EFFECT OF PREHEAT AND POST HEAT TREATMENT ON THE PROPERTIES AND THE MICROSTRUCTURE OF ALUMINIUM-6082 BY FRICTION STIR WELDING

A DISSERTATION

Submitted in partial fulfilment of the

requirements for the award of the degree

of

MASTER OF TECHNOLOGY

In

Mechanical Engineering

(With Specialization in Welding Engineering)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this seminar titled **"Effect of Preheat and Post heat Weld Treatment on the Properties and the Microstructure of Aluminium-6082 by Friction Stir Welding"** is presented on behalf of partial fulfilment of the requirement for the award of the degree of **Master of Technology** with specialization in **Welding Engineering** submitted to the department of **Mechanical & Industrial Engineering, Indian Institute of Technology Roorkee, India**, under the supervision and guidance of **Dr. Kaushik Pal**, MIED, IIT Roorkee, India.

I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Date: 25/06/2019

Place: Roorkee **Prashant Mani Sharma**

CERTIFICATION

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ABSTRACT

Friction stir welding of 6082 AA-T6 was performed using three different combinations of feed rates (40, 70 and 90 mm/min) and tool rotational speeds (664, 708 and 931 rpm). Mechanical properties of the weldments were evaluated by hardness measurements on the transverse section and tensile testing, while microstructure evaluation was done by optical microscopy. A fundamentally misfortune in hardness in the mix zone(SZ) was noted than in the thermo-precisely influenced zone(TMAZ) because of disintegration of β' and β'' second stage particles. A post weld heat treatment (PWHT) of 180 °C for 5h was given to the weldments for all welding parameters and the mechanical properties and microstructure were re-examined. The hardness and quality were marginally recuperated and this was credited to the conceivable reprecipitation of the β'' encourages. A preheat state of 200 °C for 1h was performed to examine the mechanical properties and microstructure.

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CHAPTER 1

INTRODUCTION

1.1 Introduction of Aluminium And Its Alloys

Both advantageous properties like high strength to weight ratio and great flexibility makes aluminium as more conservative and most wanted metallic materials for wide scope of designing applications . Aluminium has high ductility, so it can form in slim sheets (foils). It very well may be promptly beyond words or shaped too. Aluminium has a density of 2.7 g/cm3 , around 33% as much as steel. The high reflectivity gives aluminium an embellishing appearance.

Aluminium show high corrosive resistance. It is a non ferromagnetic material and show high electrical conductivity so that it is require in electrical and electronics industries.The main characteristics of aluminium is high workability and machinability. The best thing of aluminium that it can be draw into any shape easily by rolling, forging, extrusion etc process

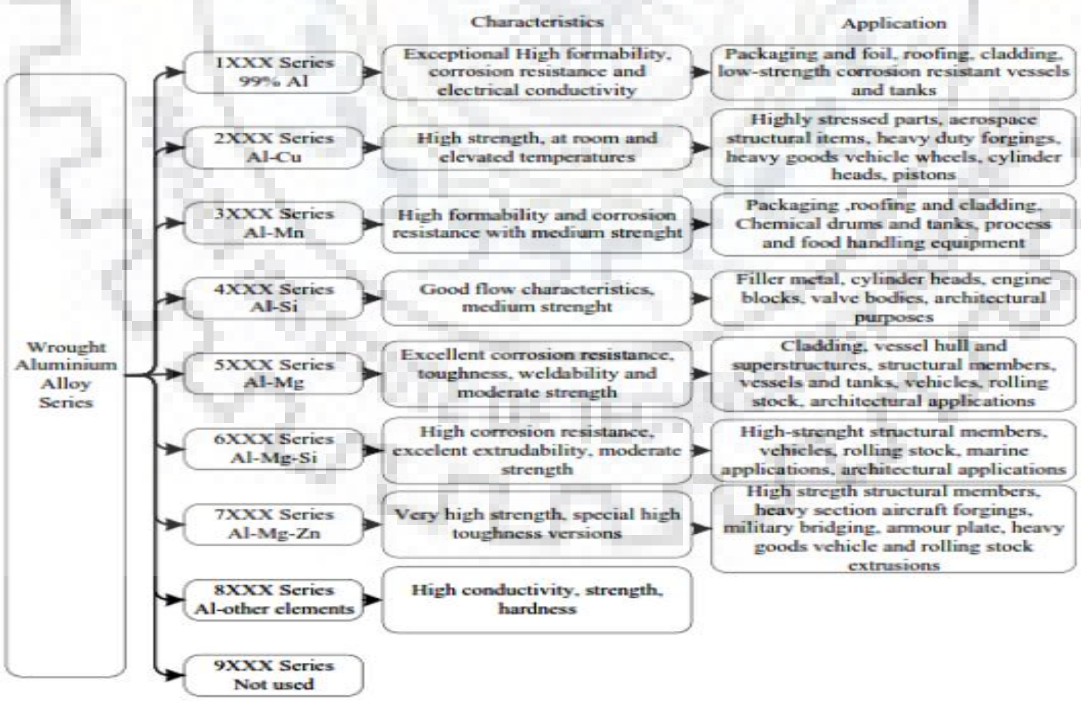


Fig. 1.1.1 Aluminium series chart(Avner 2000)

1.2 Properties and Characteristics of Aluminium 6082-T6

Aluminium alloy 6082 is medium strength and high corrosive resistance alloy. It shows high strength among the others aluminium 6000 series alloys, due to high resistance it replaces the aluminium 6061 alloy. The main constituent of this alloy are Mg and Si. Al- Mg-Si alloys are recently using for automobile body sheet panel for weight saving. It is typically formed by extrusion and rolling ,but as a wrought alloy it is not used in casting. It can also be forged and clad, but that is not common practice with this alloy. It cannot be work hardened, but is commonly heat treated to produce tempers with a higher strength but lower ductility.

Table 1.2 Composition of Al 6082 T-6 alloy

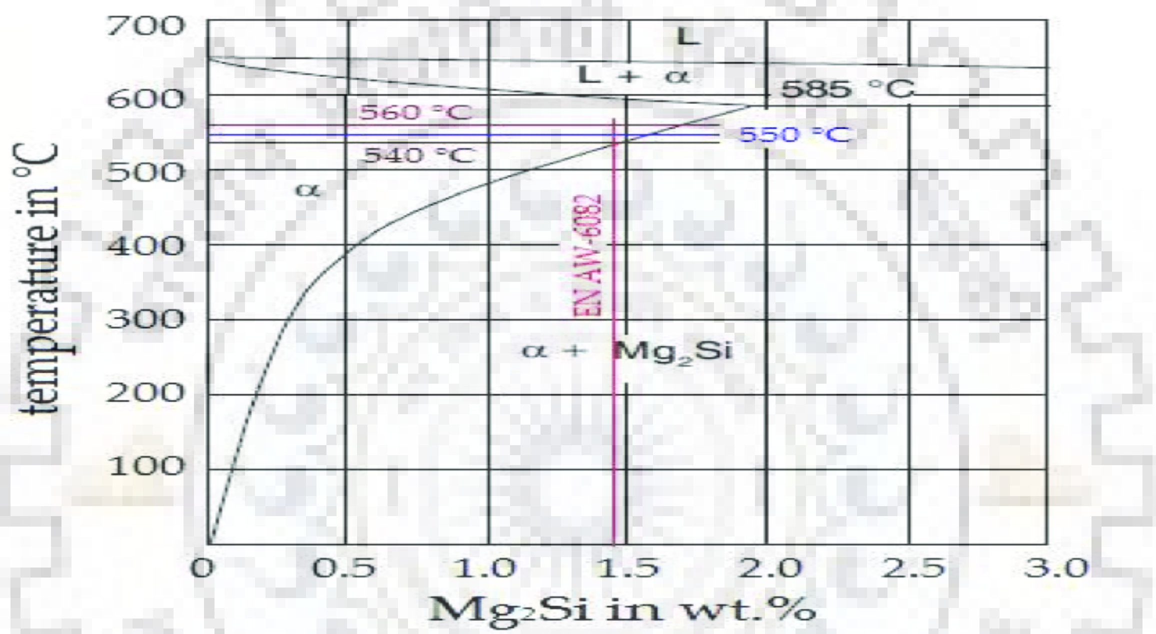
Elements	% Present
Si	1.2
Fe	0.33
Cu	0.08
Mn	0.5
Mg	0.78
Cr	0.14
Zn	0.05
Other	0.15
Al	Bal

Table 1.3 Physical properties of Al 6082 T-6 alloy

Physical Properties	Value
Density	2700 kg/cubic meter
Melting Point	555
Modulus of Elasticity	70GPa
Electrical Resistivity	0.03 8*10-6 ohm-meter
Thermal Conductivity	180 W/m K
Thermal Expansion	24*10-6 /K

1.3 Reason to Choose Aluminium 6082 T-6 alloy for this Investigation

Aluminium 6082 T-6 is solution heat treated and artificial aging alloy so it provides better results as compare to other aluminium alloys. We have seen above that this contains Al-Mg-Si alloys with high percentage. The Al–Si–Mg alloys can be hardened by the precipitation of the metastable just before to the equilibrium β(Mg2Si) phase. In order to achieve ideal characteristics, an understand -ing of these precipitation mechanisms during artificial aging is critical.



$$\alpha(sss) \rightarrow \text{GP zones} \rightarrow \beta'' \text{ needles} \rightarrow \beta' \text{ rods} + \text{lath-like particles} \rightarrow \beta + \text{Si (various morphologies)}$$

Fig. 1.3.1 Phase diagram of Al-Mg-Si alloy

where α(sss) is a supersaturated strong solution and where GP areas are spherical clusters witha u nknown composition. Composition of the alloy and the casting condition will directly influence present phase of intermetallic [1,2]. Hardening of precipitation assume different form like as under-aged, peak-aged, and over-aged and each has its own size, distribution of precipitates, and specific type.Isothermal aging for solution treated AA 6082, the hardness increases until the high aged condition reached and finally a decrement in hardness is observed when the sample becomes over aged. More the temperature, quicker the response to get peak- aged condition. However, the peak-aged hardness decreases with increasing aging temperature. A fundamentally misfortune in hardness in the mix zone(SZ) was noted than in the thermo-precisely influenced zone(TMAZ) because of disintegration of β' and β" second stage particles. A post weld heat treatment (PWHT) of 180 °C for 5h was given to the weldments for all welding parameters and the mechanical properties and microstructure were re-examined. The hardness and quality were marginally recuperated and this was credited to the conceivable reprecipitation of the β" encourages. A preheat state of 200 °C for 1h was performed to examine the mechanical properties and microstructure.As the maturing procedure proceeds past the pinnacle matured condition, the β"phase is returned to bigger, semi-lucid pole like or slat like β' particles, bringing about a conditioning of the material. At the last maturing stage, balance non-cognizant βMg_2Si and silicon particles are encouraged. In this over-matured condition, hastens are to a great extent skirted by separations through the Orowan system. The low quality of A fundamentally misfortune in hardness in the mix zone(SZ) was noted than in the thermo-precisely influenced zone(TMAZ) because of disintegration of β' and β" second stage particles. A post weld heat treatment (PWHT) of 180 °C for 5h was given to the weldments for all welding parameters and the mechanical properties and microstructure were re-examined. The hardness and quality were marginally recuperated and this was credited to the conceivable reprecipitation of the β" encourages. A preheat state of 200 °C for 1h was performed to examine the mechanical properties and microstructure.over-matured examples is because of the poor strong arrangement solidifying as most of the magnesium and silicon present in the composite is accelerated as moderately enormous Mg_2Si or silicon particles. A moment purpose behind their decreased quality is because of the lower thickness of particles, bringing about less impediments to the development of disengagements. Numerous investigations that have concentrated on the FSW of 6xxx AA arrangement combinations was dedicated for the 6061 and 6063 composites, however restricted consideration was given to especially the 6082 amalgam. The present work centers around the use of various welding parameters (rotational speed; rpm, feed rate; mm/min) on grinding blend welding of AA 6082 plates in T6 condition and assessing the mechanical properties and microstructural attributes of the welded condition just as in the wake of forcing post weld heat medicines.

1.4 Friction Stir Welding(FSW)

As of late, center has been around growing quick, effective procedures that are condition well disposed to join two disparate materials. The spotlight has been turned on Friction mix welding as a joining innovation equipped for giving welds that don't have surrenders ordinarily connected with combination welding forms. Rubbing mix welding (FSW) is a genuinely ongoing procedure that uses a non - consumable pivoting welding apparatus to create frictional warmth and plastic misshapening at the welding area, in this manner influencing the development of a joint while the material is in the strong state

Welded divergent metals have wide applications in enterprises. We will once in a while locate a made item, particularly in substantial modern settings, that is produced using exclusively one segment, part or material. This is a direct result of every segment, part or material offers its very own arrangement of one of a kind characteristics or advantages, and this seems to be valid of metals as well. While it would, obviously, be simpler if only one metal could be utilized, makers hope to utilize various metals to upgrade their items in various ways. For instance, steel offers a lot of solidarity, while aluminum is lighter and has better consumption safe properties. By joining these, you can have a solid, yet safe and lighter, last item. In any case, the fundamental issue with joining of different metals are the distinctions in the science of the materials, their softening focuses, coefficient of warm development, warm conductivity and so forth which offers a genuine test in securing brilliant joints. Welding can be performed by either Fusion Welding process or by a Solid-state joining process. In the event that we perform Fusion welding procedure to join disparate metals, the metal or amalgam with low softening point dissipates away which prompts compositional change and in this manner weld with substandard quality is acquired.

1.5 Working Principal of FSW

Friction-stir welding (FSW) is a solid-state shear joining method in which a rotational tool with a shoulder and ending in a threaded pin moves along the butting surfaces of two rigid held plates positioned on a back plate.The shoulder is in close contact with the work-piece top surface. At the shoulder and to a lesser extent at the pin surface, heat generated by friction softens the material being welded. Material is transferred to the trailing edge from the front of the instrument where it is forged into a joint.

FSW involves complex interactions between a variety of simultaneous thermomechanical processes. The interactions affect the heating and cooling rates, plastic deformation and flow, dynamic recrystallization phenomena and the mechanical integrity of the joint. A typical cross-section of the FSW joint consists of a number of zones The heat-affected zone (HAZ) is similar to that in conventional welds although the maximum peak temperature is significantly less than the solidus temperature, and the heat source is rather diffuse. This can lead to somewhat different microstructures when compared with fusion welding processes

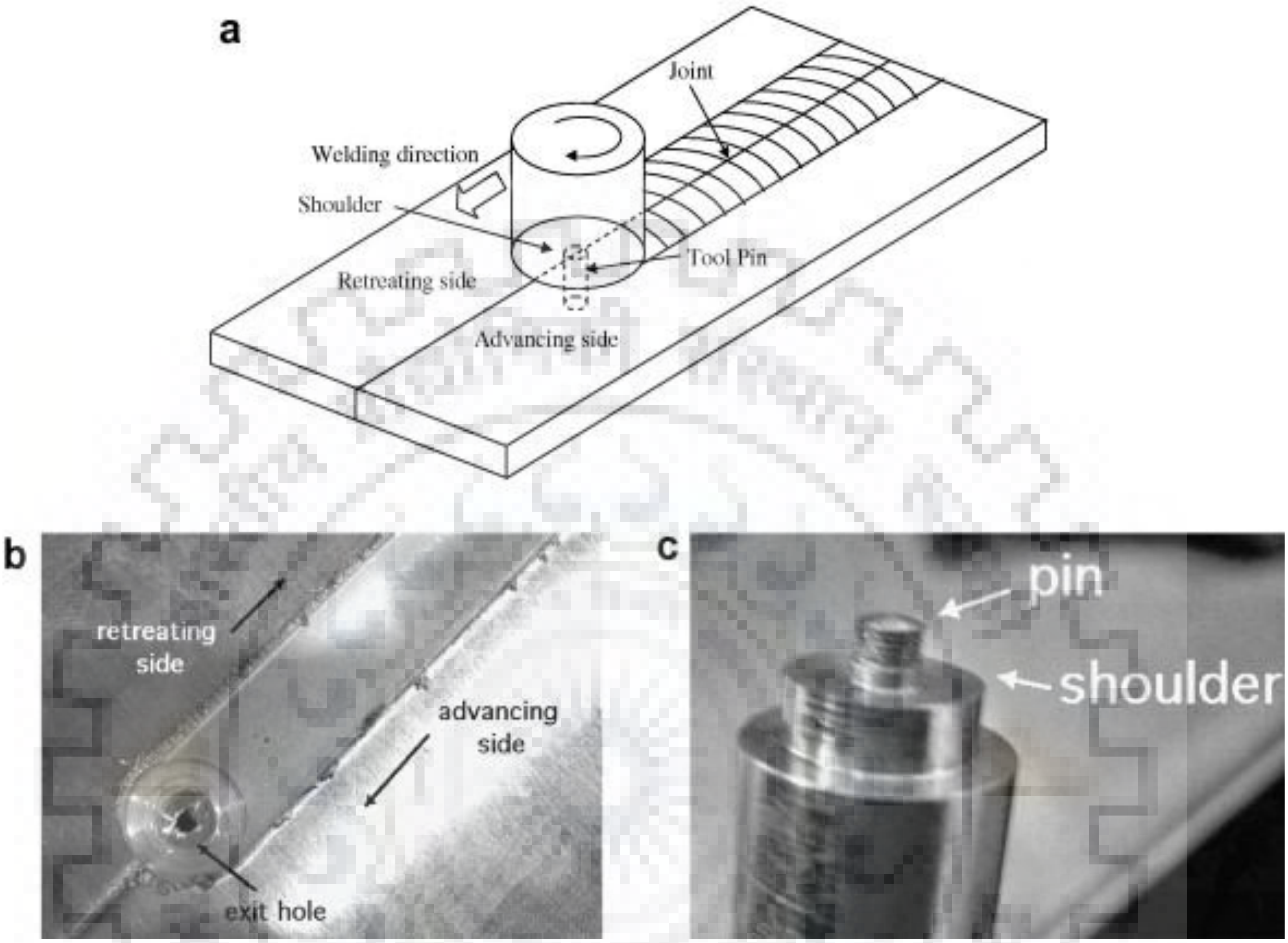


Fig. 1.1.1. (a) FSW process. (b) After FSW between aluminium sheets. (c) FSW tool

1.5.1 Advantage

- The welding procedure is relatively simple with no consumables or filler metal.
- Joint edge preparation is not needed.
- Oxide removal prior to welding is unnecessary.
- The procedure can be automated and carried out in all positions.
- High joint strength has been achieved in aluminium and magnesium alloys.
- FSW can be used with alloys that cannot be fusion welded due to crack sensitivity.
- No shielding gas required.

1.5.2 Some Industrial Applications of FSW

1-Apple's Next Generation iMac Apple used FSW to join front and back of the case components

2-Nasa's Orion Spacecraft

Fig. 1.5.2.1 Apple's Next Generation iMac

Fig. 1.5.2.2 Nasa's Orion Space Craft

3- China's High Speed Railway Carriages- The Chinese High Speed Rail Network uses FSW technology to weld the 30 metre long carriage panels used for the body of the train carriages.

Fig. 1.5.2.3 China's High Speed Railway Carriages

Fig. 1.5.2.4 The Super Liner Ogasawar

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CHAPTER 2

LITERATURE REVIEW

2.1 Effect of tool pin profile

2.1.1 Tensile properties

The effect of hardware profile on the mechanical and metallurgical properties of grinding blend welded metal joint composite was inquired about by (PavanKumar Thimmaraju et al., 2016). From the results (table 2.1) it is grasped that the joint is welded by hexagonal profiled device demonstrates high versatility.

Table 2.1 Effect of tool pin profile on mechanical properties (PavanKumar Thimmaraju et al., 2016)

S.NO	Tool profile	Load at yield(KN)	Elongation at yield(mm)	Yield stress(N/mm2)	Tensile strength(N/mm2)
1	Hexagonal	9.18	3.29	91.76	116.749
2	Square	5.5	7.02	58.55	75.588
2	Triangular	5.5	5.67	56.983	72.732

Another research was done by (A.Ramesh, 2016). They also investigated the influence of pin profile of tool on the mechanical and metallurgical properties of friction stir welded metal. They also taken tapered threat tool to see the effect of the thread pin that is given in (table 2.2)

Table 2.2 Effect of tool pin profile on mechanical properties (A.Ramesh et al., 2016).

S. No	Profile	Load	Tensile strength (MPA)
1	Triangle	13.5	174.75

2	Square	9.36	120.96
3	Tapered cylindrical threaded	14.54	223.3

From above table it understood that tapered threaded tool gives high tensile strength. Pin profile affect the microstructure and tensile strength of the joints. The difference in tensile strength of the joints was allotted to loss of cold working in the HAZ, material flow behavior, mixing and formation of macroscopic defects in the weld zone. and dissolution and over aging of precipitates

2.1.2 Microhardness

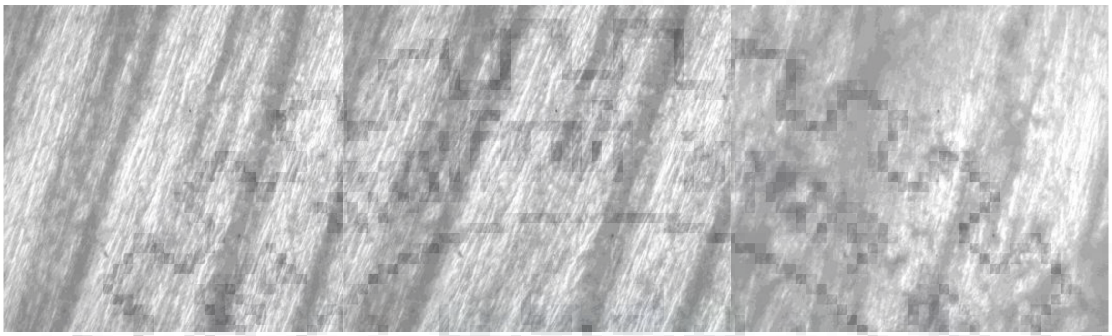
The influence of tool pin profile on microhardness investigated by (A.Ramesh, 2016). Three different tool used for investigate the hardness. Maximum hardness value obtain is 53 for tapered threaded tool. Lowest hardness value is 49.7 for square tool. All the hardness value shown in table 2.3

Table 2.3 Microhardness variation at different tool profile

S.NO	Identifi-cation	Location	Impression			
			1	2	3	Average
1	Triangle	ON SURFACE	52.3	52.3	52.6	52.4
2	Square	ON SURFACE	49.7	49.9	49.9	49.83
3	taper cylin-drical thread-ed	ON SUR-FACE	53	52.6	52.8	52.94

2.1.3 Microstructure

The microstructure was investigated by PavanKumar Thimmaraju (2016) at three type of tool profile triangular, square and tapered threaded which is shown in fig 2.1.3.1



(a) Triangle tool (b) Square tool (c) Hexagonal tool

Fig. 2.1.3.1 Micrographs of three different tool profile

On the basis of microstructural studies, it is evident that the grain size in the welded zone is reduced in comparison to base metal and the grain size in the welded joint made with hexagonal tool profile is lower in comparison to triangle and square tool profile.

2.2 Effect of rotational speed, feed and PWHT

2.2.1 Tensile properties

The influence of various rotational speed, feed rate and PWHT on mechanical properties and microstructure was investigated by Ehab A. El-Danaf and Magdy M. El-Rays in 2012. They performed fsw by using these different combinations-

1- feed rate (90,140 and 224 mm/min).

2- tool rotational speed (850, 1070 and 1350 rpm).

Another investigation on FSW of 6082 [4] with process parameters varying from 230 to 1700 rpm and from 115 to 585 mm / min, it was found that as the welding feed rises at a steady rotational speed of the tool, the heat input goes to reduce (the tool spent comparatively less time and thus less chance of friction heating).

Fig 2.2.1.1 show the effect of welding parameter and got maximum tensile strength at 850rpm-224mm/min around 197 MPa.

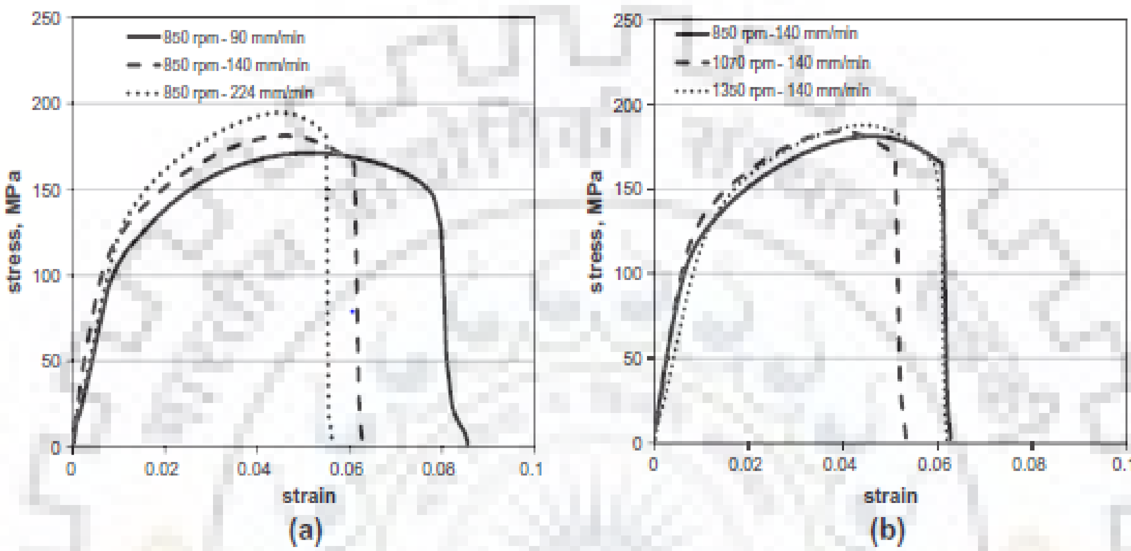


Fig. 2.2.1.1 Stress vs strain curve of welded samples to show the influence of feed rate in (a) and the influence of rpm in (b) (Adamowski J, et al., 2012)

Fig 2.2.1.2 show the influence of feed rate on tensile strength. As feed increase the tensile strength also increases this is due to heat generation. High feed rate generate low heat input Higher tensile strength achieved at 224 mm/min.

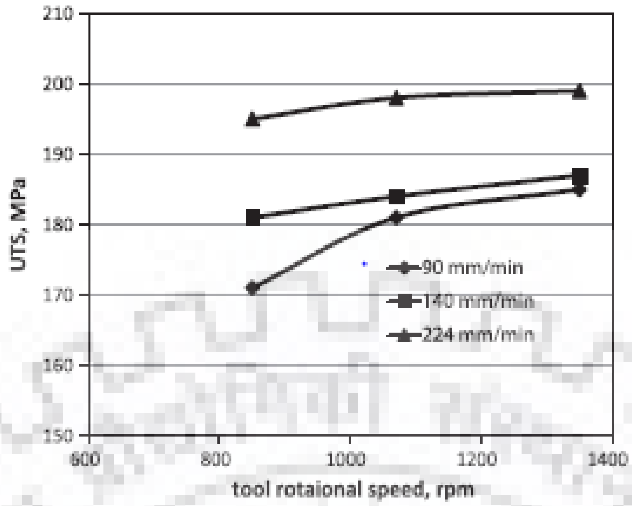


Fig. 2.2.1.2 Variation of tensile strength for different parameters (Adamowski J, et al., 2012**)**

The further investigation of the effect of PWHT on welded sample was done by Sato et al. [5] Thus a post weld heat treatment (PWHT) of 175 °C for 5 h and 12 h was taken place to all welded sample.

The percentage increase of 12 h PWHT tensile strength for these welding conditions is 28%, 17 % and 18% respectively: 850/90, 1070/90 and 1350/90.

On the other hand, for high the welding speed of 224 mm/min at the same rotational speeds, the percentage increases ; 850/224, 1070/224 and 1350/224 are 16%, 16% and 10% respectively.

Similarly, for low welding speeds (850/90, 1070/90 and 1350/90), the increase in average SZ hardness due to PWHT for 12 h was 30%, 33% and 27%, respectively, higher than 22%, 24% an d 16% for high welding speeds of 224 mm / min (1070/224, 850/224 and 1350/ 224).

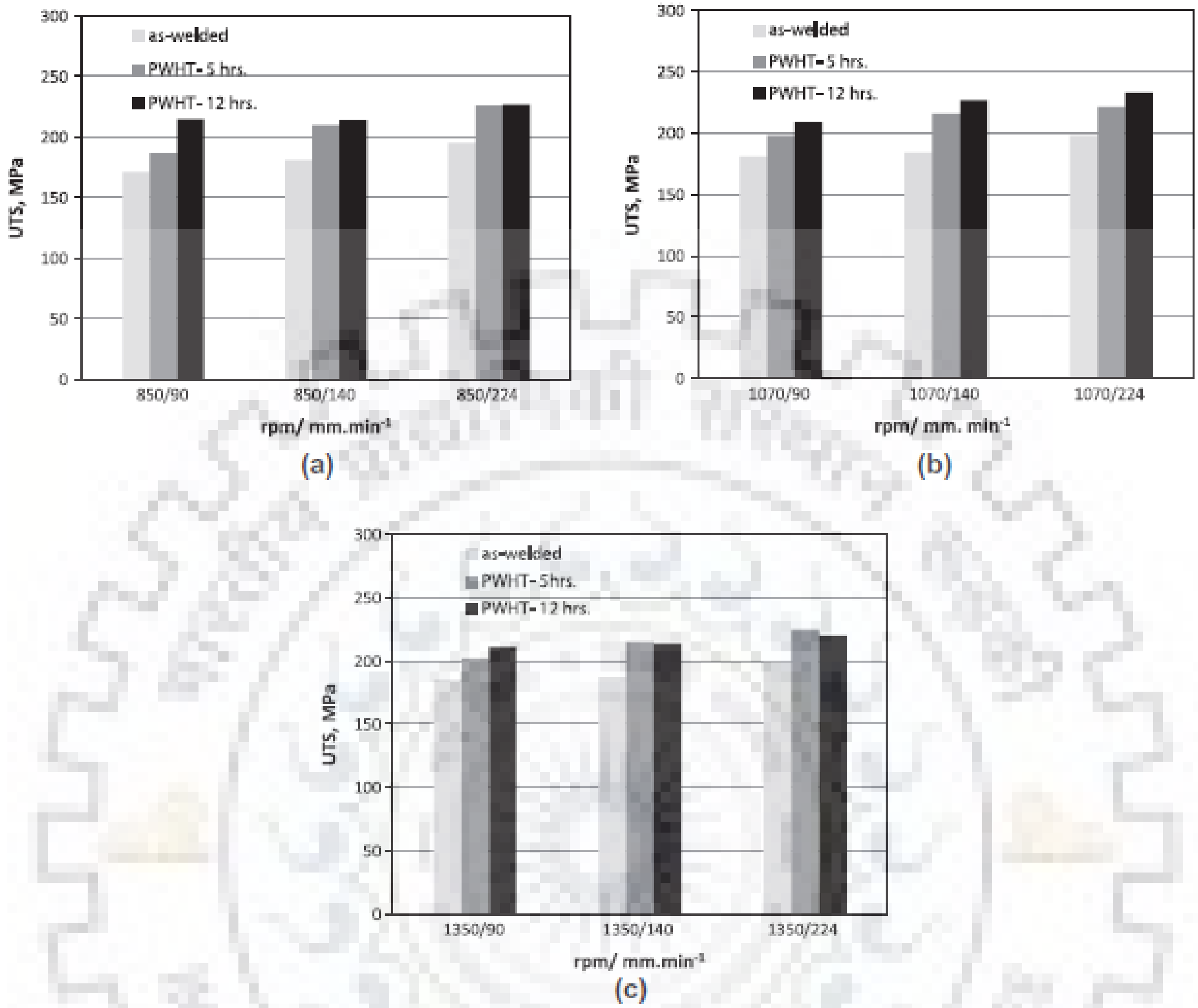


Fig. 2.2.1.3 Effect PWHT on tensile strength by a welding speed of 90 mm/min(a) and 140 mm/min(b) and 224 mm/min(c) for different rotational speeds (Sato et al., 2012)

2.2.2 Microhardness

For AA 6063 FSW, Yutaka et (2001)presented an elaborate analysis on the connection between the distribution of precipitates and the hardness profile.The existence of precipitate not affected base metal show a high density of needle shaped β"and a low density of rod shaped precipitates β',whereas in the TMAZ the needle shaped density was significantly lowered and the rod shapes density increases. In stir zone all the precipitates dissolved due to high heat input.

From fig 2.2.2.1 we can seen the effect of rotational speed and feed on microhardness. As the feed increases there is less time available to dissolve all the precipitates in solution so that hardness increase.

Further investigation was carried out to investigate the effect of PWHT at 175 °C for 5 h and 12 h and shown in fig 2.2.2.2 got maximum hardness value at 1070/244 at PWHT for 12h

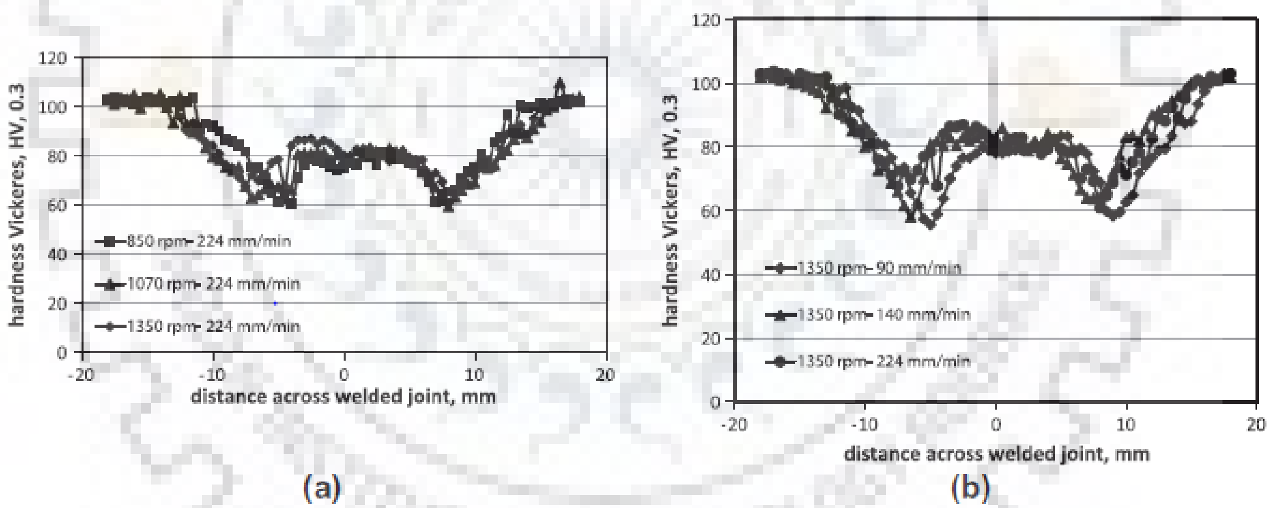


Fig. 2.2.2.1 Microhardness value and profile on transverse section show the effect for a constant feed rate of 224 mm/min in (a) and show the effect of feed rate for a constant rpm of 1350 in (b) (Yutaka et al 2001)

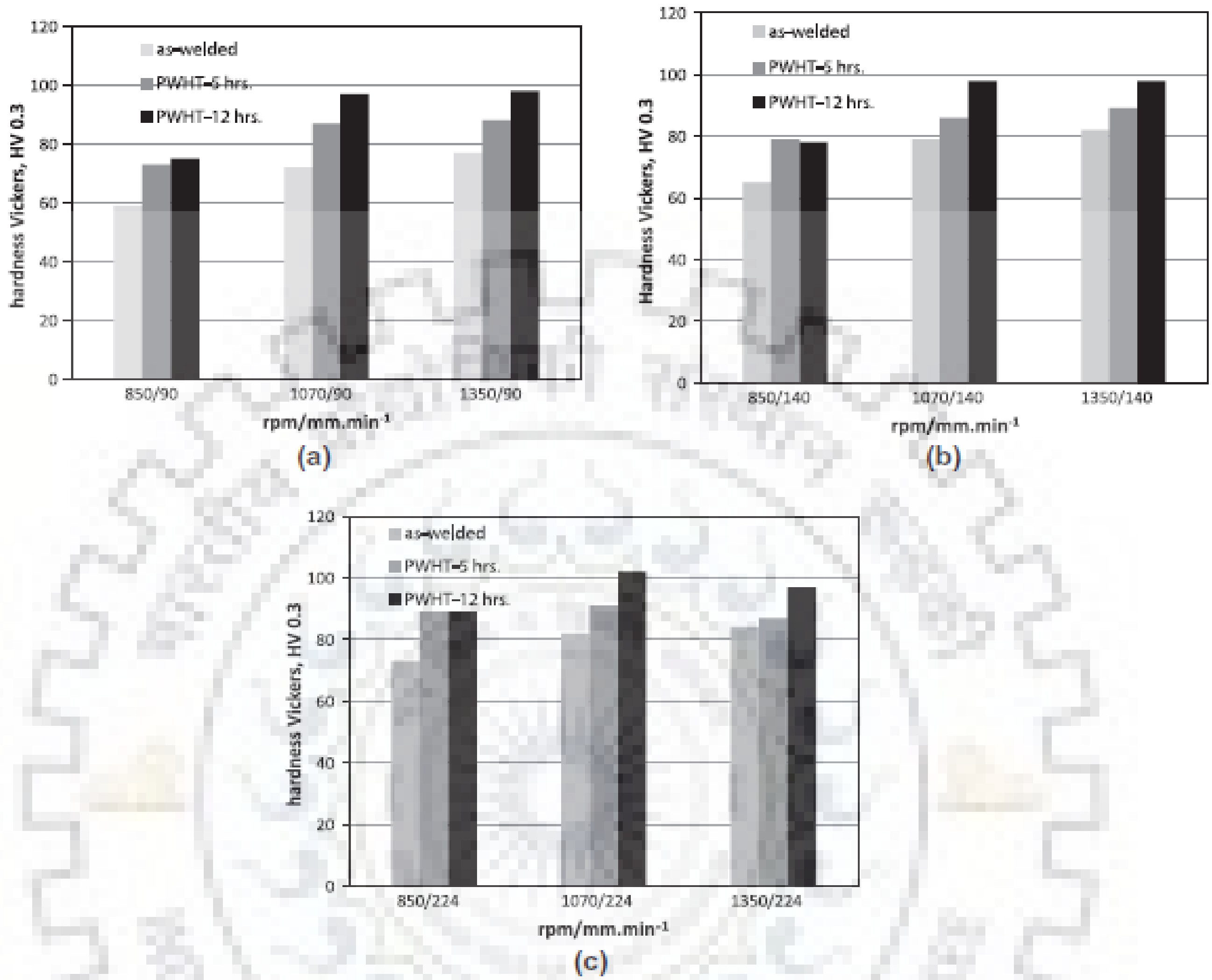


Fig. 2.2.2.2 Variation of ultimate tensile strength values with post weld heat treatment for a feed rate of 90 mm/min in (a) and 140 mm/min in (b) and 224 mm/min in (c) for different rotational speeds.

2.2.3 Microstructure

In earlier work conducted by Mroczkaet al on AA 6082, Scialpi et al on AA 6082, Rodrigues et al. [6] on AA 6061, and Yutaka et al explain the effect of rotational speed, feed and PWHT on microstructure of welded sample.

PWHT re- precipitates the β" particle in the solution so that it show the fine grain structure as compare to the welded sample.

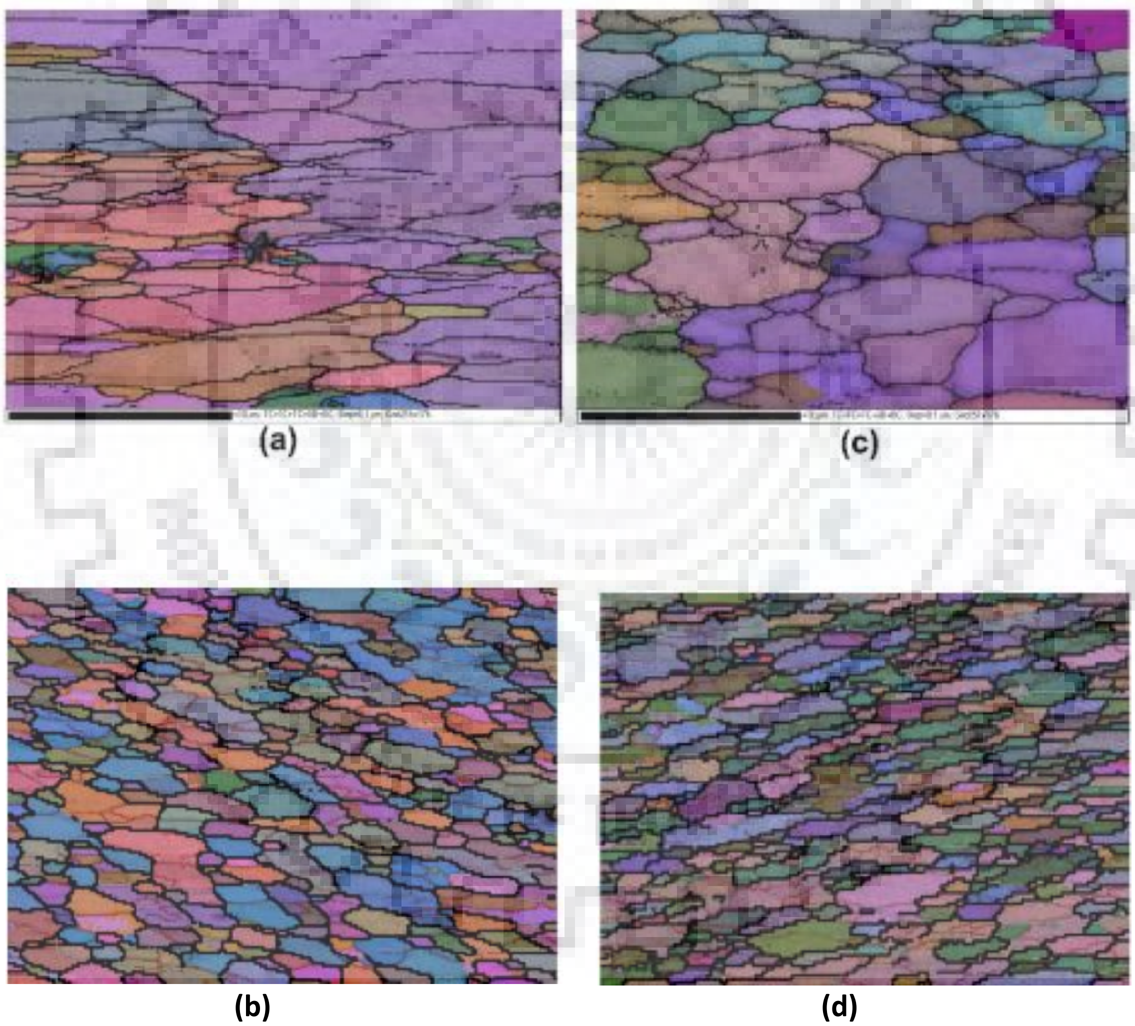


Fig. 2.2.3.1 Grain distribution ofwelded sample (1070rpm-140mm/min) in (a) and PWHT for 5h in (c) at (1070rpm-90mm/min) in (b) and PWHT for 12h in (d) (Rodrigues et al., 2009)

2.3 Summary of the literature review

From the above discussion, it is understood that the process parameters like rotational speed, feed, tool pin profile and PWHT have important effect on the mechanical properties of the FSW joints. It is also observed the the precipitation behavior of the aluminium alloys. During friction stir welding process, the thermal condition prevails in the thermo mechanical affected zone (TMAZ) and heat affected zone (HAZ) reason precipitate coarsening and dissolving of precipitates.

2.4 Scope and objective

From the above literature review, it is easily to understood the influence of processing parameters on quality of welded joint and the related to the microstructure and final mechanical properties. It is also important to understand the influence of post-weld heat treatment(PWHT) on the mechanical properties and microstructure of joints to find the best way for improving the mechanical properties. From the above results, these are the following objectives

1- Study the effect of process parameter namely feed rate, tool rotational speed, tool profile on the microstructure and mechanical properties.

2- Study the effect of pre heat and post heat on the microstructure and mechanical properties.

CHAPTER 3

EXPERIMENTAL WORK

3.1 Introduction

The main aim of this research is to make similar weld of Al 6082 plates by FSW process. Then preheat and PWHT of the plates needs to be done. After that, to see the effect of different process parameters on the simple welded samples and preheat, PWHT samples

3.2 Experimental Procedure

3.2.1 Fabrication of joint

Take Al-6082 pieces in size of 100 mm wide and 150 mm long**.**The weld faces of the plates to be joined were firstly shape and polished to make them flat.The plates were rigidly fix to fixtures so that the plates should not separate during welding. The FSW tool was slowly plunged into two material's interface. At a steady welding velocity, the rotating tool was passed along the weld line and lastly the tool was taken out.Welding process parameters, preheat, PWHT and pin profile have a important impact on the material flow pattern and distribution of temperature, thus affecting the material's microstructural evolution. In this experiment the process parameter such as tool rotational speed 640-931 rpm, tool travel speed 40-90 mm/min, tool tilt angle 2° were taken.The details of process parameter used in this experiment are given in table 3.1

Table 3.1 Welding parameters

Process Parameters	Values
Tool rotational speed(rpm)	640, 708, 931
Tool traverse speed(mm/min)	40. 70, 90
Tool tilt angle	2°

Tool material	Die steel

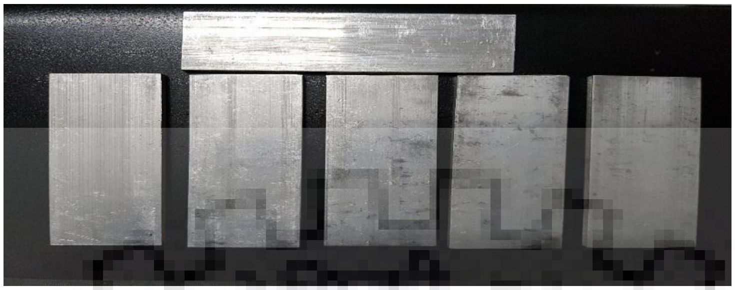


Fig. 3.2.1.1 Al-6082 pieces of size 150×100 (All dimensions in mm)

Table 3.2 Welding tool specification

Pin profile	**Tip diameter**	**Root diameter**	**Shoulder diameter**	**Pin length**
Tapered threaded	3.5mm	6mm	18mm	5.8mm

Fig. 3.2.1.2 Fsw tool of tapered threaded pin shape

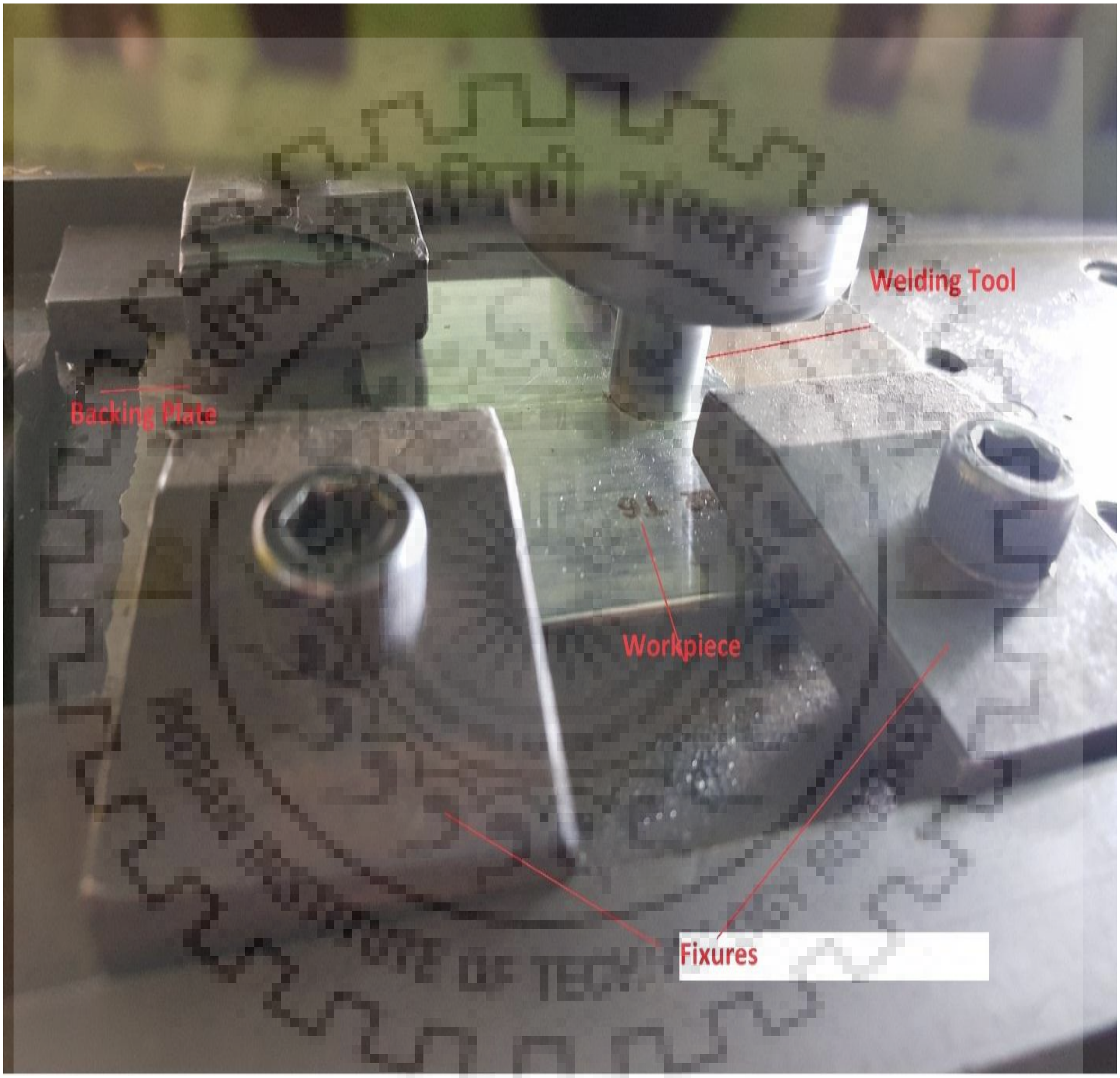


Fig. 3.2.1.3 Fsw welding machine

Fig. 3.2.1.4 Weld sample at different parameter

Fig. 3.2.1.5 Welded sample at different parameter

3.2.2 Preheat and Post heat weld treatment

Preheat and Post heat treatment is done on electric furnace whose maximum temperature goes upto 1100 °C. For post heat treatment firstly weld the workpiece by fsw with different parameter and after that put the weld sample on the electric furnace at 180 °C for 5 hour. After 5 hour weld specimens were quenched in cold water. Pre heat was done at 200 °C for 1 hour and immediately fix to fsw machine for welding. Fsw was carried out on preheat sample.

Fig. 3.2.2.1 Electrical furnace

3.3 Mechanical Properties Evaluation

3.3.1 Tensile Testing

Tensile sample was taken from weld joint and then sample were shaped by shaper to make it equal cross section from all side. The preparation of sample were followed by ASTM standard that is give in fig 3.3.1.1. The tensile sample were tested by universal tensile testing machine.

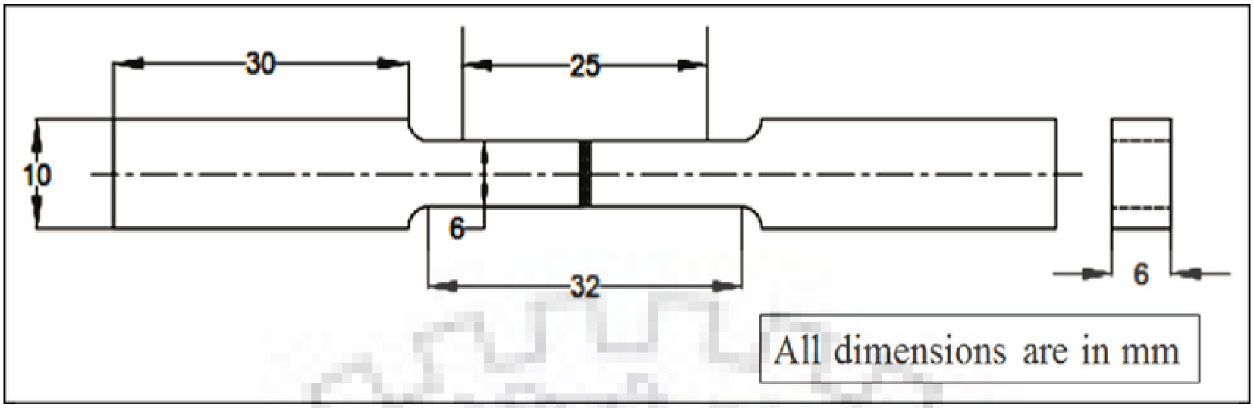


Fig. 3.3.1.1 ASTM standard of tensile test specimen

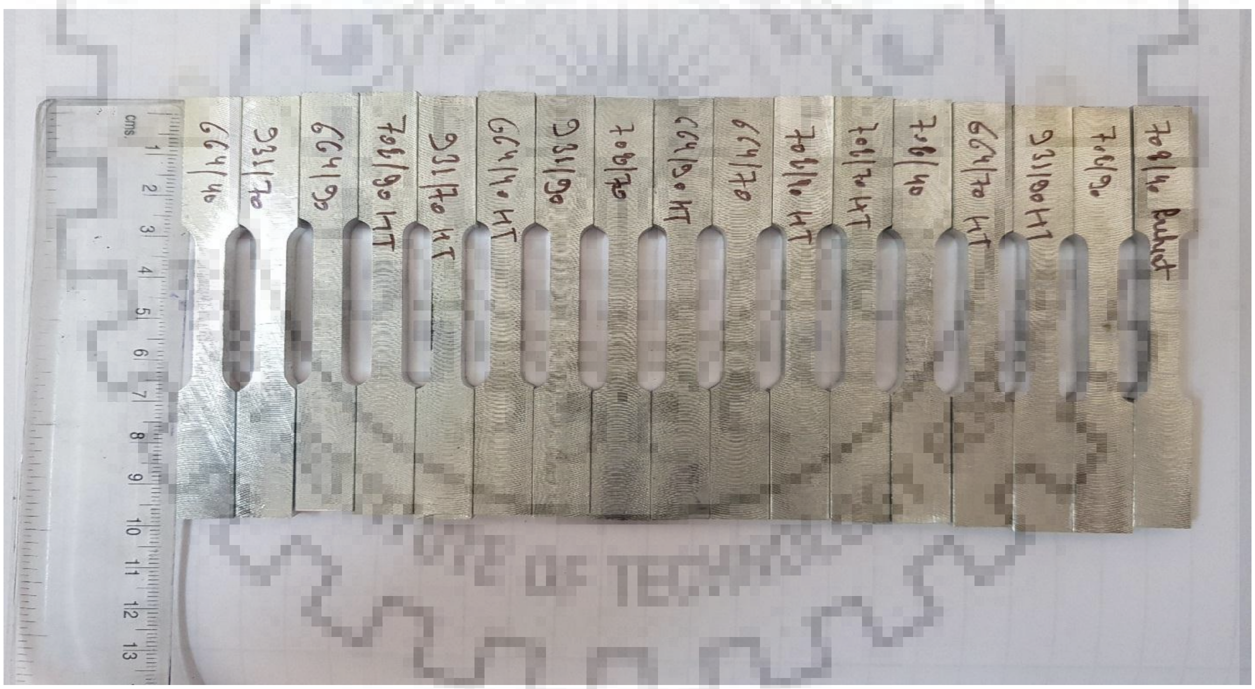


Fig. 3.3.1.2. Tensile samples of weld joint (before testing)

Fig. 3.3.1.3 Universal tensile testing machine

Fig.3.3.1.4 Tensile samples of weld joint (after testing)

3.3.2 Microhardness test

Microhardness test was performed on the cross section of weld sample by Vickers micro hardness testing machine using 100gm load with duel time of 10 sec at 1mm distance between successive indentation. The sample prepared for optical microscope used as microhardness testing. Polishing was done by emery paper number from 180 to 2000. After that use cloth polishing was done by magnesium oxide powder to make crystal clear surface.

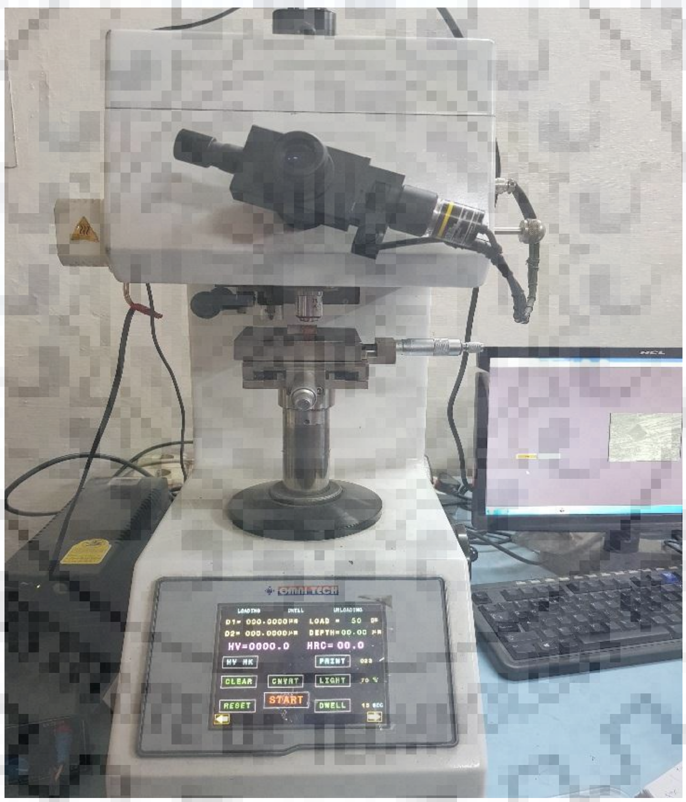


Fig. 3.3.2.1 Vickers hardness testing machine

3.4 Metallurgical Characteristics Evaluation

In this examination, the microstructure of the welded joints was analyzed by several characterizat ion processes. Microstructure examination methods include light optical microscopy (OM)

3.4.1 Optical Microscope(OM)

Optical microscope is used for to show the grains size and grain structures. It have basically 5-6 lens with varying zoom lenses. Weld sample is investigated in 5x, 10x, 20x,50x and 100x zoom lenses. Microstructure was carried out by image analysing software. Extracted specimens from welded joints to include stir zone, TMAZ, HAZ and parent metal areas. Polished the cross section side of the specimen by emery of different grade vary from 180(coarse) to 2000(very fine). Final polished was done by magnesium oxide powder by cloth. Keller's etchant (95 mL H_2O, 2.5 mL HNO_3, 1.5 mL HCl, 1.0 mL HF) and Kroll's reagent(92 mL H_2O, 6.0 mL HNO_3, 2.0 mL HF) the most popular etchants for aluminium alloys [7,8]. Weck's reagent(4g $KMnO_4$, 1gm of NaOH, 100 mL H_2O) is also a popular reagent.Some time Poulton's reagent (12ml HCL, 6ml HNO_3, 1ml HF, 1ml H_2O) and modified Poulton's reagent(20ml HCL, 8ml HNO_3, 2ml HF, 3gm Cromic oxide CrO_3, 2ml water) is also used for aluminium alloys

Fig. 3.4.1.1 Optical microscope

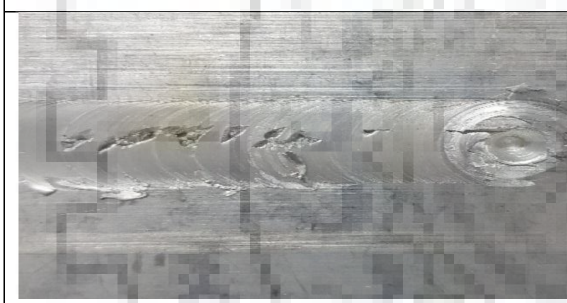
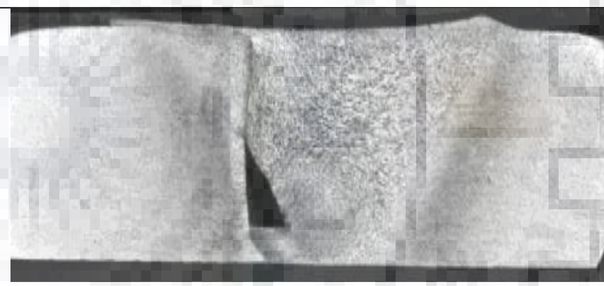
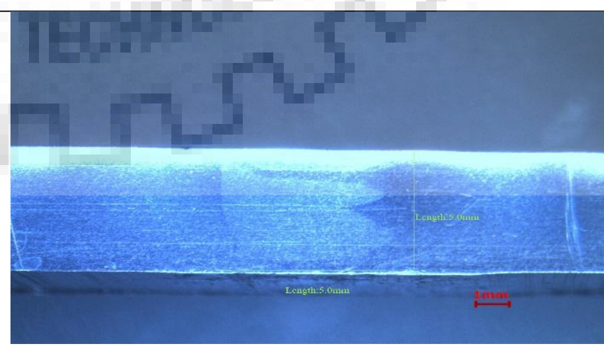
CHAPTER 4

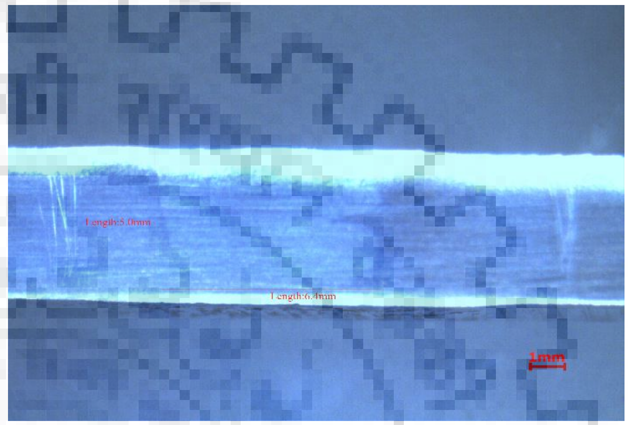
RESULTS AND DISCUSSIONS

4.1 Macrographs

Table 4.1. show the effect of different parameter and PWHT, Preheat on macrographs. It is observed that a throughout tunnel defect. So further investigation on preheat was stopped. It is observed from macrographs that all other found defect free at different parameter.

Table 4.1 Macrograph of welded sample

Top surface	**Cross sectional macrograph**	**Observation**
 Preheat sample at 200 °C		Top surface found defect and also tunnel defect found throughout.
		Defect free welded joint is found on the top surface and cross section.

Welded sample at 664rpm-70mm/min  PWHT sample 180 °C for 5h		Defect free weld joint is observed on the top surface and cross section.

4.2 Microstructure

- Fig 4.2.1and show the microstructure on the transverse segment across the boundary between the nugget / stir zone (SZ) and the base metal (BM)

- Keller's reagent was ineffective in viewing the microstructure [9].Furthermore, Kroll’s reagent showed only some narrow at the welded region’s border and also Poulton’s and modified Poulton’s reagent was ineffective to view the microstructure. The problem has two cause First, A6082-T6 base metal's tempered composition has a uniform and stable solid solution.T6 condition maintains the hardening particles in the solid solution so it opposed the precipitate them on the grain boundaries.

- Second the the solid phase plastic deformation of the welding method breaks the grains to their ultrafine size (within or below 10 mm).

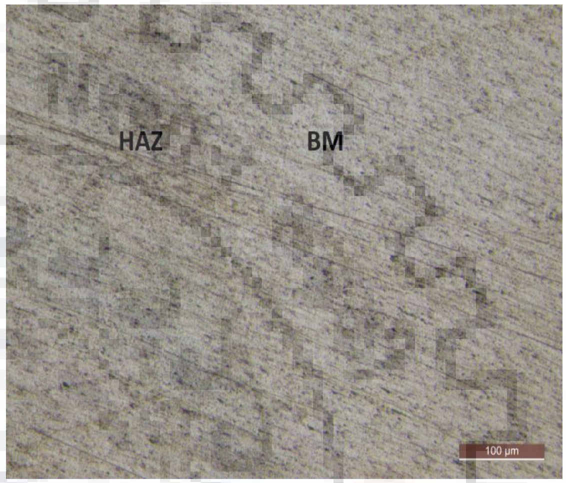
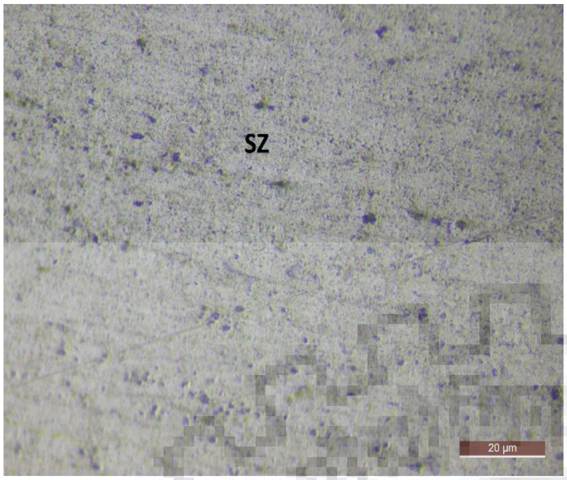
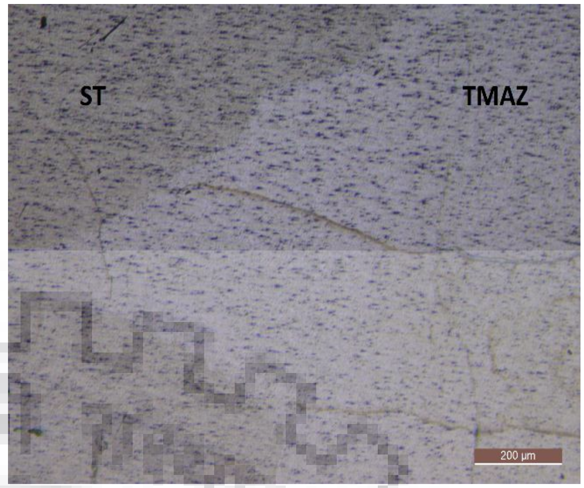


Fig. 4.2.1 Microstructure across the weld nugget by Keller’s reagent

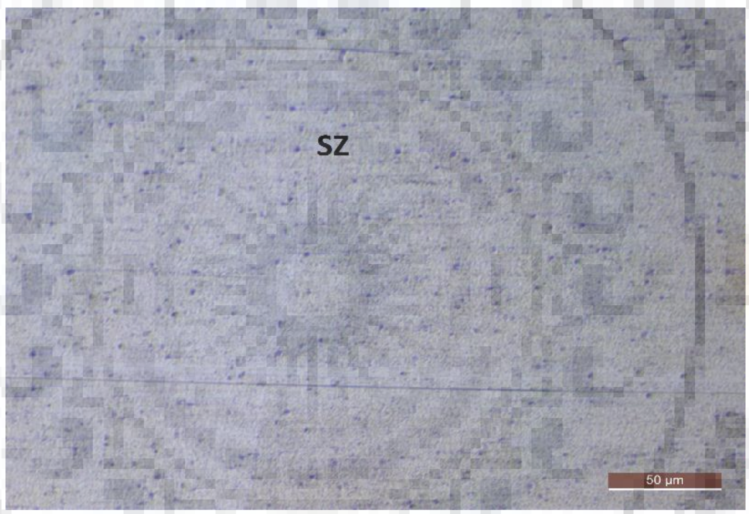
- After PWHT 180 °C for 5h grains of welded sample refined. It due to quenching of heat sample by cold water so that the grains of weld joint will not be coarse and hard β" phase precipitates will form in weld zone.



(a)



(b)



(c)

Fig. 4.2.2 Microstructure of PWHT sample at different reagent (a) by Poulton's reagent (b) by Modified Poulton's reagent (c) by Kroll's reagent

4.3 Mechanical Properties Evaluation

4.3.1 Tensile testing

- Table 4.2 shows the variation of tensile strength of welded sample at different parameter without PWHT. It is observed from table 4.3 that how PWHT at 180 °C for 5h. Effect of preheat on the tensile strength is shown in table 4.4

Table 4.2 Tensile strength without heat treatment

Tool rotational speed (rpm)	Feed (mm/min)	Tensile Strength (MPa)
664	40	117.10
664	70	120.73
664	90	127.39
708	40	117.00
708	70	177.08
708	90	180.90
931	40	121.10
931	70	182.62
931	90	191.38

Table 4.3 Tensile strength after post heat treatment at 180 °C for 5h

Tool rotational speed (rpm)	Feed (mm/min)	Tensile Strength (MPa)
664	40	129.39
664	70	133.084
664	90	135.23
708	40	125
708	70	187.21
708	90	195
931	40	139.59
931	70	193.7
931	90	200.12

Table 4.4 Tensile strength of preheat at 200 °C for 1h

Tool rotational speed (rpm)	Feed (mm/min)	Tensile Strength (MPa)
708	40	101.20

- From fig (a), (b) and (c) we conclude that as the feed(welding speed increases the tensile strength increase at constant rotation speed. The reason behind this is heat generation. Cavelier et al. [10] have shown for FSW of 6082 that with a rotation speed/welding speed ratio of 15 the peak temperature at a distance of 2 mm from the weld is around 450 °C, and for a ratio of 4 it is around 360 °C.

- Heat generation is mainly affected by welding speed. In this investigation the speed range ratio from about 7 (664rpm/90mm/min) to 23 (931rpm/40mm/min).

- It was discovered that as the welding speed ascends at a reliable rotational speed of the apparatus, the warmth information tends to reduce(the instrument invests nearly less energy and therefore less possibility of contact warming

-
- Due the high heat input it softening the weld zone by dissolution of second phase β'' particles. So tensile strength is high at low feed due to less heat input so that less dissolution of needle shape β(Mg2Si) precipitates.

- These precipitates increased the tensile strength and also hardness of weld zone. From above figures we conclude that the PWHT increases the tensile strength. The reason behind this is to heat the sample at 180 °C for 5h and then quenched in cold water so that this process re- precipitates the second phase β'' particles which was dissolved during welding. So PWHT enhance the mechanical properties.

- From table 4.4 we can see that there is no need of preheat of Al 6082 t6 because due to preheat precipitates will be dissolved in the matrix so that it will decrease the tensile strength also there will problem to give sound weld. So, the preheat is not necessary.

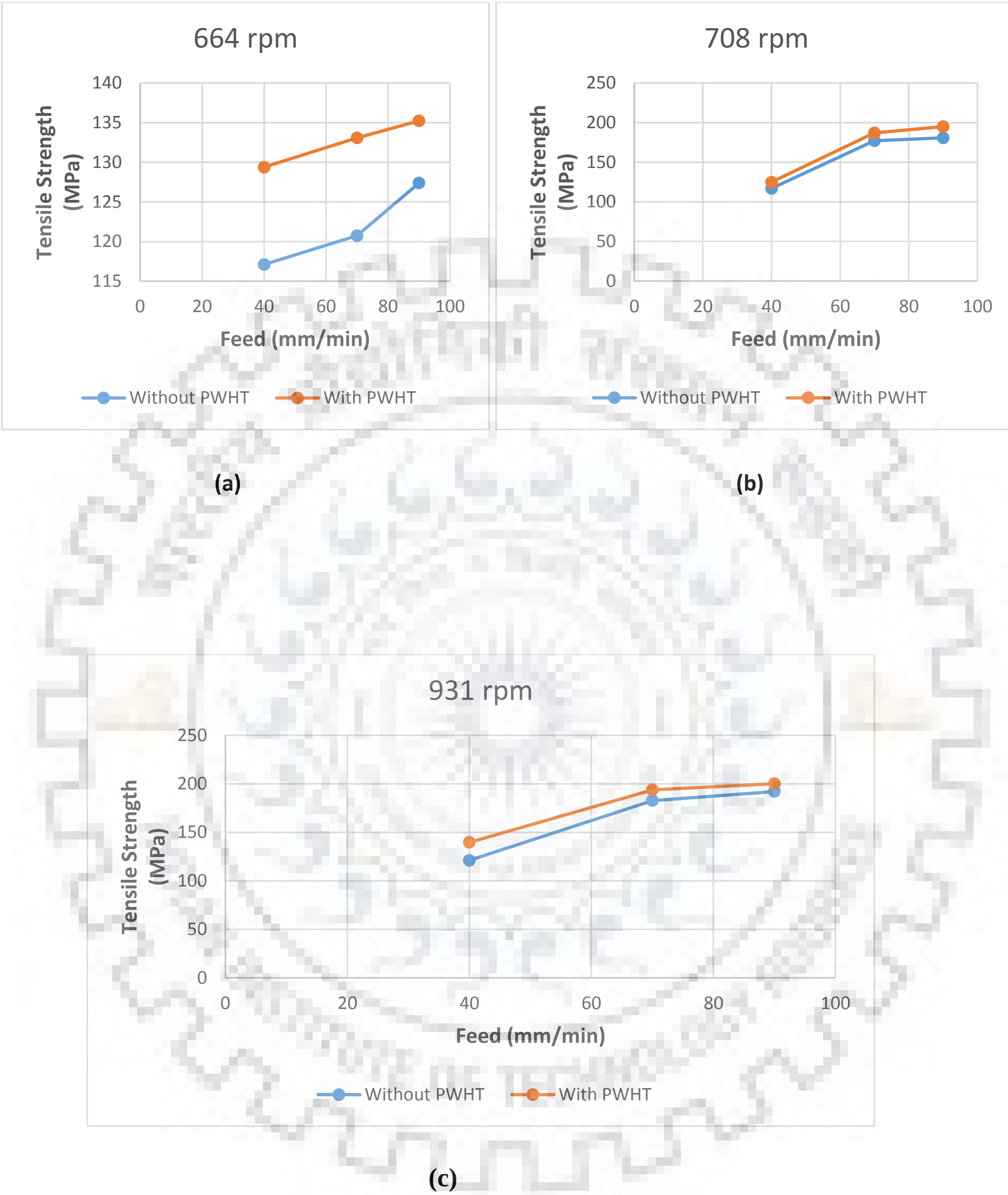


Fig. 4.3.1.1 Variation of ultimate tensile strength for various welding conditions of feed rates (mm/min) and rotational speeds (rpm) in (a), (b) and (c)

4.3.2 Microhardness

- Microhardness is evaluated by Vickers's hardness testing machine. Indentation load taken as 100gm for 10s dwell time across the weld joint at 1mm distance gap.

- Low hardness observed in stir zone due to softening of workpiece. At the stir zone high heat generation developed so that β" precipitate was dissolved.

- Heat generation is directly proportional to the rotational speed and inversely proportional to feed rate. Mainly feed rate affect the heat generation. Due to high feed their will be less time available for generate high temperature during welding. So it is observe from figure 4.1.2.1 that highest hardness observed at 90mm/min at constant speed of 708 rpm. It due to less heat generation on weld sample.

- It is observed from Fig 4.3.2.1 that advancing side show high hardness as compare to retracing side.

Table 4.5 Effect of welding parameter on microhardness of the weld sample

Welding parameter (rpm/mm/min)	**Avg hardness value**	
	AS	**RS**
931/70	62.79	61.76
931/70 PWHT	68.40	66.46
708/70	58.63	58.03
708/70 PWHT	63.69	60.93

931/40	50.65	48.99
931/40 PWHT	68.76	52.50
708/40	57.28	46.13
708/40 PWHT	76.66	74.90
708/90	59.35	55.19
708/90 PWHT	73.43	67.36
664/70	59.32	55.03
664/70 PWHT	64.03	60.12

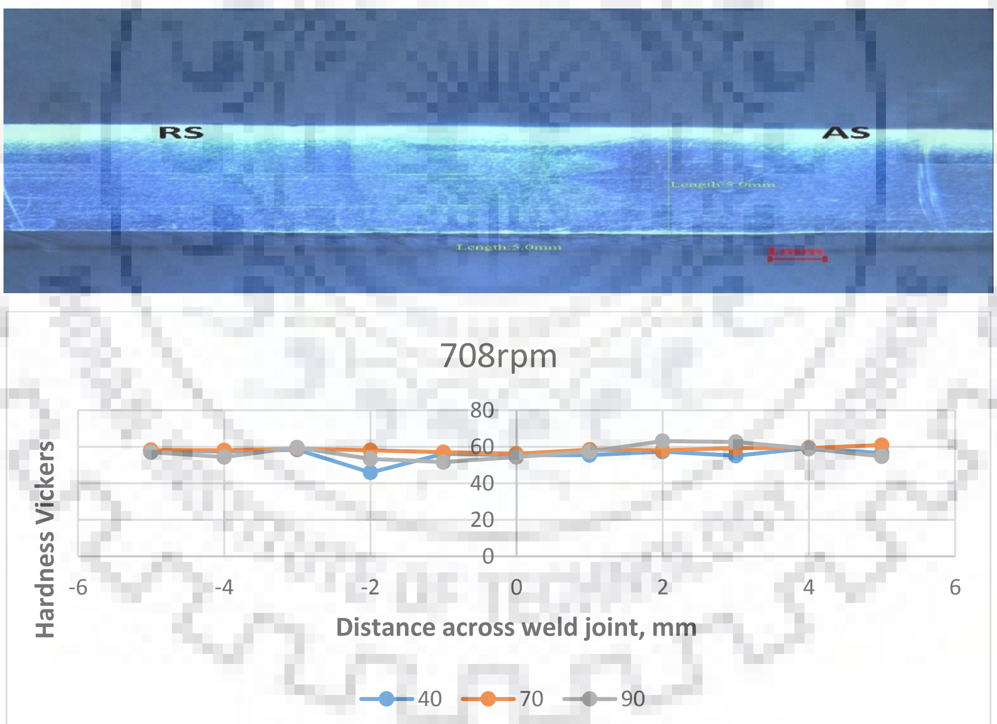


Fig. 4.3.2.1 Effect of feed rate on microhardness at constant rotational speed 708 rpm

- PWHT of weld sample at 180° C for 5h give better hardness. It is due to re-precipitation of β" needle shape particles in stir zone and β' rod shape type particle in TMAZ which was dissolved during welding process.

- Effect of PWHT shown in Fig 4.3.2.2 at 708rpm-90mm/min. It observed that without PWHT highest value of hardness is 62.68 and with PWHT the highest hardness value is found 81.46

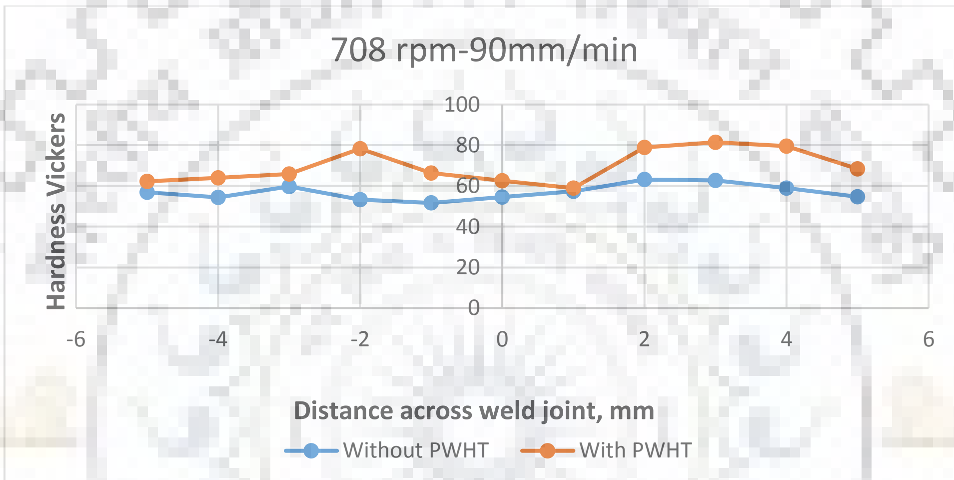


Fig. 4.3.2.2 Effect of PWHT at 180 °C for 5h on microhardness at 708 rpm and 90mm/min

CHAPTER 5

CONCLUSIONS

- Highest tensile strength is observed 191.38 MPa with tapered threaded tool at 931rpm-90mm/min without PWHT

- Highest tensile strength is observed 191.38 MPa with tapered threaded tool at 931rpm-90mm/min with 200.12 PWHT.

- PWHT give better results for mechanical properties as compare to the as welded condition.

- Soundness of the weld was not up to the desired quality after preheating. So, there is no need of preheat of Al-6082 for FSW welding.

- Maximum value of hardness is 62.79 observed at 931rpm- 70mm/min. without PWHT.

- Maximum value of hardness is 76.66 observed at 708rpm- 40mm/min with PWHT.

- Welding of 6082AA outcomes in greater weakening in the SZ and TMAZ. PWHT can partly recover this adverse impact on the strength and hardness of the welded joints.

- The reaction to PWHT of samples welded at reduced welding speeds is more pronounced than that welded at greater speeds. This observation could be ascribed to the near full dissolution of secondphase particles with reduced welding speeds owing to greater heat input, which implies more solutes are accessible in the matrix for reprecipitation of the second stage.

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