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Microscopic Behavior of Friction Welding of Aluminium 6061 and Stainless Steel-316

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ABSTRACT: Friction welding is a solid state type welding process which produces a blend of Materials by the heat obtained from mechanically-induced type sliding motion between rubbing surfaces. Work parts are put under pressure. Two pieces rotate in contact and heat necessary for welding is generated on the friction plane. Frictional heat obtained from rubbing two bodies generates heat. Mechanical heat obtained from two work pieces used to weld the work type. The materials used were Aluminum 6061 and Stainless Steel - 316. Burn off length was controlled on the dial indicator. To bracing the result a Temperate torch was used. Weld time, RPM & Burn off length shows different variations at two different levels. Length and diameter of the specimen were kept fixed. Total number of experiments conducted was eight. After friction Microscopic behavior (Microstructure, Micro hardness) of the welded region was analyzed. The Microscopic behavior with the friction welding parameters was Aluminium 6061Steel 316 studied in this work.
Keywords: Friction welding, Microscopic behaviour, Micro hardness, Microstructure, Weld time, Hardness measurement

I. INTRODUCTION

Friction welding usually joins two metals under the pressure or heat. Two pieces rotate in contact and heat necessary for welding is generated on a friction plane. Friction welding usually uses rotation of one component at rpm and another piece is to be brought in contact under high pressure.. The machine for the friction welding is similar to a vertical milling machine. This rapidly easily controlled & easily mechanized process has been used extensively in the automotive industry such as half shafts and bimetallic weld. The Fundamental principle of friction welding is to use the heat generated through motional friction to produce a clean joint, without the formation of a liquid phase. This contact force first generates heat at the interface. Once the material has become sufficiently soft, the forging pressure applied against the two components forces the heated interface material into the flash, removing any surface contaminants and producing a clean joint. The solid-state nature opens opportunities for joining materials previously considered to be UN weld able and dissimilar materials.Process parameters of Friction Stir welding: The parameters that affect the quality and outcome of the TIG welding process are given below.

a) Welding Current: Higher current in Friction Stir welding can lead to splatter and work piece become damage. Again lower current setting in Friction Stir welding lead to sticking of the filler wire. Sometimes larger heat affected area can be found for lower welding current, as high temperatures need to applied for longer periods of time to deposit the same amount of welding equipment. A high initial voltage allows for easy arc initiation and a greater range of working tip distance. Too high voltage, can lead to large variable in welding quality.
b) Inert Gases: The choice of shielding gas is depends on the working metals and effects on the welding cost, weld temperature, arc stability, weld speed, splatter, electrode life etc. it also affects the finished weld penetration depth and surface profile, porosity, corrosion resistance, strength, hardness and brittleness of the weld material. Argon or Helium may be used successfully for TIG welding applications. For welding of extremely thin material pure argon is used. Argon generally provides an arc which operates more smoothly and quietly.
c) Welding speed: Welding speed is an important parameter for Friction Stir welding. If the welding speed is increased filling materials.

Fixed current mode will vary the voltage in order to maintain a constant arc current.

d) Welding Voltage: Welding Voltage can be fixed or adjustable depending on the Friction Stir

e) Power or heat input per unit length of weld is decreases, therefore less weld reinforcement results and penetration of welding decreases. Welding speed or travel speed is primarily control the bead size and penetration of weld. It is interdependent with current. Excessive high welding speed decreases wetting action, increases tendency of undercut, porosity and uneven bead shapes while slower welding speed reduces the tendency to porosity.

Properties and advantages of Al:

Aluminium is a very light weight metal (specific weight of 2.7 g/cm^3). Use of aluminium in automobile and aerospace reduces dead-weight and energy consumption. Strength of Aluminium can be improved as per the required properties for various applications by modifying the composition of its alloys. Aluminium is a highly corrosion resistant material. Different types of surface treatment can further improve its corrosion resistance property. Aluminium is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor as copper. This has made aluminium the most commonly used material in major power transmission lines. Aluminium is ductile and has a low melting point. In a molten condition it can be processed in a number of ways. Its ductility allows products of aluminium to be basically formed close to the end of the product's design.

II. LITERATURE SURVEY:

Mumin Sahin [2013] [21] an experimental set-up was designed in order to achieve friction welding of plastically deformed austenitic-stainless steels. AISI 3016 austenitic-stainless steels having equal and different diameters were welded under different process parameters. Strengths of the joints having equal diameter were determined by using a statistical approach as a result of tension tests. Hardness variations and microstructures using scanning electron microscope (SEM) analysis in the welding zone were obtained and examined. Subsequently, the effect on the welding zone of plastic deformation was analyzed. It has been established that plastic deformation of AISI 304 austenitic- stainless steel has neither an effect on the process nor on the strength of the welding joint.

Muhim Sahin, H. Erol Akata [2014] [23] an experimental setup was designed and realized in order to achieve the friction welding of plastically deformed steel bars. The parts having the same and different diameters deformed plastically, but the same material was welded with different process parameters. The strengths of the joints were determined by tension tests. Hardness variations and microstructures in the welding zone were obtained and the effects of welding parameters on the welding zone were investigated

Mumin Sahin [2015] [26] was designed and produced to achieve the friction welding of components having equal diameter. The set-up was designed as continuous drive, and transition from friction to forging stage can be done automatically. In the experiments, high-speed steel (HSS—S 6-5

2) and medium-carbon steel (AISI 1040) were used. Post-weld annealing was applied to the joints at 650 °C for 4 h. First, the optimum welding parameters for the joints were obtained. Later, the strengths of the joints were determined by tension, fatigue and notch-impact tests, and results were compared with the tensile strengths of materials. Then, hardness variations and microstructures in the post-weld of the joints were obtained and

Ahmet Hascalik, Nuri Orhan [2016] [3] investigated the feasibility of joining Al2O3 reinforced Al alloy composite to SAE 1020 steel by rotational friction welding. The aluminum based MMC material containing 5, 10 and 15 vol% Al2O3 particles with average particle sizes of 30 and 60 micro m was produced by powder metallurgy technique. The integrity of the joints has been investigated by optical and SEM, while the mechanical properties assessment included micro hardness and shear test. Results indicated that Al/ Al2O3 composite could be joined to SAE 1020 steel by friction welding. However, it was pointed out that the quality of the joint was affected negatively with the increase in particle size and volume % of the oxide particles in the MMC.

Mumin Sahin [2016] [22] investigate experimentally the micro- structural properties and welding strengths of the joints using austenitic-stainless steel (AISI 304) parts. The experiments were carried out using a beforehand designed and constructed experimental friction welding set-up, constructed as continuous- drive. Firstly, welding experiments under different friction time and friction pressure were carried out to obtain optimum parameters using statistical approach. Later, the strengths of the joints were determined by tension, fatigue and notch-impact tests,

Muhim Sahin, H. Erol Akata, Kaan Ozel [2018] [24] 5083 aluminum alloys, which were exposed to severe plastic deformation, were joined

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with friction welding method and the variation in mechanical properties of the joist was experimentally investigated. Severe plastic deformation methods can be classified as equal channel angular pressing (ECAP) (in other words, equal cross section lateral extrusion-EXILE) and cyclic extrusion compression. Aluminum alloy as test material 5083 and square cross-sectional equal channel angular pressing die for severe plastic deformation were used in this study. Firstly, 5083 alloys, as purchased, were joined with friction welding methods. The optimum parameters for friction time, upset time, friction pressure and upset pressure, which are necessary for welding, were obtained. Afterwards, 5083 aluminum materials purchased were prepared as square cross-section and then 1 pass severe.

Mumin Sahin, H. Erol Akata, Turgut Gulmez [2017] [25] deals with the importance of welding in manufacturing methods. There are various welding methods that have been developed to obtain suitable joints in various applications. However, friction welding, which is an alternative manufacturing method, is one of the methods that have been widely used for many years. Mumin Sahin et. al. present an experimental friction welding set-up, which is a continuous drive friction welding set-up, was used in the experiments. Firstly, optimum parameters were obtained to join parts having equal diameter. Secondly, the effect of welding parameters on welding strength was investigated. Later, the mechanical properties of joints were examined by using tensile tests, fatigue tests, notch-impact tests and hardness tests. Finally, the results obtained were shown and discussed.

Antonio A. M. da Silva, Axel Meyer, Jorge F. dos Santos, Carlos Eduardo Fortis Kwietniewski and Telmo R. Strohaecker [2019] [5] investigated the feasibility of joining particle-reinforced composites by rotational friction welding. The integrity of the joints has been investigated by optical and electron microscopy, while the mechanical properties assessment included micro hardness and tensile tests. The mechanical properties assessment has indicated no detrimental effect of the joining process on the tensile properties.

E. D. Nicholas [2020], Friction welding-an introduction to the process, The Welding Institute Cambridge, PP 2-8

III. RESULT AND DISCUSSION:

Micro hardness Measurements

Micro hardness Measurements: Micro hardness measurement of the specimens was done along the weld and at the cross section on Micro hardness Machine. Stainless steel and Aluminium 6061 was taken along the weld hardness. On Aluminium 6061 and on stainless steel hardness was taken at a constant distance of 0.10mm from the interface in 4 steps. Total of 8 readings were taken, one on Intersection, 4 on Aluminium 6061 side and 4 on Stainless Steel side.. The test matrix used for Micro hardness measurements is shown in Fig

Figure 1 Vicker micro hardness test

Tensile testing: The tensile testing of friction welded specimens was performed on the UTM Testing Machine

Fig. 2: Universal Testing Machine

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IV. TENSILE RESULTS AND DISCUSSION

No. of Experiment	Parameters			UTM result	
	RPM (R)	Burn off Length (L) in mm	Weld time in sec.	UTS(N/mm2)	UTL (KN)
1	1325	1.45	14	56.4	7.2
2	1325	1.42	15	58.3	7.4
3	1325	1.44	20	57.5	7.5
4	1325	1.43	20	65.4	7.4
5	1750	2.5	15	62.67	7.4
6	1750	1.5	15	70.5	8.1
7	1750	1.5	20	74	8.1
8	1750	2.5	20	65.1	7.3

Test matrix for UTM Result

Micro hardness Measurements

Micro hardness Measurements: Micro hardness measurement of the specimens was done along the weld and at the cross section on Micro hardness Machine. Stainless steel and Aluminium 6061 was taken along the weld hardness. On Aluminium 6061 and on stainless steel hardness was taken at a constant distance of 0.10mm from the interface in 4 steps. Total of 8 readings were taken, one on Intersection, 4 on Aluminium 6061 side and 4 on Stainless Steel side. The test matrix used for Micro hardness measurements is shown in Fig.

Figure 3: Vicker micro hardness test

Micro hardness measurement along the weld: The following are the table showing micro hardness on different specimens along the weld:-

Distance from joint along Aluminium direction (mm)	Hardness (HV 0.3)
0.12	64
0.15	67
0.33	54
0.45	57

Distance from joint along stainless steel direction(mm)	Hardness (HV 0.3)
0.12	315
0.18	267
0.25	278
0.40	281

No.of experiment	Parameters			Micro hardness value		
	RPM (R)	Burn off Length (L) in mm	Weld time in sec.	AL	Interface	SS
1	1325	1.45	15	63	330	310
2	1325	1.42	15	52	314	289
3	1325	1.44	20	51	310	284
4	1325	1.43	20	51	316	288
5	1750	2.5	15	49	312	273
6	1750	1.5	15	48	323	269
7	1750	1.5	20	48	303	271
8	1750	2.5	20	47	301	269

No. of Experiment	Parameters			
	RPM (R)	Burn off Length (L) in mm	Weld time in sec.	Temperature
1	1325	1.45	15	70
2	1325	1.42	15	83
3	1325	1.44	20	89
4	1325	1.43	20	83
5	1750	2.5	15	79
6	1750	1.5	15	89
7	1750	1.5	20	81
8	1750	2.5	20	76

Table Test matrix for Temperature Measurement

Discussion of Temperature profile results: It is clear from the above Table 5.2 and Fig. 5.1-5.8 that the highest temperature of 84 degree Celsius and lowest is 78 degree Celsius is observed when temperature is measured at a distance of 10 mm for specimens. When temperature is measured at 15 mm distance, maximum temperature observed is 84 degree Celsius. Lowest temperature is 78 degree Celsius for specimen no.1, 8. It is observed that with increase in friction force while other parameters are constant, there is an increase in temperatures.

V. CONCLUSIONS

1) During tensile testing, high UTS were observed in sample no. 7 due to carbon migration from SS to weld zone during welding. Friction welding has been successfully employed to weld dissimilar metals. Strength of the joints obtained was good.
2) Microstructure evaluation of the friction welded joints revealed different zones namely, Reheat refined coarse grain region SS (RC), dendrite region Interface (D), Reheat refined fine grain region AL (RF).
3) Highest micro hardness values were observed in the specimen on the side of SS
4) At interface and AL maximum area fraction of un- dissolved regions was formed through the SEM examination. These un-dissolved regions result in higher micro hardness values.
5) Temperature modeling of friction welded joints has been efficiently accomplished.

SCOPE OF FUTURE WORK

In addition to the present work further work can be done in following directions:

1) Modeling of friction welding process can be carried out using Finite Element packages
2) We can explore the evaluation of microstructure by using different diameters.
3) After residual stress measurements, we can carry out the fracture analysis of engineering or welding components of nuclear reactor parts.
4) We can measure and correlate fatigue and corrosion properties with different friction welding parameters.
5) There were a lot of parameters (Weld time, Burn off length, RPM) which can be varied individually to see their individual effects rather than combining these parameters.

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