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Effect of Shoulder Diameter and Pin Profile on Mechanical Properties of Al 6061 Alloy Processed By Friction Stir Processing

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Abstract - *The aim of this experiment was to improve the mechanical properties of 6061 aluminium alloys by friction stir processing (FSP), a solid-state technique for micro structural modification using the heat from a friction and stirring. Welding is main fabrication method of 6061 alloy for manufacturing various engineering components. Friction stir welding (FSW) is a recently developed solid state welding process to overcome the problems encountered in fusion welding. This process uses a non-consumable tool to generate frictional heat on the abutting surfaces. The welding parameters, such as tool pin profile, rotational speed, welding speed and axial force, play major role in determining the micro structure and corrosion resistance of welded joint. In this work a central composite design with two different speeds, traverse speeds and Four tools has been used to minimize the experimental conditions. The suitable taper angles found in this regard are in the order of 30°, 60°and 45° and 15°along with other process parameters (speed of rotating specimen - 775 rpm , Axial load-3 MPa and Forge pressure- 5 MPa) to obtain friction welded joints having comparable desired mechanical characteristics with the parent metal. Further analyzed the BHN Hardness values and tensile test.*

Key Words: Friction Stir Processing, Shoulder Diameter, Pin Profile, Rotational Speed andTraverse Speed.

1.INTRODUCTION

Friction stir processing (FSP) was developed based on the principles of friction stir welding (FSW) which was developed and patented by The Welding Institute Ltd, Cambridge, UK in 1991. FSP is a solid-state welding, micro structural modification technique using a frictional heat and stirring action, has recently attracted attention for making aluminum alloys with an excellent specific strength, and its studies have been actively performed. Friction Stir processing is a special technique to improve the micro structure in the solid state by using the heat from friction for the aluminum-casting alloy, which has a higher specification. It was initially applied to aluminum alloys. The basic concept of FSW is remarkably simple. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. A rotating piece is defined as the tool, which designed and manufactured to plastically deforming the processed zone and produce heat due to stirring action between work piece and the tool pin. The tool consists mainly three parts such as tool pin, shoulder and the shank. The angle of the tool as compare to the vertical direction is known as tilt angle. The trailing and leading edge will be used to differentiate between the rear and front limb of the tool as the front is described as the direction of travel.

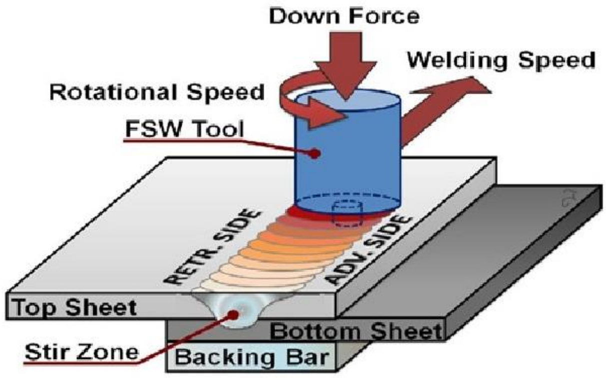

Figure 1.1: Schematic drawing of friction stir welding

2. LITERATURE REVIEW

S. Chainarong and S. Suthummanon[1] The Material used in the experiment is a SSM 356 aluminum alloy. The cylindrical pin used as the stirring tool. The tool has a shoulder diameter. pin diameter. And pin length of 20 mm, 5 mm and 3.2 mm, respectively. And these Scholars was taken as the parameters of friction stir processing for SSM 356 aluminum alloys were studied at three different traveling speeds: 80, 120 and 160 mm/min under three different rotation speeds 1320, 1480 and 1750 rpm.These Scholars was conclude by this experiment is the surface of specimen is improved by the friction stir process. However, investigation did not find any defects with the stirred. The hardness of the area was influenced by the thermal both retreating and advancing with increased hardness for all experimental conditions compared to that of base metal. But for the stir zone, the hardness can be either increased or decreased. The condition that increased the hardness is traveling speed at 120 and 160 mm/min with any rotation speed. The condition that reduced the hardness is travel speed at 80 mm/min with any rotation speed. The highest hardness, obtained at 1750 rpm with travel speed at 160 mm/min. An increase of 59.07% compared to the base metal. The average maximum tensile strength after using friction stir processing is equal to 188.57 MPa, an increase of 11.8% compared to the base metal. It was found that the conditions providing strength to pull up the average is at the speed around the 1750 rpm and at the travel speed at 160 mm/min.

S. Ramesh Babu et.al [2] The base metal used in this investigation is the extruded AZ31B grade magnesium alloy. The maximum tool rotational speed of 2500 rpm, maximum traversing speed of 135 mm/min. The two friction stir tool composed of a pin with a diameter of 6mm, pin length of 5.8 mm and shoulder diameter of 18 mm and 24 mm respectively.These scholars was tells in this experiment is The various defects and tensile strength of the friction stir processed material depends upon the combination of tool axial force, tool rotational speed, tool traversing speed and tool shoulder diameter. To eliminate the defects in the processed region, tool shoulder diameter is more significant and for the maximum tensile strength and micro hardness, tool traversing speed is the most significant parameter.

N. Saini et.al[3] Hyper-eutectic Al-Si alloy is in much more in demand due to theirhigh wear resistance, low strength to weight ratio and not much work done on the hyper-eutectic Al-Si alloys. So, these were selected as material is Hyper-eutectic Al-Si alloy. The tool geometry is was very simple with cylindrical tool i.e. shank diameter 25 mm, shoulder diameter 18 mm, pin diameter 8 mm, pin length 3.5 mm. These input process parameters used for fixed tool rotation speed of 664 rpm and variable welding speed of 26, 40 and 60 mm/min.The scope of this investigation is to evaluate the effect of input process parameters of friction stir processing to enhance the mechanical and tribological performance of the cast hyper-eutectic Al-17%Si alloy. The results were compiled by using optical microscope, hardness, tensile and EDX analysis. The results shows at the optimal input conditions of friction stir processing, the micro structure of cast alloy has been improved in terms of refinement of eutectic and primary Si particles, uniform distribution of Si and the reduction in porosity. In addition, the hardness and tensile properties were improved; the tensile elongation has been increased from less than 2 % to about 9 %.

S.Ugender ,A Kumar and A Somi Reddy [4] The base metal selected in this experiment is AA 2014 Aluminum alloy. The diameter of tool shoulder is 18 mm, pindiameter and pin length is 6 mm and 4.8 mm. Tool rotation and traversing speeds are 900rpm and 40mm/min. FSW of Al alloy using taper cylindrical pin profile was used.These scholars tells in this experiment is a With the proposed analytical approach one can directly see the peak temperature for respective taper probe angle under given process conditions which will be helpful for predicting mechanical properties for that Al alloy and hence elimination of post weld testing cost and time. If both shoulder diameter and rotational.Pin diameter increase, the flow velocity of material will also increase Moreover, an increase of the shoulder diameter can improve the flow velocity of material near the weldment surface while an increase of the pin tip diameter can be good for the material inside the weldment.

I. Sudhakar et.al [5] Base metal AA7075-T6 aluminum alloy of size 500x500x40mmWas used in the present investigation and its chemical composition. It can be concluded that friction surfacing can be successfully used to deposit hard boron carbide powder on the surface of Armour grade AA7075 alloy. Thus the metal matrix surface composite layer improved the ballistic efficiency/performance of AA7075 alloy.In this experiment these scholars discussing Friction stir processing of AA7075aluminum alloy resulted in fine and uniform micro structure consisting of carbide particles in matrix. The friction stir processing of AA7075 alloy with boron carbide powder significantly improved the wear resistance over that of the base metal. Particle size of boron carbide was found to affect the wear resistance of substrate, and the maximum wear resistance was achieved with particle size of 30 mm. Significant improvement in ballistic performance has achieved after friction stir processing of AA7075 alloy along with boron carbide particles and molybdenum disulfide. Observed result is attributed to the improvement of hardness and wear resistance, and very low friction coefficient. For the first time, the present work demonstrated successfully that the friction stir processing route is an effective strategy for enhancement of ballistic performance of AA7075 aluminum alloy which finds wider range of defense applications.

3.1 CHEMICAL COMPOSITION OF AA2219

Element	Cu	Si	Mn	Zn	Zr	Mg	Va	Ti
Minimum (%)	5.8	-	0.2	-	0.25	-	0.15	0.2
Maximum (%)	6.8	0.2	0.4	0.1	1	0.1	0.5	0.1

3.2 MECHANICAL CHARACTERISTICS OF AA2219

Density(10^3Kg=m^3)	0:6 - 2:8	Poisson's ratio	0:33
Elastic Modulus (GPa)	70 -80	Ultimate tensile strength (MPa)	440
0.2%Yield strength (MPa)	350	Percentage elongation	6

Fatigue strength (MPa)	105	Thermal conductivity (Wm-K)	170

3.3 MICROSTRUCTURAL CHARACTERISTIC STUDY

The micro structure specimen of 20 x 10 x 5 mm has been cut from each test coupon. The procedure carried out for the microstructure studies are as follows.

i) Samples for metallography examination have been cut transversely to the welding direction from length of the joints.

ii) The samples have been cold mounted and then wet grounded using successively finer grades of SiC impregnated emery papers.

iii) The samples have been mechanically polished using 6, 3 and finally 1 diamond paste as the lubricant on polishing cloths.

iv) Macroscopic examination has been carried out by etching the specimen using a caustic etch, i.e.10g NaOH in 90 ml H_2O with 50% HN O_3 solution and a final rinse in water.

v) Kellers reagent has also been used for the microscopic examination.

vi) The microstructure has been observed under Olympus optical microscope.

3.4 COMPARISON OF FRICTION STIR WELDED AND CW JOINTS

DCSP TIG, DCRP (Direct Current Reverse Polarity) TIG and ACSQW TIG welding are the different versions of TIG welding techniques, conventionally used to join aluminium alloys.DCSP TIG welding is mainly used for the aluminium alloys with thickness equal or greater than 5 mm. DCRP TIG welding is usually used to join aluminium alloy plates with thickness less than 5 mm.In DCSP TIG welding, the job (weld plate) is connected to positive lead of weld transformer and electrode is connected to negative terminal. The current is steady and the electron flow is from electrode to job. As more electrons are hitting the job, more heat will be produced at job rather than at electrode. This results in melting of job with less heat input and better weld strength. Even though the refractive oxide layer is a major problem for this, it can be eliminated by scrapping the weld joint well before welding. In the case of DCRP TIG welding more heat is generated at electrode than job. Figure 3.8 represents DCSP TIG and DCRP TIG weld formation. In ACSQW TIG welding the job and electrode are getting connected alternately

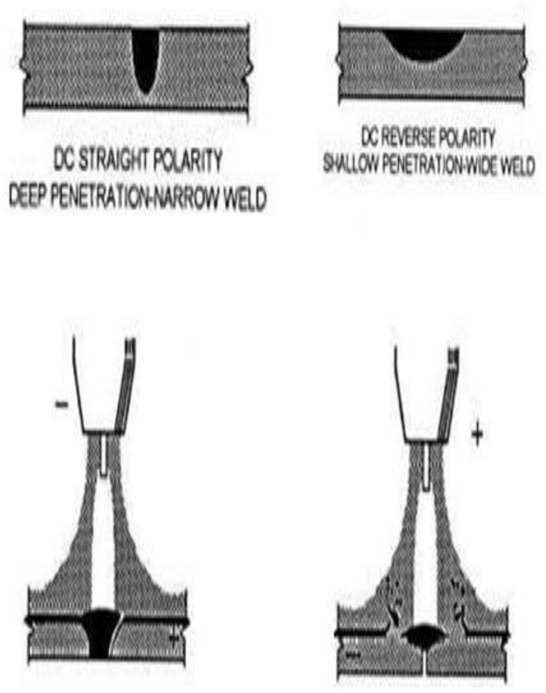

Figure.2 DCSP TIG and DCRP TIG weld formation

With positive and negative leads of welding transformer. Hence it offers less heat input in one cycle and in another cycle good cleaning of refractive aluminum oxide can be made.The dispersion of denser particles in HAZ and WZ looks like the tip of a firing bullet. In the stationary specimen side, towards the HAZ it is seen like a piercing effect. In addition to the above observation it is also seen that all other regions are equally dispersed with denser particle. Due to that, those areas are not easy to distinguish with parent material particles. This may be the reason for the equal hardness with the parent metal, its high tensile strength and torsion compared to friction welded joints with other interface taper angles.

Table 3.4: Details of DCSP TIG and ACSQW TIG welding

Sl No	Welding features	Details
1	Name of welding Machine	Miller Make
2	Name of Material used	AA2219 Alloy
3	Size of the specimen	300 X 300 mm

4	Name of filler Material used	ER2319
5	Welding Parameters	Current:210-230A (DCSP),180-220A(ACSQW) Voltage: 18-20 V (DCSP),17-19 V (ACSQW) Travel speed:70-130 mm /min Shielding Gas (DCSP): Helium, (ACSQW) Shielding Gas (ACSQW):Argon+Helium (80:20) Backup bar: Stainless steel

3.5 COMPARISON OF JOINTS BY FSW AND CW

ACSQW TIG welding involved mainly three factors with 3 levels. Hence L9 Taguchi orthogonalarray has been fixed. Table 3.5 represents the parameters with various levels used to obtain the ACSQW TIG welded joints with response as the tensile strength of each joints. ACSQW TIG welded joints have been made. Three tensile test specimen as per ASTM E8 standard have been prepared from each and found out the average value of tensile strength.

The signal to noise ratio - larger the best option has been selected to optimize the ACSQW TIG welding process parameters. Based on the analysis high response values have been obtained for welding current as 200A, voltage as 18 V and welding speed as 100 mm/minutes.

Since this combination is not in the L9 orthogonal array a confirmation test has been carried out. According to that the values for UTS strength obtained is 252.51N=mm^2. Since this welding techniques has considered only for the comparative study of tensile characteristics with friction welded joints, influence of its welding parameters has not been investigated further. However from the response table for UTS based on Taguchi (has not presented here) it is observed that the priority of influencing parameters are current, voltage and welding speed respectively.

Table 3.5: **Taguchi L9 - response table for ACSQW TIGW joints**

Sl No	Welding Current (A)	Voltage (V)	Welding speed (mm/minute)	Ultimate Tensile Strength (Mpa)
1	180	17	90	247.78
2	180	18	100	248.05
3	180	19	110	247.86
4	200	17	100	252.51
5	200	18	110	246.84
6	200	19	90	250.63
7	220	17	110	239.39
8	220	18	90	236 .98
9	220	19	100	236.57

Table 3.6: Taguchi L9 - response table for - DCSP TIG welded joints

Sl No	Welding Current (A)	Voltage (V)	Welding speed (mm/minute)	Ultimate Tensile Strength (N=mm^2)
1	210	18	80	257.00
2	210	19	100	255.00
3	210	20	120	249.51
4	220	18	100	256.56
5	220	19	120	262.76
6	220	20	80	262.01
7	230	18	120	253.68
8	230	19	80	248.75
9	230	20	100	260.25

4. RESULTS

Three tensile test specimen as per ASTM E8 standard have been prepared from each and found out the average value of tensile strength. The signal to noise ratio - larger the best option has been selected to optimize the ACSQW TIG welding process parameters. Based on the analysis high response values have been obtained for welding current as 200A, voltage as 18 V and welding speed as 100 mm/minutes. Since this combination is not in the L9 orthogonal array a confirmation test has been carried out. According to that the values for UTS strength obtained is 252.51N=mm^2. Since this welding techniques has considered only for the comparative study of tensile characteristics with friction welded joints, influence of its welding parameters has not been investigated further. However from the response table for UTS based on Taguchi (has not presented here) it is observed that the priority of influencing parameters are current, voltage and welding speed respectively.

Table 3.7: Tensile test results of friction welded and CW joints

welding technique	Ultimate Tensile Strength (MPa)	Yield strength (MPa)	Percentage Elongation
Friction Stir Welding	293.0	166.8	8.4
ACSQ wave TIG welding	252.5	158.0	5.4
DCSP TIG welding	265.0	165.0	6.4

3.8 Influence of Interface Surface Geometries

A number of researches have been conducted by various researchers on FW. Major studies includes the mechanical and microstructure characteristics of friction welded joints from similar and dissimilar metal combinations.

Almost all the research works are discussing about the optimization of process parameters especially speed of rotating specimen, axial loading on stationary specimen and upset loading. Research work related to the study on the influence of interfacing surface geometry on the characteristics friction welded joints are seen very less. Hence present study mainly aimed to check whether the interface geometry influence the characteristics of friction welded joints.

Various interface surface geometries considered are Flat-Flat (F-F), Taper-Taper (T-T), Convex-Convex (Cx-Cx) and Convex-Concave (Cx-Cv). Different speeds considered are 500, 775, 1000 and 1200 rpm. Various axial loading considered are 2, 2.5, 3 and 3.5 kN. Figure 3.21 shows various combinations used under this study. FW process has been carried out as

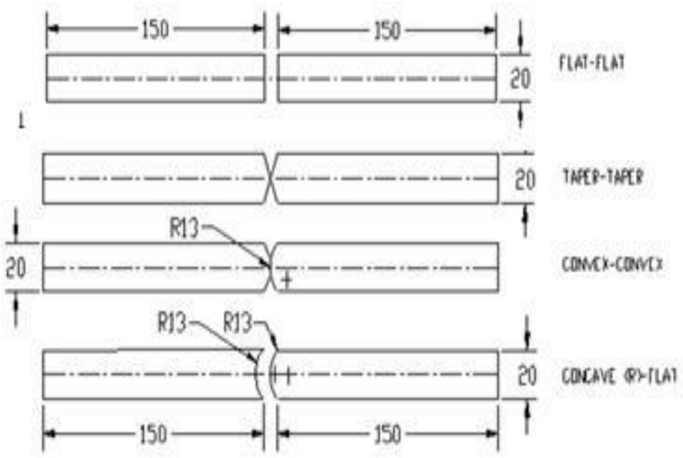

Figure 3.21: Interface geometry combinations for FW

5. CONCLUSION

The major conclusions derived based on the experimental and numerical investigations in this research work on FSW and FW are as follows. A conventional vertical milling machine has been converted in to FSW setup and friction welded joints of AA2219 alloy have been produced. Based on the tensile characteristics studies, it is found that friction welded joints have possessed higher tensile strength than conventionally welded joints by ACSQW TIG and DCSP TIG welding techniques. From the microstructure studies, it is also found that friction welded joints have not exhibited clear distinct phase changes in WZ, HAZ and parent metal region compared to conventionally welded joints. This is a strong indication of effective joints with less stress concentration and comparatively similar microstructure with the parent metal. Hence from the experimental investigations on FSW it is concluded that FSW is an effective joining technique for low weight and high strength material like Aluminum alloys. A conventional medium duty lathe has been converted into FW setup and produced friction welded joints of Al6061 alloys. Based on the experimental investigations using Taguchi analysis. It is also found that, friction welded joints formed with suitable interface taper angle can achieve desired strength characteristics with respect to the required industrial application. The microstructure characteristic studies also support these findings. Hence from the experimental investigations on FW, it can be concluded that 107 high quality friction welded joint can be produced with medium speed for the rotating specimen and suitable modifications in the interface geometry.

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