastic deformation by hot and cold working mill process such as rolling, extrusion and drawing either singly or in combination so as to transform aluminium ingot into the desired form. These are designated as AXXX (A stands for 1, 2, 3, 4, 5, 6, 7, 8, and 9). The Aluminium Association alloy designation system for wrought alloys begins with “AA” followed by a four-digit number system, where the first of the four digits in the designation indicates the alloy group. The various wrought alloys can most readily be described by adopting two basic groups, being the non heat-treatable and the heat-treatable alloys.

WROUGHT HEAT TREATABLE ALLOYS

Heat-treatable alloys can achieve a higher strength by heat-treatment and therefore they contain one or more elements chosen to obtain this higher strength by precipitation hardening during artificial ageing. These alloys include the Al-Cu-(Mg) (2XXX), Al-(Cu)-Mg-Si (6XXX) and Al-(Cu)-Mg-Zn (7XXX)-groups. The 2XXX-group contains alloys with copper as the prime hardening element. Often magnesium is added to increase the strength. These alloys obtain their very high strength by precipitation of the phases $CuAl_2$ and/or $CuMgAl_2$... They are widely used not only in aviation- and space industry, but also as machine parts, bolts and rivets. The 7XXX-group contains high-strength materials similar to Al-Cu-(Mg), but with zinc instead of copper as the main alloying element. However, copper can also be added in smaller amounts. The high strength is due to precipitation of $MgZn_2$-precipitates.

WROUGHT NON-HEAT TREATABLE ALLOYS

Non heat-treatable alloys obtain higher strength either by strain hardening (e.g. cold working) or by solid solution. They include the pure aluminum group (1XXX), the Al-Mn group (3XXX), the Al-Si group (4XXX) and the Al-Mg group (5XXX). These alloys are mostly used for flat products such as plate, thin sheet and foils. Plate and sheet are often delivered in cold-rolled tempers for high strength applications, but the best formability is in the soft annealed temper.

WROUGHT ALUMINIUM AND ALUMINIUM ALLOY SYSTEM

A four digit numbering system is used to refer to the alloys of aluminium as NXYY. N is a digit from 1 to 9 indicating the most important alloying element. X is a number that indicates the most important second element. The digits YY indicate the minimum purity level of the metal used for making the alloy. Table 2 gives the wrought aluminium alloy designation system.

Table 2: Wrought Aluminium Alloy Designation System

Aluminium Content or Major Alloying Element(S)	4-Digit Series
Aluminium6 ≥ 99.0	1XXX
Copper	2XXX
Manganese	3XXX
Silicon	4XXX
Magnesium	5XXX
Magnesium and Silicon	6XXX
Zinc	7XXX
Lithium	8XXX
Reserved	9XXX

In 1XXX group, the last two digits indicate the hundredths of a percent of aluminium above 90 % e.g. 99.45% aluminium is designated as 1X45.

VARIOUS ALUMINIUM ALLOYS

There are various aluminium alloys used in the aeronautical industries due to their high strength to weight ratio as well as their corrosion resistance. Some of the very important aluminium alloys have been listed below.

Al-Mg Alloys

Aluminium when alloyed to 8% or more magnesium gave high strength, low density and weld ability and susceptibility to corrosion due to Al-Mg precipitate compounds are highly anodic to the depleted solid solution.

Al-Zn-Mg Alloys (7XXX)

Al- Zn-Mg alloys were among the first commercial alloys of aluminium. In these alloys zinc is the main component for strength, copper is also added to improve strength but mainly to reduce hot shortness and to improve cast ability and stress corrosion resistance. The structure of the alloy is relatively simple, most of the Zn and Cu is in solid solution the rest may form the Al-Cu-Zn compound usually present at grain boundaries in the form of divorced eutectic. With copper more than 2% and silicon more than 0.5% the ternary eutectic-Cu -Al2 - Si may be present and structure are much closer to those of aluminum magnesium alloy than of the Al- Zn-Mg. Zn &Mg are the main alloying elements; high Zn: Mg ratios produce the best strength and response to heat treatment, together with the highest susceptibility to SCC. Titanium and born are normal grain refiners.

Al-Zn-Mg-Cu Alloys

German scientists had shown that Al-Zn-Mg alloys show exceptionally high tensile properties in early 1920's. These however were susceptible to stress corrosion cracking. After intensive researches, the first continuously produced Al-Zn-Mg alloy was 7076-T6. It was developed as high strength forging alloy for the production of propeller blades resistant to abrasion and fatigue. The high melting element addition like chromium 0.2-0.35% developed high resistance to stress corrosion.

IMPORTANT ALLOYS OF THE 7XXX (AL-ZN-MG) SERIES

Many aluminum alloys with zinc as the major alloying element along with magnesium and / or copper have been under continuous research and development for better aerospace requisite properties.

Aa7049

Although 7175-T736 was used successfully, it was not useful for sections thicker than about 75mm because of its quench sensitivity. Several programs were initiated in the 1960's that had the goal of developing an alloy that would provide the strength of 7079-T6 in sections of 75mm and greater thickness with higher resistance to stress corrosion cracking. Alloy 7049-T73 registered in 1968, was the first of several commercialized. Compared with 7075, the alloy contains higher zinc for higher strength and lower chromium for lower quench sensitivity. It has been used as forging in a number of airplanes in new design and as a retrofit for 7079-T6. Alloy 7049-T73 has been used in a few applications as extrusions but has not found a use as plate. A high purity version was introduced later to provide higher toughness.

Table 3: A Nominal Composition of the Alloy 7049 Is Mentioned

Elements	Zn	Cu	Mg	Si	Fe	Mn	Ti+Zr	Cr
Percentage	7.2-8.4	1.2-1.9	2.1-3.1	0.4Max	0.5Max	0.5Max	0.25Max	0.05-0.25

Aluminium 7xxx series Al-Zn–Mg–Cu alloys have wide applications as aerospace structural components because of their superior performance, high strength to weight ratio and ease of fabrication. These alloys offer a greater response to precipitation hardening treatment, with the potential for substantially enhanced strength. These alloys were subject of extensive investigation for many years. Despite attractive tensile properties and good fabrication characteristics, they have poor stress corrosion cracking resistance for thick sections. This problem was addressed to by developing over aged temper, T73 heat treatment. But this resulted in reduction in static strength up to 15% compared to the strength of peak aged T6 temper.

The main objective of the present investigation is to study the behaviour of AA7049 aluminium alloy under different heat treatment conditions. It has been proposed to systematically study the effect of heat treatment on the stress corrosion cracking resistance of Al-Zn-Mg-Cu alloy conforming to AA7049 specification. It is proposed to subject extruded examples of aluminium alloy conforming to AA7049 specification to two different heat treatment conditions, namely T6 condition and T73 condition. The basic objectives of this present work are:

- To subject AA 7049 aluminium alloy specimens to heat treatment cycles comprising T6 andT73 temper designations.
- Determine the UTS, 0.2% PS and % Elongation for these samples.
- Determine the Hardness BHN
- To conduct SCC test and determine time to failure.

ALLOY STRENGTHENING AND HEAT TREATMENT

To study the perception students have in their mind about science and scientist at work with respect to physical attributes and attributes of science.

MECHANISM OF ALLOY STRENGTHENING

The different mechanism leading to the strengthening of aluminium alloys improve the mechanical and physical properties of these alloys can be of following five types such as Solid solution strengthening, strengthening from second-phase constituents, strain hardening, grain size strengthening and precipitation strengthening. Precipitation Strengthening increases the strength of the alloy by the presence of precipitates, which is achieved through heat treatment. It refers to any of the heating and cooling operations which are performed for the purpose of changing the mechanical properties, the metallurgical structure, or the residual stress state of a metal product. One essential attribute of a precipitation-hardening alloy system is a temperature-dependent equilibrium solid solubility characterized by increasing solubility with increasing temperature. The two necessary conditions for age hardening to occur are the equilibrium diagram for the alloy must exhibit a sloping solvus line. There must be atomic matching or coherency, between the lattices of the precipitates and the matrix. Precipitation strengthening involves 3 major processes such as solution treatment, quenching and ageing**.**

SYSTEM FOR TYPE OF HEAT TREATMENT GIVEN

The temper designation for wrought and cast products that are strengthened by heat treatment employs ‘W’ and ‘T’ designations. The ‘W’ designation denotes an unstable temper, whereas ‘T’ designation denotes stable temper other than F, O or H. a number follows the ‘T’ from 1 to 10, each number indicating a specific sequence of basic treatment.

T1 - Cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.

T2 - Cooled from an elevated temperature shaping process, cold worked and naturally aged to a substantially stable condition.

T3 - Solution heat treated cold worked and naturally aged to a substantially Stable condition.

T4 - Solution heat-treated and naturally aged to a substantially aged condition.

T5 - Cooled from an elevated temperature shaping process and artificially aged.

T6 - Solution heat-treatment, quenching and artificially aged.

T73 - Solution heat-treated and over aged or stabilized.

T8 - Solution heat-treated, cold worked and artificially aged.

T9 - Solution heat treated artificially aged and cold worked.

T10- Cooled from an elevated temperature shaping process, cold worked and artificially aged.

HEAT TREATMENT OF AL AND ITS ALLOYS

Heat treatment in its broadest sense refers to any of the heating and cooling operations, which are performed for the purpose of changing the mechanical properties, the metallurgical structure, or the residual stress state of a metal product. . When the term is applied to aluminium alloys, however, its use frequently is restricted to the specific operations employed to increase strength and hardness of the precipitation harden able wrought and cast alloys [4].

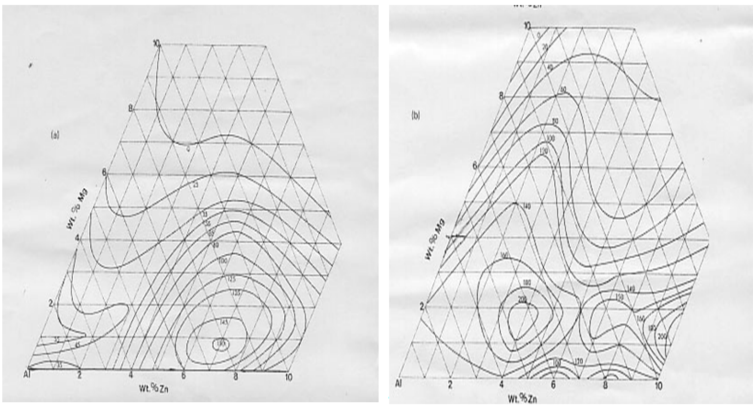
STRENGTHENING BY HEAT TREATMENT

Heat treatment to increase strength of aluminium alloys is a three-step process:

- **Solution Treatment:** Dissolution of soluble phases.
- **Quenching:** Development of super saturation.
- **Ageing:** Precipitation of solute atoms either at room temperature or elevated temperature.

Solution Treatment

This treatment is to obtain complete solution of most of the alloying elements. It is carried out by soaking the alloy at a temperature sufficiently high and for long time interval to obtain a nearly homogeneous solid solution. They are most effective near the solidus and eutectic temperature, where maximum solubility exists and diffusion rates are rapid. Even more than one soluble phase is present as in Al–Zn–Mg–Cu systems. However, care must be taken to avoid the incipient melting of low temperature eutectics and grain boundary phases. Such melting results in quench cracks and loss in ductility. The maximum temperature is also set with regard to grain growth, surface effects and economy of operation. The minimum temperature should be above the solvus, or the desired properties from ageing will not be realized. The solution heat treatment temperature is determined from the composition limits of the alloy. Fig. 3.1 a) and b) show a portion of the Al-Zn-Mg alloy system without and with copper respectively. Although ranges normally listed allow variations from the nominal, highly alloyed, controlled-toughness, high strength alloys require that temperature to be controlled within more restrictively limits. Broader ranges may be allowable for alloys with greater intervals of temperature between solvus and eutectic melting point.



a) b)

Figure 1: Al-Zn-Mg Ternary Phase Diagram A) Without Copper B) With Copper

Quenching

After solution treatment, aluminium alloy components must be cooled or quenched to the room temperature to achieve maximum super saturation of alloying elements, which subsequently come out as different phase particles during ageing. Quenching medium can be air, water, oil, liquid nitrogen etc. Water is the quench media of choice for aluminum alloys. Some alloys may be quenched with hot or boiling water; water sprayed or even air-cooled after solution treatment and still shows an acceptable response to age hardening. During the slow cooling, there is a tendency of solute elements to precipitate as coarse particles which reduces the level of super saturation and hence lowers the subsequent response of the alloys to age hardening. Micro structural changes may also occur in the region of grain boundaries, which are a consequence of slow quenching. In particular, segregation to the grain boundaries of solute elements, such as copper, may cause reduced toughness and higher susceptibility to intergranular corrosion in service.

Ageing

Ageing is the final stage to achieve the required properties in the heat treatable alloys. In ageing, the main aim is the controlled decomposition of supersaturated solid solution to form finely dispersed precipitates, usually by ageing for convenient times at one and sometimes two intermediate temperatures. There are two types of ageing processes: Natural ageing and Artificial ageing.

Corrosion Behaviour

Most aluminium alloys have good corrosion resistance in natural atmospheres, fresh waters, sea water, many soils and chemicals, and most foods, although thin-walled aluminium food containers are coated to resist perforation. A distinction must be made between durability and aesthetics. An aluminium surface may become unattractive through roughening by shallow pitting and may become dull or even black by dirt retention, but this mild surface attack has no effect on durability of the product, for example, roofing or siding. Different types of corrosion are Uniform Surface Attack, Localized Corrosion, Pitting Corrosion, Crevice Corrosion, Filiform Corrosion, Galvanic Corrosion, Deposition Corrosion, Stray Current Corrosion, Intergranular Corrosion, Exfoliation Corrosion, Stress Corrosion Cracking and Mechanism of Stress Corrosion Cracking.

Pitting Corrosion

Pitting Corrosion is the localized corrosion of a metal surface confined to a point or small area that takes the form of cavities. For pitting to occur, an electrolyte must be present. Pitting is one of the most damaging forms of corrosion. Pitting factor is the ratio of the depth of the deepest pit resulting from corrosion divided by the average penetration as calculated from weight loss. The rate of penetration may be 10 to 100 times that by general corrosion. While the shape of pit in aluminium can vary from shallow, saucer like depressions to cylindrical holes, the mouth is usually more or less round, and the pit cavity is roughly hemispherical. This distinguishes pitting from intergranular corrosion, in which attack is confined to subsurface tunnels along grain boundaries, usually visible only on metallographic examination of cross sections. Intergranular corrosion may occur along with pitting, in which case intergranular fissures advances into the metal laterally and inwardly from the pit cavity. Corrosion products often cover the pits. A small, narrow pit with minimal overall metal loss can lead to the failure of an entire engineering system. Pitting corrosion, which, for example, is almost a common denominator of all types of localized corrosion attack, may assume different shapes.

Inter Granular Corrosion

It refers to the preferential corrosion along the grain boundaries. Grains are crystals on a microscopic level and that constitute the microstructure of the metal and alloys. It has been defined commonly as a form of localized attack on the grain boundaries of a metal or alloy in corrosive media which results in the loss of strength and ductility. The localized attack may lead to the dislodgement of the grain.

It works inwards between the grain and causes more loss of strength than the same total destruction of metal uniformity over the whole surface. The attack is distributed over all the grain boundaries cutting the surface. Intergranular" or 'intercrystalline" means between grains or crystals. As the name suggests, this is a form of corrosive attack that progresses preferentially along interdendritic paths (the grain boundaries). Positive identification of this type of corrosion usually requires microstructure.

Exfoliation Corrosion

Exfoliation corrosion is a special type of inter granular corrosion where the grains have been subjected to deformation process example rolling, extrusion, forging. Exfoliation appears like leaves. Exfoliation, also called layer corrosion or lamellar corrosion, is a type of selective subsurface attack that proceeds tack is usually narrow paths parallel to the surface of the metal. It is a lamellar form of corrosion resulting from an attack along elongated grain boundaries parallel to the metal surface. The direction attack results in the leafing action or alternate layers of thin, relatively uncorroded metal and thicker layers of corrosion product that are more bulky than the metal from which they came.

Some laboratory methods have been developed to test for exfoliation corrosion susceptibility in aluminum alloys. These include metallographic examination, visual rating, and weight loss measurements after exposure to corrosive environments at ambient and elevated temperatures. Some of the methods and tests are described in ASTM Standards G34 (EXCO), G43 (SWAAT), and G66 (ASSET).Exfoliation is common in wrought products Al-Cu; Al-Zn-Mg-Cu & Al-Mg alloys are most prone to exfoliation corrosion. Exfoliation occurs rapidly in marine atmosphere.

Stress Corrosion Cracking

Stress corrosion cracking refers to cracking caused by the simultaneous presence of tensile stress and specific corrosion medium. The two classic cases of stress corrosion cracking are season cracking of brass and the caustic embrittlement of steels. Both of these obsolete terms describe the environmental conditions present that led to stress corrosion cracking. Season cracking refers to the stress corrosion cracking failure of brass catridge cases. During heavy rainfall, cracks were observed in the brass catridge cases at the point where the case was crimped to the bullet. It was later found that important environmental component in season cracking was ammonia resulting from the decomposition of organic matter. Many explosions of riveted boilers occurred in early steam driven locomotives. Examination of these failures showed cracks of brittle failures at the rivet holes. These areas were cold worked during riveting operations and analysis of the whitish deposits found in these areas showed caustic, or sodium hydroxide, to be a major component. Hence brittle fracture in the presence of caustic resulted in term caustic embrittlement. The important variables affecting stress corrosion cracking are temperature, solution composition, metal composition, stress and metal structureThe study employed the ex post facto and descriptive comparative strategies, the data were collected using a researcher devised questionnaires with items on educational services. A minimum sample size of 775 respondents was determined using the Sloven’s formula. A purposive sampling was utilized to select the respondents of the study. This involved finding any CBS in a lecture room, computer laboratory, resting place at a university campus and requesting them to participate in the study. The request involved self-introduction and soliciting students’ cooperation by explaining the objective of the study. Any CBS who accepted was selected to fill in the questionnaire. Cronbach’s alpha coefficient test revealed that the questionnaire was reliable at (a = 0.947). The data were analyzed using summary statistics, such as means and ranks, while the null hypothesis was tested using t-test and analysis of variance (ANOVA).

EXPERIMENTAL METHODS

Introduction

The experiment was aimed to find mechanical properties, hardness and residual stress level of extruded AA 7049 aluminum alloy at two different heat treatment conditions viz., T6 and T73 tempers. Thus the whole setup started right from the meticulous characterization of raw material to check its conformity with the specified chemical composition ranges, followed by Micro structural analyses and the Non Destructive testing methods such as ultrasonic flaw detector test and radiography testing to check the soundness of the raw material for carrying out the heat treatment processes. Finally heat treatments were carried out as planned in different sections leading to T6 and T73 condition.

RAW MATERIAL CHARACTERIZATION

Chemical Analysis

Chemical Analysis was carried out on BAIRD optical emission spectrometer. It reveals the type of elements and their respective percentage present in the test sample with reference to the standard sample.

Non Destructive Testing

Ultrasonic flaw detector and radiography testing were conducted on the randomly selected raw materials samples.

Heat Treatment Process

Heat treatments were carried out in two different categories of T6 and T73. Three samples were solutionized at 470 ^{o}C in T6 category and then subsequently water quenched and aged at 120 ^{o}C for 24 hours to T6 condition. Similarly three another samples were put to solutionizing at 470 ^{o}C , water quenched and then were left for natural ageing for a period of 48 hours. Samples were then subjected to two steps of artificial ageing of 120 ^{o}C-24hours air cooled and then 160 ^{o}C-14 hours and air cooled leading these to the over aged T73 condition.

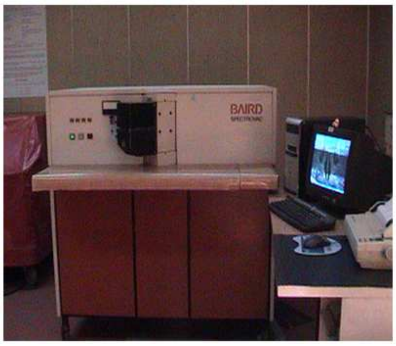


Figure 2: Baird Spectrovac

Figure 3: Heat Treatment Furnace

Heat treatment was carried out in an electrically heated oven with an accuracy of ±5 ^{0}C. The furnace fitted with automatic temperature controller and recorder with a calibrated thermocouple having a working range of 150-550^{o}C was used. The temperature was maintained within 5^{o}C from the set point. After soaking at a solutionizing temperature of 470^{o}C for a predetermined time, the sample was quenched in water at room temperature. The container with a dimension of 50cmx50cmx60cm filled with water was taken to ensure that there is no rise in temperature of water. The aging temperatures of 120^{o}C, 140^{0}C and 160^{0}C were maintained using automatic controller... The temperature uniformity inside the oven was achieved through air circulation. The samples after aging treatment were air-cooled.

Heat Treatment Process

The details of T6 and T73 temper heat treatment are as given below.

T6 temper: This process consists of 2 stages of heat treatment.

Stage 1: Solutionising Treatments

Temperature: $470^0C \pm 5^0C$

Soaking duration: 60 minutes, followed by Water Quench

Stage 2: Aging Treatment

Temperature: $120^0C \pm 5^0C$

Soaking duration: 24 hours, followed by Aircooling

T73 temper: This process consists of 3 stages of heat treatment.

Stage 1: Solutionising Treatment

Temperature: $470^0C \pm 5^0C$, Soaking duration: 60 minutes, followed by Water Quench

Stage 2: Natural Aging

The samples are allowed to age in air for a period of 48 hours

Stage 3: Low Temperature Aging Treatment

Temperature: $120^0C \pm 5^0C$, Soaking duration: 24 hours, followed by Air-cooling

Stage 4: High Temperature Aging Treatment

Temperature: $160^0C \pm 5^0C$, Soaking duration: 14 hours, followed by Air-cooling

Characterization and Evaluation of Heat Treated Samples

The following are the properties evaluated for the samples after the heat treatment (T6 & T73 condition).

- Mechanical Properties**: 0.2%P.S, UTS& %elongation**
- Hardness**: BHN**
- Residual Stresses**: MPa**

Figure 4: Ultrasonic and Radiography Instrument

Mechanical Property Evaluation

All the heat treated samples were tested for mechanical properties such as yield strength; ultimate tensile strength, ductility and hardness. To carry out tensile test, the tensometers were used and the dimension of the tensile test specimen is shown in Figure 5.5.

Hardness Testing

Hardness may be defined as the resistance to plastic deformation (usually) by indentation. Hardness may also refer to stiffness or temper or resistance to scratching, abrasion or cutting. In the present work Hardness is measured by portable hardness tester on Brinell Hardness Scale. Small piece of approximate dimensions of 10mmX20mmX20mm were taken. The sample piece was cold mounted. The cold mounted sample was ground polished by applying adequate pressure on the Belt grinder. Flatness is ensured. Specimens were wet ground by using series of emery papers ranging 80,180,280 and 400 grit sizes.

Figure 5: Hardness Testing Machine

Figure 6: Brinell Microscope

INDENTEC Hardness testing machine was used to measure the hardness on Brinell hardness scale. The values reported are an average of minimum four readings having machine details such as Ball indenter Diameter: 2.5 mm, Load : 62.5 kg, Dwell time for load : 10 seconds, Magnification : 100X (for eyepiece viewing).

Tensile Testing

Tensile Test is carried out to evaluate the properties like yield strength, Ultimate Tensile strength and % of

Elongation. The specimen was prepared as shown in Figure. Specimens for tens meters are cut in the longitudinal direction of extruded billet heat treatment conditions. Care was taken to have fine surface finish without any machining marks. The tensometers dimensions are 5±0.05 mm diameter and 25 mm gauge length. Tensile Test was carried on TIRA Universal Testing machine at room temperature as per ASTM E-8M standard. TIRA Universal Testing machine is a table model and consists of test frame, measuring and control unit extended by personnel computer. Technical specification of TIRA Universal Testing machine:Maximum Test load : 100 kN, Strain rate : $2X10^{-3}$ sec^{-1}, Crosshead displacement Measurement : Incremental-resolution 0.001 mm. Tensile test specimens are prepared according to the dimensions shown in the table 5.1. Specimen was obtained as shown in the figure from each sample in the longitudinal direction of the extrusion.

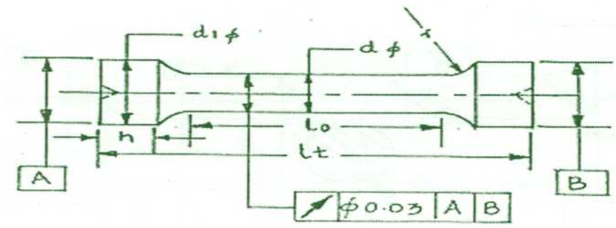


Figure 7: Schematic Sketch of Tensile Test Specimen

Table 4: Dimensional Values of the Tensile Specimen

Size	D	D1	R Min	H	L_0(5d)	L_t
5	5+/-0.01	7.9+/-0.2	1	**5+/-**1.0	25+/-0.05	32.2+/-2.0

(All dimensions are in mm)

The various parameters determined from tensile tests were:

1) 0.2% proof strength (0.2%PS)

2) Ultimate tensile strength (UTS) 3) % Elongation (%E)

Subsequent chapter deals with the analysis of the experimental results obtained from these examinations.

Stress Corrosion Cracking

Stress Corrosion Cracking (SCC) is a cracking process that takes place under the simultaneous action of a corrodent and a sustained tensile stress. SCC resistance can be measured by accelerated stress corrosion cracking testing as per ASTM standard G47. This is a constant load and alternate immersion test for smooth specimens. ASTM standard provides a comprehensive procedure for accelerated stress corrosion testing of high strength aluminum alloy product forms, particularly when stressed in the short transverse direction. The test procedure calls for the tests to be conducted under constant strain loading on 5.6mm diameter tension specimen as shown in the following figure , exposed to 3.5% sodium chloride solution by alternate immersion. Tests were performed in the short transverse direction as required by ASTM standard. In constant strain SCC tests, the specimen is constantly loaded to the required stress level of 60% of 0.2% yield strength. Specimens drawn from short transverse direction were exposed to cycles of one hour each consisting of an alternate 10 minutes immersion in NaCl solution followed by 50 minutes drying cycle out of the solution. The duration requirement for passing the test is 20 days without failure. The photograph of the equipment is as shown.

RESULTS AND DISCUSSIONS

Intensive sets of data were generated from the experiments conducted right from the characterization of raw material, followed by the rigorous heat treatment trials to record the mechanical properties, hardness and time to failure under stress corrosion cracking test.

Raw Material Characterization by Chemical Analysis

The chemical analysis of alloy 7049 under study was done using BAIRD Spectrovac Chemical Analyzer. The obtained chemical composition of the alloy is given in table 5.1 and is an average of three values of each element at three different locations on the test specimen. Result of the analysis showed that the constituents were well within the range of specification

Non Destructive Testing

Ultrasonic flaw detector tests and radiographic tests were conducted which showed that there were no significant surface or subsurface defects in the raw materials procured for the heat treatment trials**.** The test obtained from the ultrasonic test was further supported with those of the radiographic images scanned.

Table 5: Spectrovac Chemical Analyses of a Heat Treated Sample

Element	Zn	Mg	Cu	Zr	Fe	Ti+Zr	Si	Mn	Ti	Cr	Al
Composition obtained (wt %)	7.82	2.12	1.22	0.13	0.24	0.15	0.25	0.29	0.02	0.23	Rem
Requirement (wt %)	7.2-8.4	2.1-3.1	1.2-1.9	–	0.5Max	0.25Max	0.4Max	0.5Max	–	0.05-0.25	Rem

MATERIAL CHARACTERIZATION AFTER HEAT TREATMENT

Mechanical Properties and Hardness Evaluation

The values of mechanical properties and hardness of the specimens of AA 7049 aluminum alloy are given in the following table. It can be observed that the mechanical properties are superior at T6 temper. The ultimate strength of 661 MPa and 0.2% PS of 605MPa (longitudinal direction) was observed at T6 temper which were high when compared to T73 temper. However the % elongation is comparatively higher at T73 temper. The hardness of 182 BHN was observed at T6 temper when compared to 162 BHN at T73 temper. Similar trends were observed in transverse direction properties. The mechanical properties like UTS, 0.2% PS are low in transverse direction. In this project, the transverse mechanical properties are important mainly to conduct SCC test. The literature (6-12) suggests that the fine grain structure at T6 temper would be responsible for the higher strength. The T73 temper consists of coarser grain structure when compared to T6 temper. The raw material (as extrusion, without heat treatment condition) the values are very inferior and after heat treatment the values are enhanced. It indicates that the AA 7049 aluminum alloys are heat treatable.

Stress Corrosion Cracking Test

The values of time to failure after conducting SCC test are presented in the following table. In structural applications under loaded condition, especially in ST direction and in the presence of corrosive environment, the material should have minimum defined strength properties without failure. Accelerated stress corrosion tests are carried out to prove that no failure occurs for a minimum time under a prescribed load. SCC test is carried out on a specimen chosen in transverse direction. It can be observed that the time to failure in T6 temper condition is 73 hours. The specimen failed due to stress corrosion. However, the specimens at T73 temper withstood under 3.5% NaCl solution for minimum period of 20 days without failure, which indicates that the material is not prone to SCC and has better corrosion resistance in T73 condition. The test results are given in the Table. The literature suggests that at T73 temper the corrosion resistance of the high strength aluminum alloy corresponding to 7000 series is higher when compared to T6 temper. This could be attributed to presence of low residual stresses at T73 temper.

Figure 8: Photograph of Tensile Test Specimen

Figure 9: Photograph of SCC Test Specimen

Figure 10: Specimen Installed in Setup

Figure 11: View of Salt Water Circulation

Table 6: The Mechanical Properties and Hardness at T6 & T73 Temper

Temper Condition	Solutionising Temper Ature	Soaking Temperature	Ageing Temperature	Ageing Duration	Hardness BHN	UTS Mpa	0.2% PS Mpa	% E
T6 temper	470^{0}C	60 minutes	120^{0}C	24 hours	86	61	605	6.7
T73 temper	470^{0}C	60 minutes	28-32^{0}C 120^{0}C 160^{0}C	48hours 24 hours 14 hours	62	7	577	7.6
Raw Material	Not Applicable	Not Applicable	Not Applicable	Not Applicable	5	12	228	12.5

Table 7: The Mechanical Properties at T6 & T73 Temper in Transverse Direction

Temper Condition	T6 Temper	T73 Temper
Solutionizing Temperature	470^0C	470^0C
Soaking Temperature	60 minutes	60 minutes
Ageing Temperature	120^0C	28 – 32^0C 120^0C 160^0C
Ageing Duration	24 hours	48hours 24 hours 14 hours
UTS MPa Transverse direction	583	497
0.2% PS MPa Transverse direction	507	434
% E Transve rse direction	5.3	7.3

Table 8: SCC Test Results at T6 & T73 Temper

Temper Condition	T6 Temper	T73 Temper
Solutionising Temperature	470^0C	470^0C
Soaking Temperature	60 minutes	60 minutes
Ageing Temperature	120^0C	28 – 32^0C 120^0C 160^0C
Ageing Duration	24 hours	48hours 24 hours 14 hours
Stress level MPa (50% of actual strength)	275	250
Time to failure	Failed after 73 hours of exposure	Did not fail up to 20 day and tests stopped after 20 days.

Figure 12: Test Specimen under Tensile Load

CONCLUSIONS

In the present study, Hardness, mechanical properties and time to failure after SCC test at T6 temper and T73 temper of the AA7049 aluminum alloy have been examined. Evaluation of the test results led to the following conclusions:

- AA 7049 aluminum alloys are heat treatable. The Mechanical Properties and hardness enhances and induces strength in the material when subjected to T6 and T73 heat treatment tempers. Heat treatment induces compressive strength in the material.
- The hardness value of 186 BHN was observed at T6 temper, which was high when compared to 162 BHN at T73 temper.

- The ultimate strength of 661 MPa, 0.2% PS of 605 (longitudinal direction) was observed at T6 temper, which were high when compared to 605 (UTS) and 577 (0.2%PS) at T73 temper. However percentage elongation of 7.6% was observed at T73 temper, which was high when compared to T6 temper. As per the literature (6-13), the high strength at T6 temper can be attributed fine grain structure at T6 temper.
- The strength level in transverse directions is low at both T6 and T73 tempers. However the T6 temper exhibited higher strength in transverse direction when compared to T73 temper.
- The specimen failed at 73 hours in case of T6 temper, when exposed to alternate immersion of 3.5% NaCl solution and dry air as per ASTM G 47 test standard. However the T73 tempered specimens exhibited higher corrosion resistance and the specimens did not failed up to 20 days under SCC test. The literature (6-13) suggests that T73 temper heat treatment induces better corrosion resistance in the high strength aluminum alloys.

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