iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** IV **Month of publication:** April 2022

DOI: https://doi.org/10.22214/ijraset.2022.41372

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue IV Apr 2022- Available at www.ijraset.com

Experimental Investigation of the Friction Stir Welded Dissimilar Aluminium Alloys

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Abstract: Friction stir welding is the solid-state welding method that is used to weld mostly aluminium alloys. A cylindrical tool with a shoulder and pin rotates at high rpm is penetrated at the interface between two materials to be welded. The high rotational speed causes the material to flow plastically and the joint is formed with the traverse movement of the tool. The tool profile, material nature, rpm of tool, traverse speed are the major factors that affect the weld quality. In this research Al 1100 and Al 6061-T6 aluminium alloys were used and the joint is made using Friction Stir Welding. The joint is then tested for the impact strength, tensile strength and microhardness. The tensile test done on Universal Testing Machine and the highest strength was 202.56Mpa found at 1000 rpm and 12mm/min traverse speed. In the impact Charpy test the highest strength found is 0.1494 kj/mm2. The micro hardness test gives the highest value of 52hv at the weld zone at 100 rpm and 12mm/min weld speed.
Keywords: Friction Stir Welding, Aluminium alloys, tensile strength, impact strength, Micro hardness.

I. INTRODUCTION

Friction Stir Welding is a type of welding process invented at The Welding Institute, UK in the year 1991. This joining technique was initially used for aluminium alloys only. The working process of this welding technique is simple and is widely used these days for metal joining. [2] It is most used welding process for aluminium alloys because those are difficult to weld by using fusion welding processes without causing the welding defects like hot cracking, porosity and distortion. [3]

In Friction Stir Welding process a rotating tool is used which includes a pin and a shoulder which is inserted in the interface between two plates to be welded and is traversed along the line. The side on which the tangent to tool rotation and the tool travel direction are same in while is called advancing side while the side on which the tangent to tool rotation and the tool travel direction are opposite in while is called retreating side. The tool used in the FSW mainly serves the three purposes which includes the heating of the joint interface, movement of the material at the joint interface and containing the heat produced the joint. [2]. The Friction heat produced makes the material to flow plastically and the axial movement of the tool helps in the formation of the joint along the interface. [1]. The tool shoulder prevents the flow of the material above the shoulder level resulting into making a clean joint.

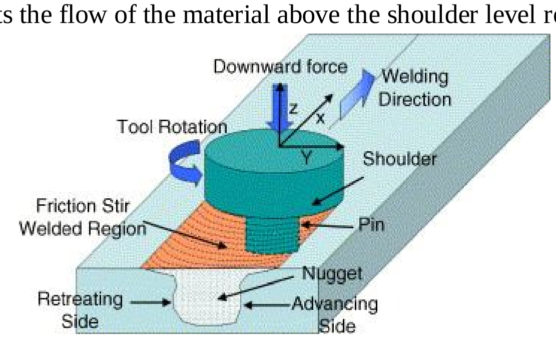

Fig `1– Friction Stir Welding Process schematic diagram[21]

Tool pin design selection plays an important role in deciding the quality of welded joint. The major function of tool is to heat up the parent metal, generate material flow and plastic deformation. Tool rotation speed do the function of stirring of material and mixing of it. Rise in the RPM also increases the heat generation which lead high stirring and mixing of the material. The heat input is largely affected by the force applied, RPM of tool, the length of pin and the diameter of the shoulder.

The shoulder diameter of the tool has important role in increasing the frictional heating which causes the workpiece to undergo plastic deformation. The shoulder of the tool is given some concavity many times which serves very important purpose. The concavity helps to accumulate the material which is then displaced by the pin of the tool to form the joint and the concavity also helps to push the material behind when the tool moves forward with some traverse speed [11].

Aluminium and its alloys are the widely used materials in the various manufacturing industries. Al 6061 is the alloy of 6xxx aluminium alloys with magnesium and silicon as its major alloying elements. The Al 6061 alloy has good weldability and can be easily deformed into desired shape. Therefore, this alloy founds number of applications in the manufacturing industry. The Al 6061 has good yield strength, ultimate strength, shear strength and fatigue strength properties. Due to its weldability, corrosion resistance and formability the Al 6061 has several applications in Marine industry, architectural. structural. automotive and aerospace industries [3].

Al 1100 is mostly made using cold working techniques. Al 1100 is one of the softest Aluminium which limits its applications to the low strength and low pressure. Mostly plumbing and lighting industries use the aluminium 1100 apart from that fin stocks, utensils for cooking, reflectors are also made using this alloy of aluminium. Aluminium 1100 can be welded by various solid state welding techniques in which the friction stir welding is the one. [17]

II. LITERATURE REVIEW

Kumbhar and Bhanumurthy (2008) did the post weld heat treatment (PWHT) helps in reducing the in homogenities which are present in the FSW welded joints and the mechanical properties are substantially improved after PWHT.[13] Naurani et al. (2011) joined the Al 6061 alloys and used Taguchi optimization method and a temperature-field finite element model to minimize the distance of HAZ from the weld line and the peak temperature.[22] Doos et al. (2007) did the feasibility study of FSW on Al 6061 Aluminium pipe and found that the maximum welding efficiency was obtained in the terms of Tensile strength at 630 RPM rotational speed and the travelling speed of 1 mm/sec.[7] Jannet et al. (2013) studied the mechanical properties of the welded joints of 6061 T6 and 5083 O aluminium joints using the FSW and the conventional fusion welding methods and found that in case of FSW joints the tensile strength was higher and the heat affected zone was narrow as compared to fusion welded joints.[9] A viscusi et al (2019) did the study about the effect of rotational and transverse speed on the strength of lap joint of AA 2024 T3 using friction stir welding and the tensile tests were performed on the specimens the confirmation of the results was done using shear analysis. The best results obtained at 1250 Hz.[1] Fazel et al. (2011) did study on Friction stir welding for stainless steel and titanium and found that composite carbides are useful as the tool material and the two major qualities of the tool are attainable toughness and the resistance to wear [8].

Deghani et al (2013) found that the use of threaded pin can prevent tunnel by forming a bell-shaped nugget zone and stated that the joint strength between aluminium and steel is weak when the rotational speed is high and the plunge depth is low due to the lack of bonding.[15] . Balram et al. (2016) worked using three different welding parameters that consists of rotation speed, travel speed and diameter of the shoulder. Tensile strength value found was 140 Mps. It was concluded that tool geometry has influence on the micro structural properties of the joint. [4] Caizhi Zhou et al (2005) found that the fatigue life of welds made by Friction Stir Welding is 9-12 times is higher than the MIG welds under R = 0.1. The values of fatigue characteristics raised from 39.8 MPa MIG to 67.3 MPa for FSW. [27] Murr et al (1997) found that the microstructures of friction-stir welded 1100 and 6061 Al alloys is mostly consisted of dynamic recrystallization. The researchers also welded 6061 Al to Copper and found that a complex, intercalated microstructure similarly consisted of the dynamic recrystallization. [21, 22] Saini et al (2021) did the evaluation of FSW joint of AZ61a Magnesium alloy and found that highest tensile strength and microhardness were found at 2000 rpm and1800 rpm respectively with welding speed of 20 mm/min each. Microscopic examination of the joints showed the formation of equiaxed grains in the TMAZ and stir zone because of the dynamic recrystallization. [25]

III.EXPERIMENTATION AND RESULTS

A. Problem Formulation

Al6061-T6 and Al1100 are two materials that finds applications in manufacturing of several mechanical parts such as aeronautical and aerospace machinery, marine structures, heat exchangers etc. Frictional stir welding of Al6061-T6 and Al1100 will give an opportunity to use both metals together. The problem here to analyze the tensile and impact strength of the joint made by joining Al6061-T6 and Al1100.

Recommended font sizes are shown in Table 1.

B. Research Objectives

1) To find and analyze the tensile strength of the joint of Al6061-T6 and Al1100 made using Friction Stir Welding.
2) To find and analyze the Impact strength of the joint of Al6061-T6 and Al1100 made using Friction Stir Welding.
3) To find and analyze the Microhardness of the joint of Al6061-T6 and Al1100 made using Friction Stir Welding.

C. Materials, Tools and FSW Parameters

In this study the 6mm thick Al 6061-T6 and Al 1100 materials were used as the workpieces for the Friction Stir Welding. The given table shows the chemical composition of the Al 6061-T6 and Al 1100 aluminium alloys. The tool used for the process is made of H13 steel with threaded cylindrical pin. The tool was prepared on Lathe machine by performing required operations. After the fabrication of tool, it was oil quenched to bring its hardness to 55 so it can be effectively used for FSW process.

Material	Al	Zn	Mn	Be	Cu	Fe	Si	Ti	Mg	Cr
Al 1100	99	0.1	0.05	0.0008	0.1	0.95	-	-	-	-
Al 6061-T6	95.8	0.25	0.15	-	0.15	0.7	0.8	0.15	0.8	0.1

Table I – Chemical composition of Al 6061-T6 and Al 1100 (%)

The various parameters of Friction Stir Welding to be used consists of the tool rotation speed, feed rate, material of the tool, plunge depth and tool pin profile. The machine tools used in this process are lathe machine for tool fabrication, cutting machine for material cutting, vertical milling machine for Friction stir welding, water jet machine for preparing tensile test specimens.

The following table shows the various process parameters and their ranges –

Sr. no.	Process Parameters	Range
1.	Tool pin diameter	6 mm
2.	RPM	800-1200
3.	Traverse Speed	10-12 mm/min

Table II – Process Parameters

Number of work specimens = 6
Dimensions of work specimen = 80 mm X 70 mm X 6 mm
Dimensions of work specimens after welding = 160 mm X 70 mm X 6 mm.
The Friction Stir welding in the research was performed on the CNC vertical milling machine at Central Tool Room Ludhiana. The CNC vertical milling machine provides the utility to control tool rotation speed and welding speed easily with the programming.

The specifications of the machine are as follows –
Type of Machine: FANUC CNC vertical milling machine
Travel : x = 2000, y = 1000, z = 800
Speed : 30-10000 rev/min
Load : 2500 kg

D. Analysis and Testing

The specimen for the analysis and testing were prepared as per ASTM standards. The tensile specimens were prepared according to ASTM E8 standards. The impact test specimens were prepared according to the ASTM A370.

1) *Tensile Test:* The tensile test was performed on the Universal testing machine (available at Chandigarh University Mechanical Engineering Department) on the work specimens prepared using ASTM E8 standards. The given image shows the tensile testing of the specimens. The weld samples exhibited higher tensile strength as compared to the Al 1100 alloy but less than the Al 6061-T6 alloy. The values of Yield strength have also shown the similar behaviour. The joint efficiencies are better. The fracture of sample was observed that it occurred on the side of 6061 despite its large tensile strength. The fracture did not happen at the weld centre as it was 3 mm away from the weld centre. The fracture in all the samples was ductile. Despite some defects the samples at 800 rpm show good mechanical properties. The joints produced at 800 rpm and 10 mm/min feed have shown lower tensile strength and while the highest tensile strength was obtained at 1000 rpm and 12 mm/min. The specifications of the Universal Testing Machine by Fine Manufacturing are –

Capacity – 10 KN
Maximum crosshead travel – 1100mm
Testing Speed range – 0.001 to 1000 mm/min
Maximum crosshead speed at 5kN – 500 mm/min

2) *Impact Test:* Impact Charpy test was performed at the room temperature using pendulum type impact testing machine. The values of the energy absorbed in the fracture were noted and that absorbed energy is termed as impact toughness of the material. The impact test carried out at three different rpms and two different feed speeds. The work specimens were placed with weld joint at the centre line. The impact strength first increased with increase in the tool rotational speed due to proper mixing of material to form joints but with more increase in tool rotation speed the impact strength starts decreasing due to high heat which forms the coarse grain structure. The specimens do not split into two parts during the impact test which is due to the high ductility of the joint. [5] The specifications of the impact testing machine are as follows –

Initial potential energy (Joules) – 300
Pendulum drop angle (degree) – 140
Angle of striking edge – 30
Radius of Striking edge – 8 mm
Distance between Anvils – 40 mm
Width of tip – 4mm.

3) *Microhardness:* Microhardness test was performed at Micro hardness tester at the Bicycle and sewing machine research and development centre Ludhiana. The work specimens were prepared according to ASTM E384 standards. The specimens were polished at the Metallurgy lab of the same institution. The deformation on the surface was formed using the pyramid which is diamond shaped. Hardness calculation was done according to the load applied on the specimens. The load applied in the s hardness test was 200 grams or 0.2 gm for 10 seconds. The dimensions of the impressions made with diamond were recorded with the help of the scale of eyepiece.

E. Results and Discussions

The work specimens were first welded at 600 rpm and 10 mm/min but there were several defects consisting of holes and rough surface. Then the parameters were changed to 800 rpm and 10 mm/min which resulted in the sound welds with minimum defects. The specimens were welded with variation of RPM and feed rate then tensile tests were conducted on the specimens.

Fig 2– Work specimens after tensile test on UTM

The results obtained from tensile test had been recorded in the given table –

Sr no.	Speed(rpm)	Feed (mm/min)	Yield Strength (MPa)	Tensile Strength (MPa)
1	800	10	115.75	170.34
2	800	12	119.92	178.98
3	1000	10	125.65	192.45
4	1000	12	132.87	202.56
5	1200	10	129.54	190.78
6	1200	12	124.64	186.44

Table III – Tensile test values

The given graph shows the tensile strength variation with respect to speed and feed –

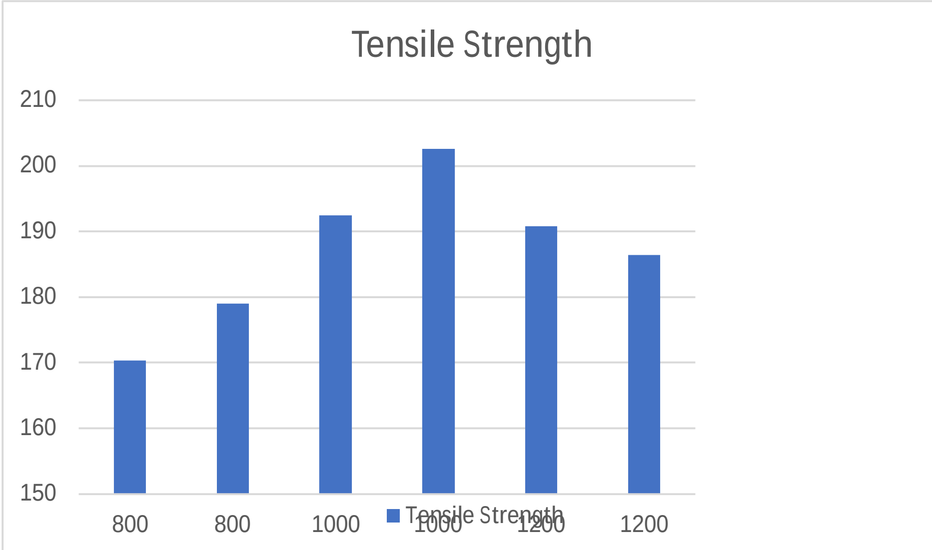

Fig 3 – Tensile strength plot

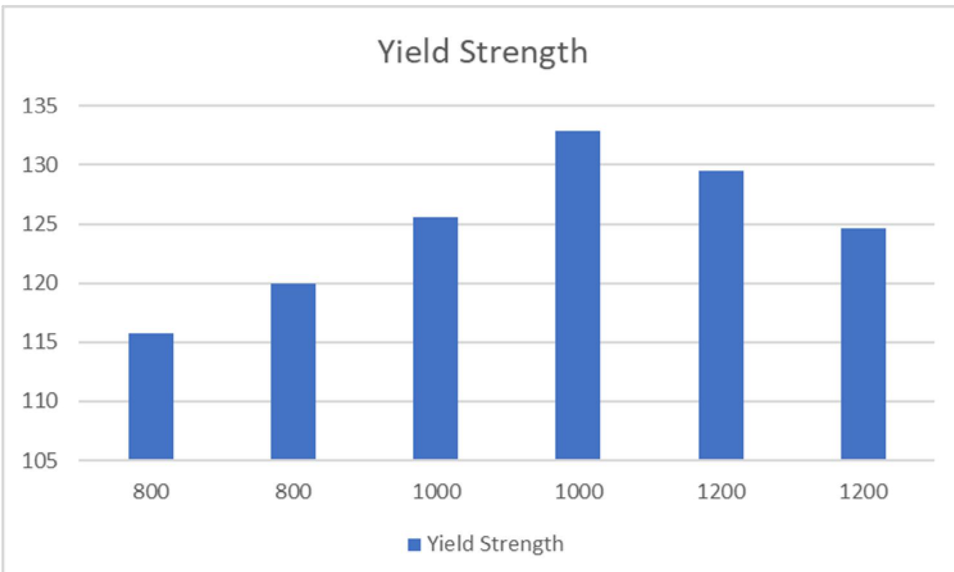

Fig 4 – Yield strength plot

The values of impact energy were recorded from the machine scale after the impact test of each specimen then the impact strength values were calculated using the value of cross-section area.

Fig 5 – Work Specimens after Impact Charpy test

, Sr no.	Speed	Feed	Impact energy (J)	Impact strength (kj/mm^2)
1	800	10	71.5	0.143
2	800	12	72.5	0.145
3	1000	10	73.5	0.147
4	1000	12	74.7	0.1494
5	1200	10	73..8	0.1476
6	1200	12	73.2	0.1464

Table IV– Impact test values

The given plot shows the variation of Impact energy with the tool rotation speed –,

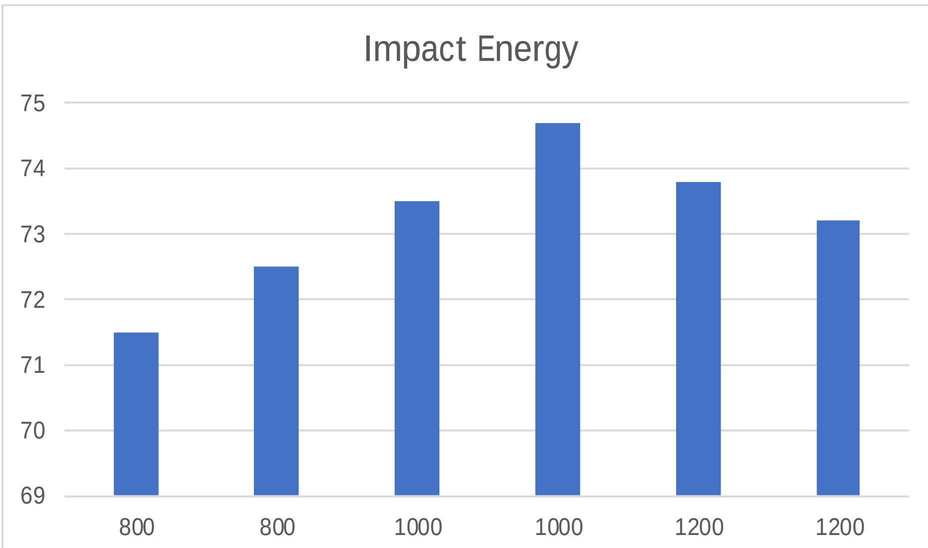

Fig 6– Impact energy Plot

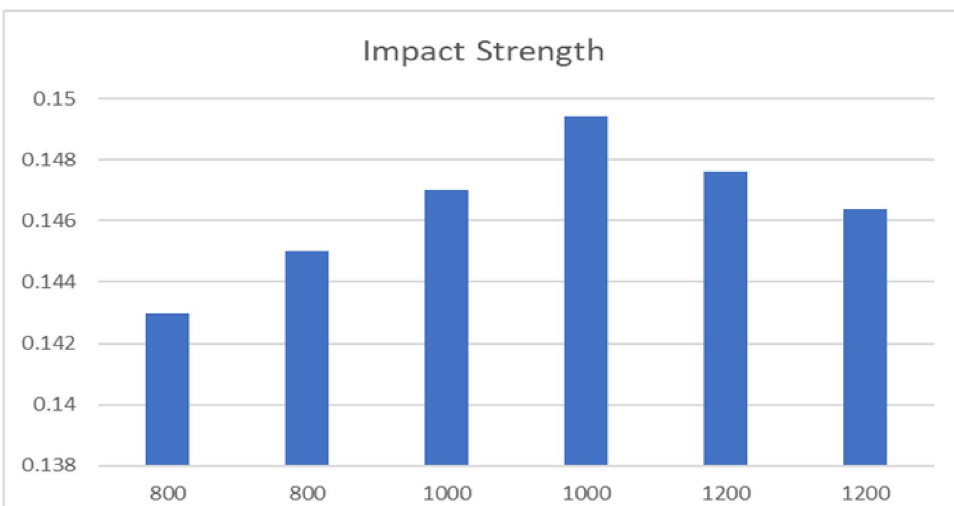

Fig 7 – Impact strength Plot

The impact energy and the impact strength were found to increase with increase in the rpm and feed. The highest values were obtained at the tool rotational speed of 1000 and feed of 12 mm/min.

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
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The hardness tester gives the direct values of the micro hardness because of the calibration done. The variation of the hardness on both sides from the weld zone was calculated and the graph was plotted.

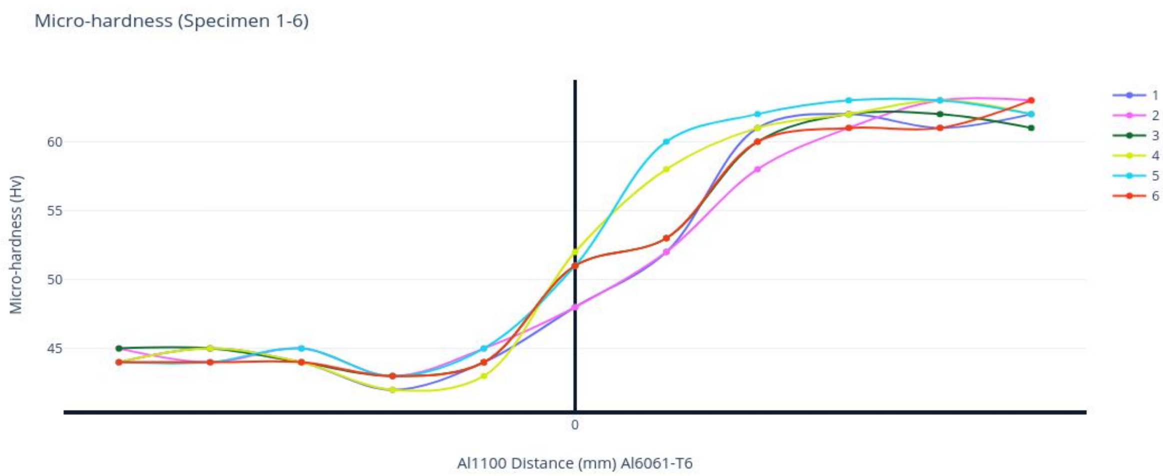

Fig 8 – Microhardness Plot

The given plots show the Micro hardness values obtained after the Microhardness testing. The microhardness of the base metal Al1100 is approximately 45 Hv while the microhardness value for Al6061-T6 is approximately 63 Hv. In the weld zone the micro hardness is between 48 Hv to 52 Hv. The highest value was found at 1000 rpm and welding speed of 12 mm/min. The value of Microhardness at friction stir weld zone was observed to be higher than base metal value of Al1100 but lower than the value of Al6061-T6. The particles of the intermetallic compounds played a major role in increasing the microhardness value at the weld zone. The values of microhardness rise with rise in the distance from the weld zone after decreasing.

F. Future Scope

The research has vast future prospects that can be explored further to refine the research and explore more in the Friction Stir Welding of Al 6061-T6 and Al 1100.

1) Microstructure investigation of the joint can be done to explore the grains size and uniformity in the Heat generation zones.
2) Taguchi method can be applied to find the optimized parameters for the Friction Stir Welding of Al 6061-T6 and Al 1100.
3) Temperature distribution analysis can be done for the joint using the thermal modelling of Friction stir welding.

IV. CONCLUSIONS

The Friction stir welding of Al 6061-T6 and Al 1100 work specimens was performed on the vertical milling machine. The tool used for the welding process is cylindrical threaded pin tool. The samples were prepared by cutting the specimens using water jet cutting machine. The samples were tested for obtaining the tensile strength on the Universal testing machine.

1) It was found that the tensile strength first increases with increase in the tool rotation speed then decreases with increase rpm.
2) The Impact strength values were obtained with Impact Charpy test using Impact testing machine. The highest impact strength value was obtained at tool rotation of 1000 rpm and 12 m/s.
3) The joints exhibit good mechanical properties at the tool rotation speed of 1000 rpm with increase in tool rotation speed the tensile strength and impact strength decreases due to coarse grain structure.
4) The microhardness value of the weld zone lies between the microhardness values of both alloys.
5) The microhardness value increases after decreasing when moving both sides from the weld zone.

V. ACKNOWLEDGMENT

Author is thankful to Dr. Jasgurpreet Singh for providing testing facilities at Strength of materials lab, Department of Mechanical Engineering, Chandigarh University.

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