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TEMPERATURE MODELLING OF FRICTION WELDING OF ALUMINIUM 6026 AND STAINLESS STEEL-304

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ABSTRACT

Friction welding is widely used solid state welding method for joining of similar and dissimilar metals that uses rapid rotation of one component at high rpm and other component is brought in to contact at high forging pressure to get upset. Two pieces rotate in contact and heat necessary for welding is generated on friction plane.

For this purpose a friction welding setup was designed. Vertical Milling Machine was used for friction welding. The materials used were Aluminium 6026 and Stainless Steel - 304. A Dial indicator was used to control the burn off length. Temperature torch was used to measure the temperature to simulate the results.

Three parameters were varied Weld time, RPM & Burn off length at two different levels. Fixed parameters were length and diameter of the specimen. Total number of experiments conducted was eight.

After friction welding macroscopic behavior (Tensile Strength, Temperature produced during friction welding & Composition change) & Microscopic behavior (Microstructure, Micro hardness, SEM) of the welded region was analyzed.

The Microscopic and Macroscopic behavior with the friction welding parameters was studied in this work.

INTRODUCTION

Friction welding is widely used solid state welding method for joining of similar or dissimilar metals. Friction welding requires rapid rotation of one component at high rpm and other component is brought into contact at high forging pressure to get upset. Two pieces rotate in contact and heat necessary for welding is generated on friction plane. The machine for the friction welding is similar to a vertical milling machine.

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 unweldable and dissimilar materials. This rapidly easily controlled & easily mechanized process has been used extensively in the automotive industry such as half shafts and bimetallic weld.

One important characteristic of friction welding is its ability to weld alloys and combination of alloys previously regarded as unweldable. It is possible to make dissimilar metal joints, joining steel, copper and Aluminium 6026 to themselves and to each other and to successfully weld alloys such as the 2.5% copper-Al 2618 and the Al Zn Mg Cu alloy 7075 without hot cracking.

LITERATURE REVIEW

Ahmet Hascalik, Nuri Orhan [2016] [3] **i**nvestigate 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% $Al2O_3$ 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/ $Al2O_3$ 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 [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 examined.

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, and results were compared with strengths of materials. Hardness variations and microstructures in the interfaces of the joints were also obtained and examined. Then, obtained results were compared with those of previous studies.

Mumin Sahin [2013] [21] an experimental set-up was designed in order to achieve friction welding of plastically deformed austenitic-stainless steels. AISI 304 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 same and different diameters deformed plastically, but 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.

Muhim Sahin, H. Erol Akata, Kaan Ozel [2015] [24] 5083 aluminum alloys, which were exposed to severe plastic deformation, were joined 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-ECSLE) 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 method. The optimum parameters for friction time, upset time, friction pressure and upset pressure, which are necessary for welding, were obtained. Afterwards, 5083 aluminum materials as purchased were prepared as square cross-section and then 1 pass severe plastic deformation was applied to specimen by equal channel angular pressing die. The obtained parts as square formed were prepared as cylindrical form by machining and then the parts were joined by continuous drive friction welding equipment that was designed and produced in laboratory conditions before. Later, the tensile strength of parts, obtained at optimum conditions, was compared with those of the joined parts as purchased form. Then, hardness variations and microstructures of joints were examined.

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.

Ahmet Z. Sahin, Bekir S. Yibas¸, M. Ahmed, J. Nickel [2018] [4] the heat-transfer mechanism initiating the friction welding process was examined and a transient two-dimensional heat conduction model for the welding of two dissimilar cylindrical metal bars was introduced. The bar materials consist of copper and steel. To relate the theoretical predictions with the resulting welds, experiments are conducted under different welding conditions by means of which metallurgical and microprobe analysis of the weld cross-sections was carried out. This provides visualization of the melted zones and of the diffusion depths. A statistical analysis was carried out for the affecting parameters on the mechanical properties of the resulting welds. The factors affecting the weld include the speed of rotation, the weld duration (burn off time), and the friction load, while the mechanical properties include the tensile strength, the yield strength, the ultimate yield strength and the micro hardness of the weld cross-sections.

Antonio A. M. da Silva, Axel Meyer, Jorge F. dos Santos, Carlos Eduardo Fortis Kwietniewski and Telmo R. Strohaecker [2012] [5] investigate 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.

RESULTS & DISCUSSION

MACROSCOPIC BEHAVIOUR

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

Universal Testing Machine

Tensile Result 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	1400	1.5	14	64.4	7.3
2	1400	2.5	15	66.3	7.5
3	1400	1.5	20	68	7.7
4	1400	2.5	20	65.4	7.4
5	1800	2.5	15	62.67	7.2
6	1800	1.5	15	70.5	8.2
7	1800	1.5	20	74	8.5
8	1800	2.5	20	65.1	7.4

Test matrix for UTM results

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 6026 was taken along the weld hardness. On Aluminium 6026 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 6026 side and 4 on Stainless Steel side.. The test matrix used for Micro hardness measurements is shown in Fig

Figure 4.9 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 Aluminum direction (mm)	Hardness (HV 0.3)
0.10	63
0.20	52
0.30	51
0.40	51

Hardness Profile

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Distance from joint along stainless steel direction(mm)	Hardness (HV 0.3)
.10	310
.20	284
.30	281
.40	281

Hardness Profile

No.of experiment	Parameters			Micro hardness value		
	RPM (R)	Burn off Length (L) in mm	Weld time in sec.	AL	Interface	SS
1	1400	1.5	15	63	329	310
2	1400	2.5	15	52	311	283
3	1400	1.5	20	51	309	281
4	1400	2.5	20	51	314	280
5	1800	2.5	15	49	308	273
6	1800	1.5	15	48	304	269
7	1800	1.5	20	48	303	270
8	1800	2.5	20	47	301	267

Table Micro hardness value

Measurement of Temperature Profiles: Temperature was noted down experimentally with the help of a temperature torch. On eight samples a hole of 2 mm depth was drilled at a height of 10 mm from the interface on SS side where welding was to be done. While on another Eight samples a hole of 2 mm depth was drilled at a height of 15 mm from the interface on SS side where welding was to be done. The temperature reading was noted down with the help of a camera. The Table 4.5

No. of Experiment	Parameters			
	RPM (R)	Burn off Length (L) in mm	Weld time in sec.	Temperature
1	1400	1.5	15	77
2	1400	2.5	15	83
3	1400	1.5	20	81
4	1400	2.5	20	83
5	1800	2.5	15	79
6	1800	1.5	15	83
7	1800	1.5	20	82
8	1800	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 specimen. 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 increase in temperatures.

APPLICATIONS OF FRICTION WELDING

- Friction welders are versatile enough to join a wide range of part shapes, materials, and weld sizes.
- Friction welded applications typically include aircraft and aerospace components, cutting tools, agricultural machinery, automotive parts, oil field pieces, waste canisters, military equipment, spindle blanks and bimetallic materials.
- Production of bimetallic shafts, steering shafts and worm gears, control shafts, axle shafts, engine valves, transmission shafts etc., for automobile industry, joining of super alloy turbine wheels to steels shafts, joining of thin walled containers to base etc.
- Production of cutting tools like drills, taps, reamers and some of the milling cutters where HSS cutting body can weld to carbon steel shanks.

Conclusion

1) Friction welding has been successfully employed to weld dissimilar metals. Strength of the joints obtained was good.

2) During tensile testing, high UTS was observed in sample no. 7 due to carbon migration from SS to weld zone during welding.

3) 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).

4) Highest micro hardness values were observed in the specimen on the side of SS due to high

5) At interface and AL maximum area fraction of un-dissolved regions was formed through the SEM examination. These un-dissolved regions results in higher micro hardness values.

6) Temperature modelling of friction welded joint has efficiently accomplished.

SCOPE OF FUTURE WORK

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

1) We can explore the evaluation of microstructure by using different diameter.

2) After residual stress measurements, we can carry out the fracture analysis of engineering or welding components of nuclear reactor parts.

3) Modelling of friction welding process can be carried out using Finite Element packages.

4) We can measure and correlate fatigue and corrosion properties with different friction welding parameters.

5) There was lot of parameters (Weld time, Burn off length, RPM) which can be varied individually to see their individual effects rather than combining these parameters.

6) Modelling of residual stress generation during friction welding can also be carried out.

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