Investigate the Friction Stir Welded 6082 – T6 Aluminum Alloy Properties by Varying Tool Geometry and Process Parameters

Saumil K. Joshi, NamJoshi Sadanand, Deepak Paliwal

Abstract*: *Today's world diverts toward the light weight and high strength material at very fast rate. Consequently, aluminum alloy replaces steel structure at so many places in industries as well as in common applications. Due to that quality fabrication of aluminum alloys is essential. But non-conventional welding processes is not more efficient to join aluminum alloy. Therefore, novel green friction stir welding technology is used in the present work. Friction stir welding technology is sub-part of solid-state welding processes because it joins the metal parts before the temperature of weld zone cross the melting point with the application of axial pressure. To fulfil the objective of quality and sound welding of aluminum, effect of six different shoulder geometries are investigated in the present work. By using six non-consumable rotating FSW tools, 5 mm thick 6082 – T6 aluminum alloy plates are being welded at different tool rotation speed (600, 800 & 1000 RPM) and tool travel speed (35, 45 & 55). To check the quality of weld, tensile test and micro-hardness test are performed. From those experimental results, it is concluded that shoulder geometry of tool – 3 gave sound and quality weld with 240.42 MPa strength and 60 HV hardness.

Index Terms*: *Friction Stir Welding, Shoulder geometry, Pin geometry, Mechanical properties, Aluminum alloy

I. INTRODUCTION

Now-a-days industries like aerospace, marine, automobile, aviation etc., are move toward the light-weight with good strength material for their heavy structure's components to increase the efficiency of machines. So that the use of aluminum and its alloys are rapidly growing in these applications due to its favorable properties like high strength to weight ratio superior that of the steel, corrosion resistance, good formability, etc. Generally, Tungsten Inert Gas (TIG) welding method is used to weld aluminum and its alloy. During the welding of aluminum, air contamination is there, which increase the solubility of hydrogen and oxidation of workpiece causing loss of mechanical as well as thermal properties. In addition, defects like porosity, cracks, shrinkage are detected on the and under the weld surface. [1, 2, 3] Thus, the joining or welding of aluminum and its alloys is difficult through conventional or fusion welding technique. But recently Friction Stir Welding (FSW) technology is emerging alternative method to joint aluminum and its alloy. [4, 5, 6] Friction Stir Welding is novel solid-state welding method to join similar as well as dissimilar material. In which the frictional heat is generated through rubbing action at the fraying surfaces. It was firstly conceived by Wayen Thomas at The Welding Institute (TWI) at Cambridge, UK in December' 1991. Thus, TWI registered first patent of FSW process. From its begging, FSW attract researchers and industrialist as an alternative of conventional or fusion welding technique for similar as well as dissimilar material like Al – Al, Al – Ti, Al – SS, Al – Cu, etc. FSW welding process cycle divided into three phases graphically shown in figure (1).

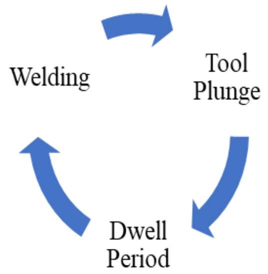


Fig. 1: Cycle of Friction Stir Welding Process

In the initial stage, non-consumable rotating tool with the extra ordinary design of pin as well as shoulder force-fully plunged up-to the chosen depth with the pre-define tool rotation speed (RPM) at the frying surface of the tightly clamped two components which being weld. Non-consumable rotating FSW tool is the important part of the welding process. It serves three main functions specifically heating of the base metal through frictional heat, stir the plasticized base metal to form the joint and kept the plasticized material under the tool shoulder. After the plunging of the rotating tool up-to top of the weld surface, specific time period keeps dwell to generate the fractional heat at the interface of frying surface and the tool shoulder, which enough for plasticize the material. After the generation of specific heat, FSW tool start its traverse action along the weld line with the chosen tool travel speed. Figure (2) shows the principle definition of the FSW process. The frictional heating softens the workpiece material nearby the FSW tool with the tool rotating and forwarding action, which leads the movement of material.

Revised Manuscript Received on 30 May 2019.
***** Correspondence Author
Saumil K. Joshi*, Mechanical Engineering Department, Madhav University, Pindwara-307026, Rajasthan, India.
Dr. NamJoshi Sadanand, Mechanical Engineering Department, Madhav University, Pindwara-307026, Rajasthan, India.
Dr. Deepak Paliwal, Geetanjali Institute of Technical Studies, Udaipur-313022, Rajasthan, India.

This palatized material move from advancing side which is on the right-hand side or directly opposite to the direction of the metal flow to the retreating side which is on the left-hand side or parallel to the direction to the metal flow and forming the solid-state weld of materials. At the end of the welding, FSW tool withdraw from the weld zone and it left with key whole.

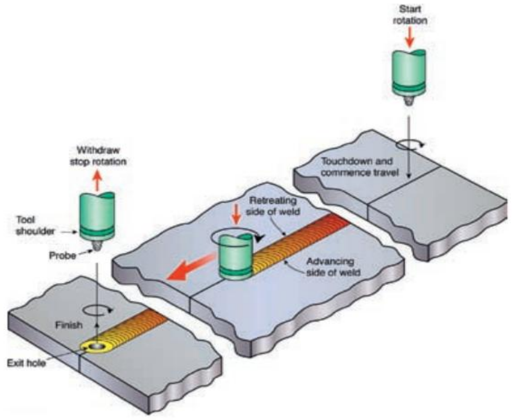


Fig. 2: Working Principle of the Friction Stir Welding [7]

Friction Stir Welding tool is mainly answerable for the quality of the weld zone. Shoulder geometry was mainly responsible for generation of the frictional heat at the weld line however pin geometry was responsible for the shearing and forward moving of the plasticize material from the leading edge to the trailing edge of the weld zone.[8] Thus for more sound weld with good mechanical properties and defects free weld, shoulder geometry plays crucial role. Since its begging, flat, concave and convex type shoulder features with different pin geometries are considerably use for research. [9, 10, 11, 12] Apart from above shoulders, Galvao et al. [9] done the Friction Stir Welding of 1 mm thick copper sheets with the help of concave, flat and scroll shoulder. They found that scroll shoulder features gives higher heat generation, higher hardness and sound grain structure compared to other two. Scialpi et al. [11] investigated the effect of various shoulder with round pin on 6082 aluminum alloy plated and noted substantial up and down in the heat generation and size of weld zone. In addition, Leal et al. [12] experimented scrolled shoulder geometry and come out with statement that scrolled geometry moves the plasticized material in proper way which leads proper mixing and keep the material under the shoulders. Biswas et al. [13] studied the friction Stir Welded aluminum alloy joint and concluded that tool pin is only responsible for material deformation. Also, they noted that shoulder plays key role in plasticize the base metal instead of pin probe. The comparative study conducted by Khodaverdizadeh et al. [14] between two different pin geometry named square and threaded shape. They noted that square pin geometry gave more superior properties compared to threaded pin geometry due to the eccentricity. The effect of shoulder end geometries on heat generation and temperature distribution studied by Mugada et al. [15] and they pointed out that shoulder end features gives more proper heat flow and material distribution instead of flat or featureless shoulder tools.

Thus, so may research has been done which addressing the effect of different pin geometries on friction stir welded zone of workpieces. Therefore, current paper represents the effect of six different shoulder geometries with square pin probe on the friction stir welded 6082 T6 aluminum alloy.

II. EXPERIMENTAL MATERIAL AND METHOD

In present research, Friction Stir Welding process carried out on 6082 T6 aluminum alloy plates which was 5 mm thick with 300 mm length and 75 mm width as shown in figure (3). The chemical composition of 6082 aluminum alloy is listed in table (1). Magnesium and silicon are the main two alloying elements of 6082 T6 aluminum alloy which increase its strength, ductility and toughness. Due to these enhanced properties of 6082 aluminum alloy, it takes the place of 6061 aluminum alloy in many applications. It is also known as structural alloy due to its properties which are listed in table (2). To join these plates, six different FSW tools were designed as shown in figure (5), which made from H-13 die steel material. Basic dimensions of the tools are schematically representing in figure (4).

Table 1: Composition of 6082 T6 aluminum alloy (%)

Material	% Composition
Al	95.2 – 98.3
Si	0.7 – 1.3
Mg	0.6 – 1.2
Mn	0.4 – 1.0
Fe	0.5 Max
Cr	0.25 Max
Zn	0.2 Max
Ti	0.15 Max
Cu	0.1 Max
Other	0.05 Max

Table 2: Properties of 6082 T6 Aluminum Alloy

Properties	Value in Matric Unit
Yield Strength	260 MPa
Ultimate Tensile Strength	310 MPa
Elongation (%)	10 %
Hardness (HV)	95
Melting Point	555 ˚C
Density	2.7 g/cm3
Thermal Conductivity	167 W m-1 K-1

Table 3: Chemical Composition of H13 Die Steel (%)

Cr	Mo	Si	V	C	Ni	Cu	Mn	P	S
4.7 – 5.5	1.1 – 1.7	0.8 – 1.2	0.8 – 1.2	0.3 – 0.4	0.3	0.25	0.2 – 0.5	0.03	0.03

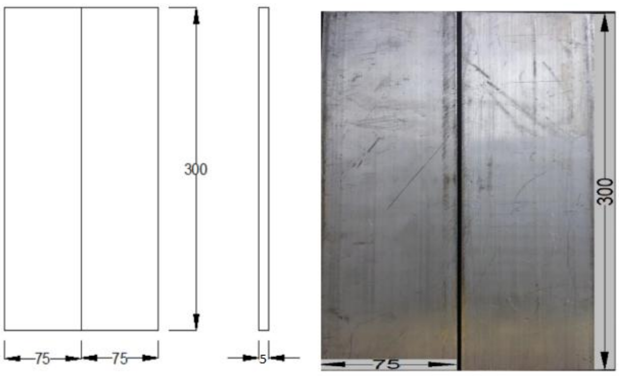


Fig. 3: Workpiece Material with Dimension (mm)

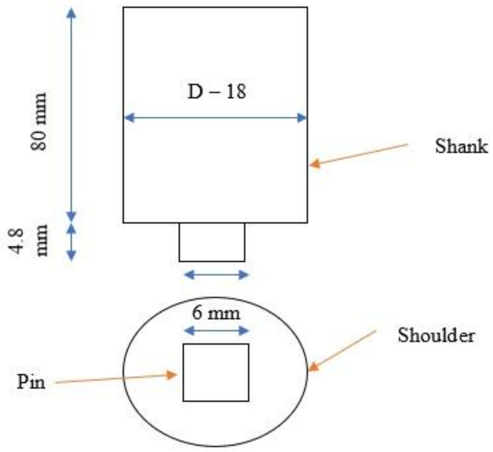


Fig. 4: FSW Tool Design (all dimensions are in mm)

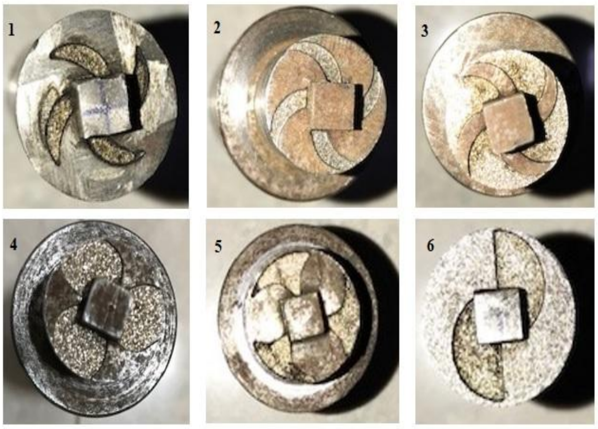


Fig. 5: Six Different Friction Stir Welding Tools

Table 4: Process Parameters

Process Parameters	Symbol	Unit	Level 1	Level 2	Level 3
Tool Rotation Speed	N	RPM	600	800	1000
Tool Travel Speed	V	Mm/min	35	45	55

Based on trial experiments, the process parameters were selected with various levels, which are listed in table (4). The welding experiments were carried out on Jyoti PX 10 Vertical Machining Centre (VMC) at Chandubhai S. Patel Institute of Technology, CHARUSAT University, Changa, Gujarat. This 3-axis Vertical Milling Centre machine equipped with SINUMERIK 802 D SL Controller. Figure (6) shows the experimental setup of the Friction Stir Welding. VMC machine has the maximum spindle rotation speed around 8000 RPM with maximum table load 400 kg.

Fig. 6: FSW Welding Experiment Setup on VMC

Proper planning of the experiment is needed to avoid unnecessary experiments. To do proper design of experiment, taguchi method is used in current work. Here, Taguchi method is only used to optimization of the input variables. Following table (5) represent all the combination of input variables for all the six tools individually. Thus, overall 54 welding experiments were performed. After completion of all the experiments, tensile and hardness testing samples were extracted perpendicular to the weld zone to interpret the quality of the welding. All the samples were cut as per the ASTM E8 standard through abrasive water jet machining (AWJM) to avoid excess heating of the weld zone. Figure (7) indicate the standard dimensions of the sample specimens. Tensile test and hardness test were performed at room temperature on universal testing machine and micro-hardness tester respectively to measure the mechanical properties.

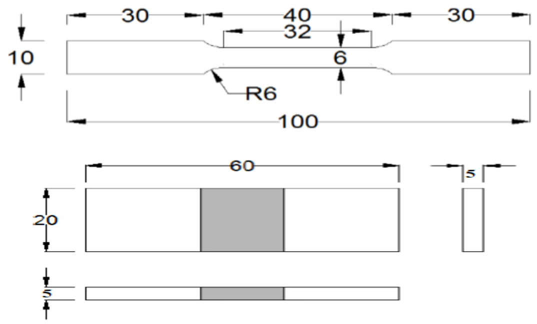


Fig. 7: Specimen for Tensile test and Hardness Test [16]

Table 5: Design of experiments

Experiment No.	Tool Rotation Speed (RPM)	Tool Travel Speed (mm/min)
1	600	35
2	600	45

3	600	55
4	800	35
5	800	45
6	800	55
7	1000	35
8	1000	45
9	1000	55

III. RESULT AND ANALYSIS

As per design of experiment, all the experiments were performed on VMC. To interpret the weld quality, tensile test and hardness test were performed on those specimens which are cut down as per ASTM standard. Initial the visual inspection was done, to analyst the roots and crown of the welding. Key hole was also inspected as per Lloyd's register [17]. The impression of the pin of FSW tool due to its plunging action is always remain there on weld zone. With the 100 % complete key hole, the possibility of getting sound weld is increase. So, appearance of weld top surface gives the detail about the weld quality. So, quality analysis of top surface of welded workpiece has been done through visual inspection. It demonstrated that all the welded specimens have no deformities. Figure (8) represent the top surface (crown) of welded workpiece through six tools at higher tool rotation speed. From observation of crown of different specimen, tool 3, 4 and 5 gives smooth weld surface with little flash. Whereas, tool 1,2 and 6 generate higher flashes which is remove as continuous chip as shown in figure (8). The UTS (Ultimate Tensile Strength – MPa) of the weld specimen evaluated as per the L9 orthogonal array experimental design for each tool as shown in table (2). Combination of process parameters are also given in the same table. The tensile strength obtained from experiments are represented in the graphical form as shown in figure (10). To avoid the measurement error, three ultimate tensile strength specimens were measured. Figure (9) shows actual tensile test specimens of the weld zone. So, graphs of tensile strength represent average UTS values. The joint efficiency of the weld specimens is defined as the ration of UTS of the fabricated joint to the UTS of the base metal. The highest tensile strength 240.42 MPa obtained through tool 3 with tool rotation speed 1000 RPM and 35 mm/min welding speed as shown in graph (10). Shoulder geometry of Tool – 3 generate higher frictional heat and proper stirring action compared to other tools. Also, the substantial increment in tensile strength is observed from all the graphs with increment in tool rotation speed from 600 to 1000 RPM. Also, concluded that every raise tool gives higher tensile strength compared to recessed tool features.

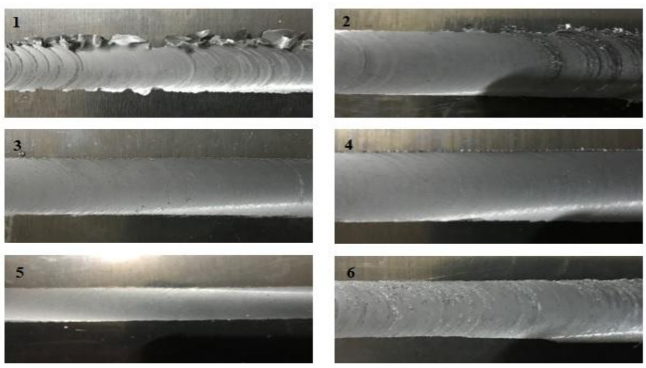


Fig. 8: Crown Get from Six Different Tools

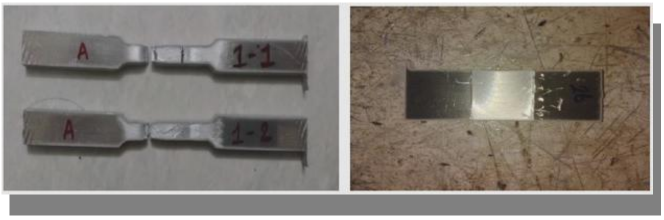
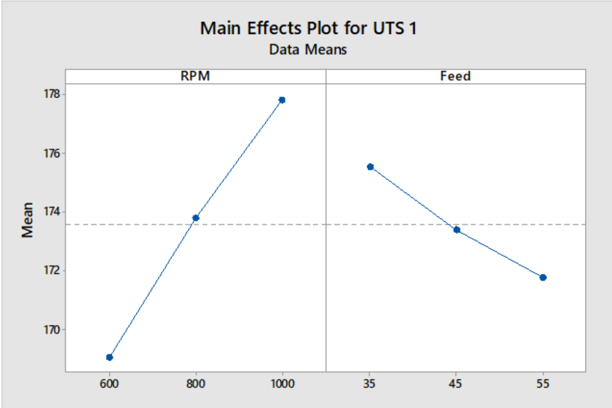
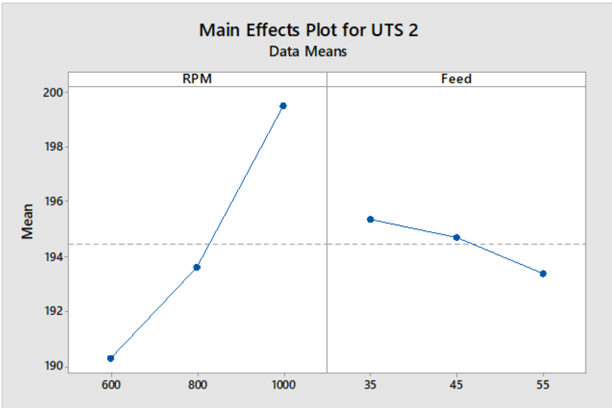
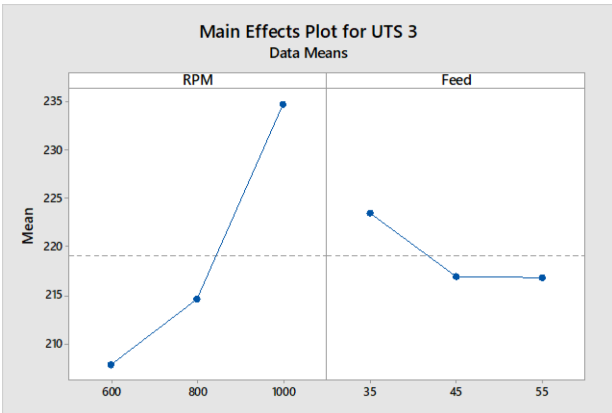


Fig. 9: Atual Specimen of Tensile and Hardness Specimen







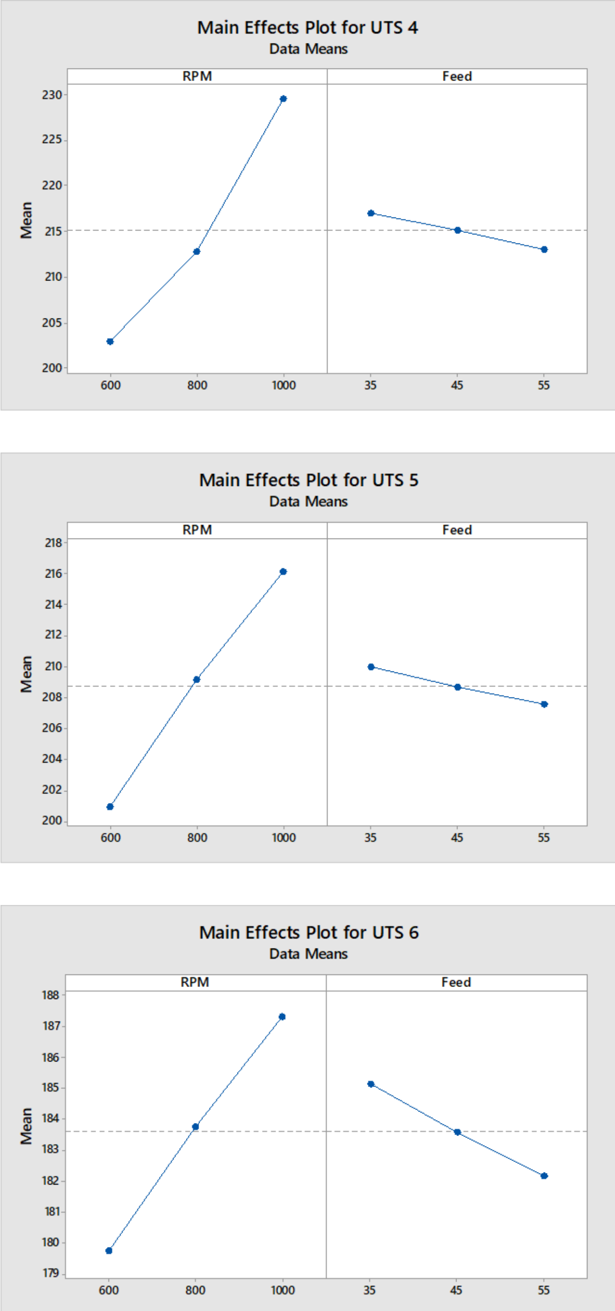
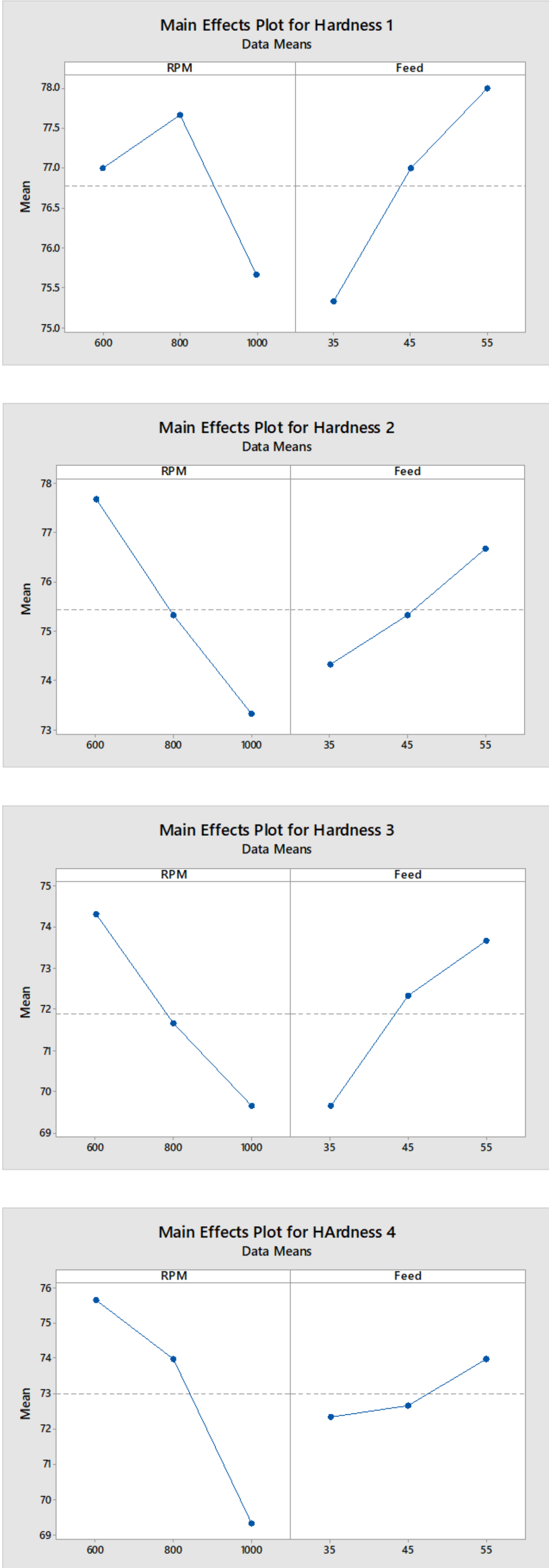
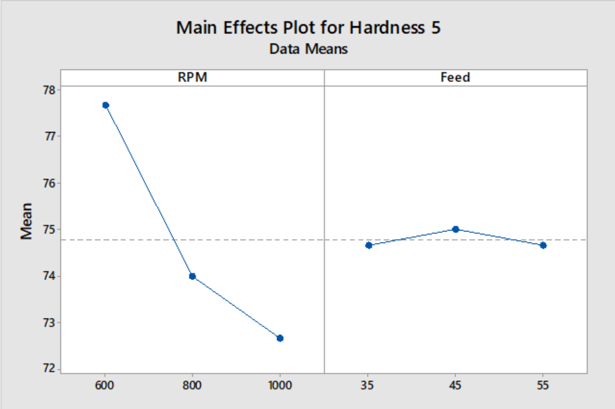


Fig. 10: Graph ection Plot between RPM & Feed vs UTS

Micro-hardness value was obtained from the mid-section of the welded workpiece. Obtained micro hardness values longitudinal to the fabricated zone by using various tool geometries shown in figure (11). These graphs show the significant effect of variation in the tool profile in the weld zone and heat affected zone (HAZ). Base metal specimens were T6 heat treated condition, also its reflection can be observed in micro – hardness distribution over a length. Due to the initial cold and worm condition, more hardness was experiential on advancing side (AS) compared to retreating side (RS) and also observed the higher temperature on the advancing side (AS). Figure (9) schematically shows actual micro – hardness specimens. From following graphs, the significant increment in micro-hardness of the weld zone is observed with increment in tool travel speed. Also, the hardness obtained from the weld zone is always lower compared to base metal hardness and the range of it is 65 – 80 HV.





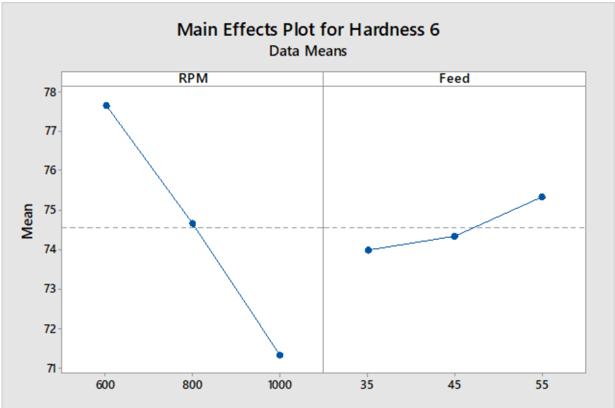


Fig. 11: Graph of RPM &Feed vs Micro-Hardness

IV. CONCLUSION:

In present work, a study has been carried out the effect of six different shoulder geometry with the square pin profile at different machine parameters (Welding tool rotation speed: 600, 800, 1000 RPM and tool travel speed: 35, 45, 55 mm/min). By using these tools, 5 mm thick 6082 – T6 aluminum alloy plates were welded and analyst. From visual evaluation of the crown or upper surface of the weld zone, it was summaries that all different tool shoulder geometry develops very diverse crown quality. From observation of crown, Tool 3 develop perfect onion ring surface with tiny flash which is removed as a continuous chip formation. Therefore, visual inspection concluded that shoulder geometry number three produce sound quality weld in the form of crown. Also, the tensile strength is measured and compared with the strength of the base metal. From this test, it is concluded that tensile strength of the weld zone significantly affected by shoulder geometry. Because shoulder geometry has maximum contact area with weld zone and 80 – 85 % of total heat is generated by it. Experimental results show that tool 3 and 4 gave higher strength compared to other tool shoulder geometries. During this study, maximum 80 % tensile strength is achieved compared to base metal by using tool 3. Micro-hardness test was carried out to measure the hardness of the weld zone. Through these different shoulder geometry, lower hardness is obtained compared to base metal. This shows that friction stir welding increase the flexibility or softness of the metal being weld. Therefore, Shoulder geometry of tool – 3 considered best tool among above listed six tools with 1000 rpm and 35 mm/min tool travel speed due to its ability of generating high frictional heat and good stirring action during the weld. Tool – 3 provide higher tensile strength around 240.42 MPa with 68 HV with good crown surface.

REFERENCES

1. Verma, S., and J. P. Misra. "Study on temperature distribution during Friction Stir Welding of 6082 aluminum alloy." Materials Today: Proceedings 4.2 (2017): 1350-1356.
2. Hwang, Yeong-Maw, et al. "Experimental study on temperature distributions within the workpiece during friction stir welding of aluminum alloys." International Journal of Machine Tools and Manufacture 48.7-8 (2008): 778-787.
3. Hwang, Y. M., P. L. Fan, and C. H. Lin. "Experimental study on Friction Stir Welding of copper metals." Journal of materials processing technology 210.12 (2010): 1667-1672.
4. Song, M., and R. Kovacevic. "Thermal modeling of friction stir welding in a moving coordinate system and its validation." International Journal of machine tools and manufacture 43.6 (2003): 605-615.
5. Maeda, M., et al. "Temperature field in the vicinity of FSW-tool during friction stir welding of aluminum alloys." Welding in the World 49.3-4 (2005): 69-75.
6. Rajamanickam, N., et al. "Effect of process parameters on thermal history and mechanical properties of friction stir welds." Materials & Design 30.7 (2009): 2726-2731.
7. Friction Stir Welding, Technical Handbook, ESAB AB, Welding Automation, SE-695 81, LAXA, Sweden.
8. Schmidt, H., Jesper Hattel, and John Wert. "An analytical model for the heat generation in friction stir welding." Modelling and Simulation in Materials Science and Engineering 12.1 (2003): 143.
9. Galvão, I., et al. "Influence of tool shoulder geometry on properties of friction stir welds in thin copper sheets." Journal of Materials Processing Technology 213.2 (2013): 129-135.
10. Cederqvist, Lars, et al. "Improved process stability during friction stir welding of 5 cm thick copper canisters through shoulder geometry and parameter studies." Science and technology of welding and joining 14.2 (2009): 178-184.
11. Scialpi, A., L. A. C. De Filippis, and P. Cavaliere. "Influence of shoulder geometry on microstructure and mechanical properties of friction stir welded 6082 aluminum alloy." Materials & Design 28.4 (2007): 1124-1129.
12. Leal, R. M., et al. "Material flow in heterogeneous friction stir welding of thin aluminum sheets: effect of shoulder geometry." Materials Science and Engineering: A 498.1-2 (2008): 384-391.
13. Biswas, P., D. A Kumar, and N. R. Mandal. "Friction stir welding of aluminum alloy with varying tool geometry and process parameters." Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 226.4 (2012): 641-648.
14. Khodaverdizadeh H, Heidarzadeh A, Saeid T. Effect of tool pin profile on microstructure and mechanical properties of friction stir welded pure copper joints. Mater Des 2013; 45: 265–70.
15. Mugada, Krishna Kishore, and Kumar Adepu. "Role of tool shoulder end features on friction stir weld characteristics of 6082 aluminum alloy." Journal of The Institution of Engineers (India): Series C (2018): 1-8.
16. Kumar, S. Senthil, S. Denis Ashok, and S. Narayanan. "Investigation of friction stir butt welded aluminum alloy flat plates using spindle motor current monitoring method." Procedia Engineering 64 (2013): 915-925.
17. Przydatek, J. "A ship classification view on friction stir welding." First International Symposium on Friction Stir Welding. Thousand Oaks, CA. Cambridge, UK: The Welding Institute Ltd. 1999.

AUTHORS PROFILE

Saumil K. Joshi. Currently pursuing Ph.D. in Mechanical Engineering Department at Madhav University, Rajasthan, India. Published 8 research paper as well as review paper in different international journals and conferences. Also, completed Master of Engineering and Bachelor of Engineering from Gujarat Technological University (GTU), Ahmedabad, India in 2016 and 2014 respectively.

Dr. Namjoshi Sadanad working as a Professor in Mechanical Engineering Department at Madhav University, Rajasthan, India. Awarded Ph.D. degree from Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat. He has total 16 years of academic experience Also having so many research paper publications in different international journals and conferences. Currently he is guiding 7 research scholars.

Dr. Deepak Paliwal working as Professor at Mechanical Engineering Department, Geetanjali Institute of Technical Studies, Udaipur, Rajasthan, India. He was awarded Ph.D. from Sir Padampat Singhania University (JK Group), Udaipur, India in 2014. He has total 11 years academic experience in different institution and 2.5 years industrial experience. He published around 20 research papers in different well-known international journals.