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Microstructural Analysis of Post Weld Heat Affected Zone of Al Alloy

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ABSTRACT: In this paper, the effect of post-weld heat treatment (PWHT) on mechanical properties and change in microstructure of friction stir welded 2024 and 7075 aluminum alloys are studied. Solution heat treatment and various ageing treatments were given to the welded joints. The PWHT procedures caused abnormal coarsening of the grains in the weld zone, which resulted in a drop in micro-hardness at the weld zone compared to the base material of the joints. Another objective of this work is to study effect of Post Weld Heat Treatment on hardness and tensile properties of material. To gate optimum result, hardness and tensile properties of parent material, welded material and heat treated material is compared. Vickers micro hardness test is used to study hardness of samples.

KEYWORDS: Friction Stir Welding, Microstructure, aluminium, heat treatment.

I. INTRODUCTION

Today aluminium alloys are widely used in many manufacturing areas like aerospace, railways, military and automobile sector. Aluminium has low density and good mechanical properties as compared to other metals.

Welding is widely used method for joining the alloys of aluminium. But welding of aluminium alloy is big challenge for designers because of oxide layer cavity and hot cracking sensitivity of aluminium alloy. After the welding process aluminium weld lose some mechanical, microstructural properties. It becomes 30-40% weaker as compared to parent material. To improve these properties post weld heat treatment is carried out after the welding. Few studies are carried out to study the effect of post weld heat treatment on aluminium alloy [1, 4 and 6]. Shivraj et al. [6] observed that tensile properties of Al 7075 alloy is improved after post weld heat treatment. Kumar et al. [2] show that improvement in corrosion resistance of aluminium weld is takes place after post weld heat treatment.

Precipitation heat treatment offers promise of minimizing the negative effect of welding on the mechanical properties of the family of 6XXX alloys. In this study Friction Stir Welding process is used for welding of aluminium alloy [7]. This machine was invented by Weld Institute of Cambridge in 1991. Friction Stir Welding Machine is well suited for joining aluminum alloys which are typically considered to be not weldable, such as 2XXX and 7XXX series aluminum alloys

The focus of the current study was to determine the mechanical properties of welded and artificially aged aluminium alloy Al 2024 and Al 7075 having thicknesses commensurate with what is currently being used in aluminium alloy. Comparative analysis is carried out to study what changes occurs in mechanical and microstructure properties of aluminium alloy after weld and after post weld heat treatment. Also study is carried out on the effect of post-weld heat treatment (PWHT) on the mechanical properties of friction stir welded 2024 aluminium alloys in the T4 temper state.

II. DESIGNATION SYSTEM USED FOR ALUMINUM ALLOYS

A. 1xxx Series Alloys: This series is often referred to as the pure aluminum series because it is required to have 99.0% minimum aluminum. It is non heat treatable aluminum alloy. They are weldable. Because of their narrow melting range, they require certain considerations in order to produce acceptable welding procedures. These alloys are selected primarily for their superior corrosion resistance such as in specialized chemical tanks and piping or for their excellent electrical conductivity as in bus bar applications. These alloys have relatively poor mechanical properties and would seldom be considered for general structural applications. It is used in capacitors, decorative finishes, foils and in chemical process equipments.

I. 2XXX SERIES ALLOYS: These are aluminum / copper alloys with copper additions ranging from 4.0 to 4.6%. 2xxx alloys are heat treatable with ultimate tensile strength of 27 to 62 ksi. They have high strength, high performance that are often used for aerospace and aircraft applications. They have excellent strength over a wide range of temperature.



B. Because of their susceptibility to hot cracking and stress corrosion cracking, some of these alloys are considered non-weldable by the arc welding processes. However, others are arc welded very successfully with the correct welding procedures. It used in welding wires and in fuel tanks.

C. 3xxx Series Alloys –These are the aluminum and manganese alloys.They arenon-heat treatable with ultimate tensile strength of 16 to 41 ksi. 3xxx aluminium has moderate strength and good corrosion resistance. These type of aluminium alloy widely used in heat exchangers in vehicles and power plants. It is readily fabricated and have moderate strength. It provides solid solution strengthening. It is used in roofing sheets, manufacturing beverage cans and foils. It also used in variety of strain harden tempers.

D. 4xxx Series Alloys: These are the aluminum and silicon alloys with silicon additions ranging from 3.6 to 13.5%. It is only series which contain both heat treatable and non-heat treatable alloys. Silicon, when added to aluminum, reduces its melting point and improves its fluidity when molten. 4xxx aluminium alloy widely used as filler material. It is used as welding and brazing wire. It is also used in forged engine pistons.

E. 5xxx Series Alloys It is non-heat treatable and it has ultimate tensile strength of 18 to 51 ksi.5xxx aluminum alloys are the aluminum / magnesium alloys and have the highest strength of the non-heat treatable alloys. In addition, this alloy series is readily weldable, and for these reasons they are used for a wide variety of applications such as shipbuilding, transportation, pressure vessels, bridges and buildings. The magnesium base alloys are often welded with filler alloys, which are selected after consideration of the magnesium content of the base material, and the application and service conditions of the welded component.

F. 6XXX Series Alloys – These are the aluminum / magnesium - silicon alloys and are found widely throughout the welding fabrication industry, used predominantly in the form of extrusions, and incorporated in many structural components. The addition of magnesium and silicon to aluminum produces a compound of magnesium-silicate, which provides this material its ability to become solution heat treated for improved strength. These alloys are naturally solidification crack sensitive, and for this reason, they should not be arc welded autogenously (without filler material). It is used in transportation of structural plates, pressure vessels and large tanks for petrol and milk.

G. 7XXX Series Alloys- It is heat treatable with ultimate tensile strength of 32 to 88 ksi. Al 7xxx has yield strength might be double to Al- Mg and Al-Mg-Si alloys up to 600 MPa). It has stress corrosion cracking resistance. It is used in **light weight military bridges and aircraft applications.**

H. 8XXX Series Alloys

Aluminium alloy with all other element listed as 8xxx alloys. 8001 aluminum alloy used to nuclear energy installations, Al-Li used to aerospace applications.

Table No. 1 Aluminum alloys and their characterization ^[4]

Number (Wrought)	Alloying Element	Percentage
1xxx	Aluminium	99.0
2xxx	Copper	4-4.6%
3xxx	Manganese	.3-1.6%
4xxx	Silicon	3.6-13.5
5xxx	Magnesium	0.5-5.5%
6xxx	Magnesium and Silicon	Mg: 0.4-1.5%, Si: 0.2-1.7%
7xxx	Zinc	1.0-8.2%

III. MECHANICAL PROPERTIES OF FRICTION STIR WELDED ALUMINIUM 7075 JOINT

To study mechanical properties of post weld heat treated aluminium alloy Al 7075 alloy with T651 rolled plates are used. These plates are 6.5 mm thick, 50 mm wide and 100 mm long. To study change in tensile properties 50 KN universal testing machine is used. It is found that ultimate tensile strength of base material .s 568 MPa. For welding harden steel is used. Tool is machined and subjected to heat treatment process to increase hardness. By using conventional vertical milling machine butt welds are made. After the welding process all weld specimens are naturally aged with same period of time. Hardness and tensile tests are carried out on the weld to study post weld heat treatment efficiency.

A. Change in tensile properties after weld^[3]

All the welds are inspected visually. After visual inspection tensile tests and hardness tests are carried out on the welds. The specimens are cut perpendicular to weld and machined to make it tensile specimens. Yield tensile strength of Al

7075 alloy is 503 MPa. After welding it is reduced to 192 MPa. After aging heat treatment, yield tensile strength is increased to 275 MPa with an elongation 8.62%. It clearly shows increase in tensile strength is takes place after post weld heat treatment of weld.

B. Change in microstructure properties of weld^[6]

Using optical microscope optical micrograph is captured. Very fine insoluble second phase precipitates seen in base material. Friction Stir Weld converts flat grains in parent metal to equiaxed recrystallized grains in nugget zone. This change of microstructure occurs due to high speed of pin of tool. In thermo mechanically affected zone bending of grains is observed. This bending is occurred due to plastic deformation.

C. Change in hardness of weld^[5]

Vickers Hardness test is carried out to study the hardness of material. Hardness of parent material is 160 HV. It is found that minimum hardness is present in nugget zone. Increase in hardness value is observed towards the base material from centre of weld. This variation of the micro hardness values in welded area and parent material is because of the difference between the microstructures of the base material and weld zone.

IV. EFFECT OF PWHT ON AL 2024 T4 ALLOY

A. Material and welding conditions

To study effect of PWHT on aluminium alloy Al 2024 alloy selected for study. Composition is shown in table No. 2. This alloy consists of 4.5 percent copper and 1.5 percent magnesium. 3 mm thick plates of Al 2024 alloy is used for welding. Using manual vertical milling machine butt welding is carried out on metal plate. Tool used to weld the plate is made up of 1.2367 harden steel. This tool have angel 3° from direction of normal to plate and it rotates clockwise direction. Advancing rate of tool is 40 mm/sec and it rotates at speed 2140rpm.

Table No. 2: Metal composition of Al 2024 Post-weld heat treatments

Material	Cu	Mg	Mn	N	Fe	Al
AA2024	4.5	1.5	0.5	0.20	0.40	Balance

Aluminium alloy is initially at T4 temper state. To obtain T4 temper state solution heat treatments carried out at 510°C for 2.5 hours and quenching at 0°C . After friction stir welding various aging treatments and solution heat treatments are carried out on welded material.

1) Metallography

To study change in microstructure scanning electron microscope (SEM) is used. The weld was cut perpendicularly to observe transverse cross sections of weld optically. Microstructures of parent material and as welded material are compared by optical micrograph.

2) Mechanical tests

To study change in hardness of alloy, Vickers micro hardness test is carried out along centreline of cross section and perpendicular to direction of weld. Load of 50 g for 10 seconds is used for Vickers hardness test. To study change in tensile strength in aluminium alloy tensile tests are carried out perpendicular to welding direction. Using Zwick Z 050 tensile testing machine tensile tests are carried out at cross head of 10mm/min in the room temperature.

B. Effect of PWHT on microstructure

1) Microstructures of parent material and as welded material

To study change in microstructure, micrograph of parent material is captured using optical microscope (Fig. 1). Then Friction Stir welding is carried out. Welded 2020-T4 joint consist of several zones involving different microstructures: (I) Nugget Zone, (II) Thermo Mechanically Affected Zone, (III) Heat Affected Zone, And (IV) Base Material Zone. In every zone experiences many deformations and thermal cycle. Due to this complex mixture of microstructure is seen. Thermo mechanically affected zone present outside nugget zone and it is distinguishable from nugget zone. Fig. 2 shows optical micrograph of welded zone of as welded material. This micrograph is compared with micrograph of unwelded material (Fig. 1).

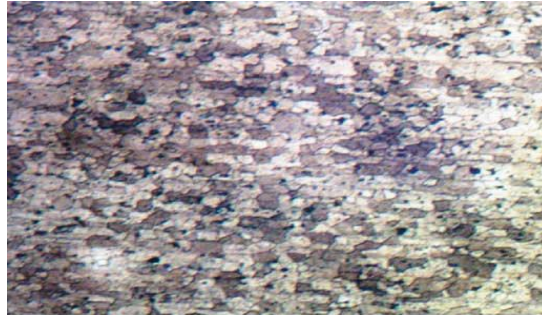


Fig. 1: Optical micrograph of un-welded parent material^[1]

It is seen that the grains in Thermo Mechanically Affected Zone are significantly rotated and slightly elongated. Thermo mechanically affected zone is subjected to thermal alterations. It is also seen that the grain size and precipitate state in Base Material was not affected by friction stir welding.

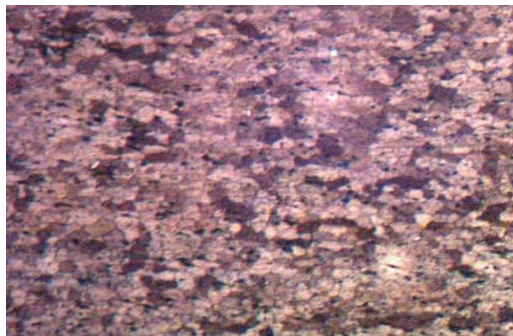


Fig. 2: Optical micrograph of FSW zone of as welded material^[1]

Al 2024 alloy with T4 temper state contains very fine hardening precipitates. After Friction Stir welding, these hardening precipitates become coarse in the weld zone. Due to this very vast difference in mechanical properties takes place across the weld. These variations in mechanical properties are detrimental to performance of joint.

2) Change in microstructure after T6 heat treatment

T6 heat treatment is carried out on the weld at 190⁰C for 10 hours



Fig. 3: Optical micrograph of FSW zones of PWHT joints T6 (190⁰ C for 10h)

Fig. 3 shows the optical micrograph of heat treated welded zone. It is found that T6 heat treatment temperature has a significant effect on grain stability. Large grains with hundred microns to some millimetres were observed in welded region. It clearly shows the abnormal grain growth in welded region. One of the main reasons of this abnormal grain growth is welded zone was associated with inhomogeneous deformation pattern during welding process.

C. Effect of PWHT on hardness^[1]

Fig. 4 shows the microhardness profile of material with different stages.

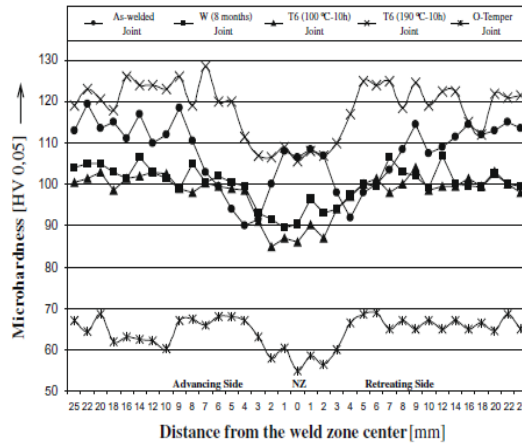


Fig. 4: Micro-hardness distribution in joints^[1]

Vickers microhardness test is used to find hardness of weld with 50 g load for 10 seconds. Hardness of precipitation hardening alloy is depends on distribution and size of hardening precipitates. Hardness of T4 tempered Al 2024 aluminium alloy is 120 HV. After Friction Stir welding is done it reduced to 90 HV in TMAZ zone and 108 HV in Nugget zone. To study effect of PWHT three types of heat treatment process are carried out. One sample heat treated with T6 heat treatment at 190°C for 10 hours, second heat treated with 100°C for 10 hours and third sample heat treated with O temper heat treatment. Hardness of all samples is compared graphically. The graph clearly shows that hardness value of post weld heat treated joints is depends on post weld heat treatment procedure. Hardness of O temper heat treated sample is reduced to 52 HV at nugget zone. Hardness of T6 heat treated at 100°C sample is decreased to 85 HV. Hardness value of friction stir welded region is much lower as compared to parent material. This reduction of hardness is occurs due to thermal cycles during FSW process. T6 heat treated weld at 190°C have hardness value 119 HV in the nugget zone. The microstructure of T6 heat treated at 190°C alloy contains uniformly distributed as well as fine hardening precipitates. Due to this, it gives maximum hardness in welded region.

D. Effect of PWHT on tensile strength

Table No. 3 shows the tensile properties of parent material, as welded and post weld heat treated material. Un-welded aluminium material has yield strength 351 MPa and ultimate tensile strength 492 MPa.

Table No. 3: Tensile properties of the un-welded parent metal and the as-welded and PWHT joints (average values).^[1]

Sample	yield strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation A (%)
2024 Un Weld	351	492	21.9
As Welded Joint	279	389	9.0
T6 (100 ⁰ C for 10 h) treated Joint	248	379	11.3
T6 (190 ⁰ C for 10 h)	345	430	6.0

After welding, the yield and ultimate tensile strength reduces to 279 Mpa and 389 Mpa respectively. Three different types of heat treatments are carried out on the welds. One sample of weld is heat treated with T6 (100°C for 10

h) and second sample heat treated with T6 at (190⁰C for 10 h). Ultimate tensile strength and yield strength results are compared with each other. Tensile tests shows significant improvement in post weld heat treated weld samples. In T6 heat treated at 100⁰C shows yield strength 248 Mpa and ultimate tensile strength 379 Mpa. Post weld heat treated at 190⁰ at 10 h shows yield strength 345 MPa and ultimate tensile strength 430 MPa but the elongation value is only 6%. The yield strength of T6 (190⁰C at 10 h) joint is almost equivalent to that of the un-welded original metal, but the tensile strength and elongation show 12.6% and 72.6% reductions, respectively, compared with the un-welded original metal. However, theyield and tensile strength of the T6 (190⁰C – 10 h) joint are about 24% and 11% greater, respectively, than those of the as-welded joint. The low elongation in this joint is attributed to low fracture toughness. The elongation value of parent material is 21.9 percent and as welded material is only 9 percent. It shows that there is 60 percent reduction in elongation after welding. Aging heat treatment shows improvement of 34 percent and 21 percent as compared with as welded material.

V. CONCLUSION

In this study, the effect of post-weld heat treatment on mechanical and macrostructural properties of friction stir-welded 2024 and 7075 aluminium alloys was investigated in detail.

It is found that hardness value is significantly increased in thermo-mechanically affected zone and heat affected zone after T6 (190⁰C at 10 hours) post weld heat treatment. In addition strength of weld increases after T6 aging procedure. But T6 aging heat treatment led to ductility deterioration in the joint. After T6 heat treatment microstructure shows relatively coarse and closely spaced precipitates along the grain boundaries and the fine precipitates within the grains

After welding of Al 2024 alloy, yield strength and ultimate tensile strength is reduced by 19.84 and 21 percent respectively. T6 heat treatment helps to improve the tensile properties of weld. Hardness of weld is increased by 27 percent after T6 aging heat treatment. Post weld T6 aging heat treatment improves mechanical, macrostructural and tensile properties of the weld.

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