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A Research Paper on Temperature Modelling of Friction Welding of Aluminium and Stainless Steel-304

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Abstract: In this paper we study friction welding by using vertical milling machine. We have study the material stainless steel-304 and aluminium. The parameter we have study the parameter rpm, weld time, blow off length etc. Friction welding is widely used solid state welding method for joining of similar or dissimilar metals. . 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.

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 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. The primary reason for this is that no melting takes place and thus no brittle intermetallic phases are formed. Initially parts are loaded by the welder: one is placed in a rotating spindle and the other is positioned in a stationary clamp. The process can be described best in the three steps as follows:

STEP 1: Component in the spindle is brought up to pre-determined rotational speed and then a pre-determined axial force is applied.

STEP 2: These conditions are maintained for a pre-determined amount of time until desired temperatures and material conditions exist.

STEP 3: Rotational speed is then stopped and axial force is applied until desired upset is obtained. Then the components are unloaded and the cycle is repeated.

Stainless steel is an alloy, which is iron based and contains various combinations of other elements to give its characteristics suitable for a wide range applications, in the areas such as chemical, diary equipments, food processing, pharmaceutical equipments, cryogenic vessels, heat exchangers and beverage sectors. Friction welding is a solid state joining process that produces coalescence by harnessing heat developed through controlled rubbing of the faying surfaces. Due to the heat, the material reaches the softened state, at which the plasticized material begins to form layers that intervene with one another and results in good quality weld. Friction has been shown to have significant economic and technical advantages. To produce good quality joint, proper process parameters have to be used. The welding process is a multi-input & multi-output joining process in which the quality of joints is closely associated with welding parameters.

LITERATURE REVIEW

Most of the journals and research papers regarding to the friction welding on the similar and dissimilar metals has discussed in literature review.

Ahmet Hascalik, Nuri Orhan [2005] [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% 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 [2005] [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 [2007] [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 [2009] [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.

Mumin Sahin, H. Erol Akata, Turgut Gulmez [2006] [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.

Ahmet Z. Sahin, Bekir S. Yibas¸, M. Ahmed, J. Nickel [1997] [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.

D. Ananthapadmanaban, V. Seshagiri Rao, Nikhil Abraham and K. Prasad Rao[2009] [6] mechanical property variation under different friction welding conditions for mild steel stainless steel joints by D. Ananthapadmanabam et. al. Yield strength, ultimate tensile strength, percentage elongation of the welded joints and hardness variations across the weld interface has been reported. The integrity of the joints has been investigated using optical microscopy and scanning electron microscopy.

F. Rotundo, L. Ceschini, A. Morri, T. S. Jun, A. M. Korsunsky [2010] [8] evaluate the possibility of using the linear friction welding (LFW) technique to produce sound joints on a 2124Al/25 vol.% SiCp composite. The MMC joints were subjected to micro structural and mechanical characterization, including hardness, tensile and fatigue tests, without any post weld heat treatment. The micro structural analyses showed substantially defect-free joints, with a uniform particle distribution in the central zone and a relevant plastic flow of the aluminium matrix alloy. The hardness decrease in the welded zone was approximately 10% in respect to the base material. The joint efficiency was higher than 80%, both in respect to the ultimate tensile strength and fatigue strength at 107 cycles. S-N probability curves were calculated using the maximum likelihood method. Generally the fracture occurred in the Thermo-Mechanically Affected Zone (TMAZ), with a relevant reduction in the elongation to failure.

Hakan Ates, Mehmet Turker and Adem Kurt [2007] [10] effect of friction pressure on the properties of friction hot rolled MA956 iron-based super alloy plate, produced by mechanical alloying, has been investigated. Joining processes were carried out by various friction welding parameters. Tensile strengths and hardness values of the weld interface were determined and the microstructure features of these samples were investigated. Optimum friction pressure for this material was determined.

Hazman Seli, Ahmad Izani Md. Ismail, Endri Rachman, Zainal Arifin Ahmad [2010] [11] friction welding of two dissimilar materials, two rods are welded together by holding one of them still while rotating the other under the influence of an axial load which creates frictional heat in the interface. In this study, mechanical properties of mild steel and aluminum welded rods were evaluated to understand the thermal effects, and an explicit one-dimensional finite difference method was used to approximate the heating and cooling temperature distribution of the joint. The thermal effects of the friction welding were observed to have lowered the welded materials hardness compared to the parent materials. The tensile strength of the welded rods is lower than the parent rods due to incomplete welding. The preliminary predictions were compared to actual thermocouple data from welds conducted under identical conditions and were shown to be in fair agreement. The finite difference method proposed in this work will provide guidance in weld parameter development and will allow better understanding of the friction welding process.

H.C. Dey, M. Ashfaq, A.K. Bhaduri and K. Prasad Rao [2009] [9] gives the details of mechanical tests, microstructure analysis using optical and scanning electron microscopy. The dissimilar metal joint of titanium (Ti) to 304L stainless steel (SS) is essential in the nuclear industry for the dissolution of spent fuel that is carried out in boiling nitric acid in the dissolver vessel (made of Ti) and the dissolved solution is transported through the 304L SS pipes to the other plant components made of 304L SS. Because of the radioactive environment, leak tightness and corrosion resistance of this dissimilar joint are important. In this work, friction welding process was attempted to join Ti to 304L SS. Direct friction welding of Ti to 304L SS results in a stronger weld in which failure occurs in the Ti base metal during tensile testing. However, the joints have almost zero bend ductility that has been attributed to the formation of intermetallics due to mechanical alloying, strain hardening of Ti near the joint interface and residual stresses. Post-weld heat treatment marginally increases the bend ductility to 5° because of relieving of the effects of strain hardening and of residual stresses at the joint interface. Corrosion test in boiling nitric acid is as per ASTM A-262 practice. The average corrosion rate is 10 mpy with the joints remaining intact after the corrosion test.

Hyung-Seop Shin, Jung-Soo Park, Yoon-Chul Jung, Jung-Ho Ahn, Yoshihiko

Yokoyama, Akihisa Inoue [2008] [12] the friction welding of three kinds of Zr-Cu-Al bulk glassy alloys (BGAs) which show eutectic or hypoeutectic compositions to similar and dissimilar BGAs and crystalline metals has been tried. The shape and volume of the protrusion formed at the weld interface were investigated. In order to characterize the friction welded interface, micrographic observation and X-ray diffraction analysis on the weld cross-section were carried out. A successful joining of Zr-Cu-Al bulk glassy alloys to similar and dissimilar BGAs was achieved without occurrence of crystallizations at the weld interface through the precise control of friction conditions. In addition, the joining of Zr50 Cu40 Al10 BGA to crystalline alloys was tried, but it was only successful for specific material combinations. The residual strength after welding of dissimilar BGAs was evaluated by the four-point bending test.

Hyung-Seop Shin, Young-Jin Jeong, Ho- Yeon Choi, Hidemi, Kato, Akihisa Inoue [2006] [13]friction welding of Zr based bulk metallic glass (Zr55 Al10 Ni5 Cu30 alloy) has been tried. Friction time and friction pressure were chosen as the control parameters for the friction welding process. Their influences on the shape and volume of the protrusion formed from the welded interface were investigated. Temperature distribution around the interface during friction was measured using an infrared thermal imager. Successful joining of Zr55Al10 Ni5 Cu30BMG was accomplished through the precise control of friction time and friction pressure.

I. Mitelea, C.M. Craciunescu [2009] [14] the influence of the main friction welding parameters, such as the axial pressure, the friction stroke and the upsetting temperature on the compositional, structural and hardness gradient is shown for dissimilar joints made out of carburized and volume-hardened steels. The expulsion of the carbon-enriched layer in the burr as a qualitative factor is analyzed. Low axial pressure and long friction time favors' to the presence of a carburized layer in the joint plane. A high axial pressure, as well as increase in the friction stroke favors' the expulsion of the carbon-enriched layer from the joining area into the burr. A high upsetting pressure leads to an increase of the plasticized material expulsion in the burr.

A. A. Essa, A. S. Bahrani [1991] [1] methods of solid phase bonding of metals to ceramics are reviewed with particular emphasis on friction welding. The results of experiments on the direct friction welding of an aluminum alloy to 94% alumina are reported in this study by A. A. Essa et. al. High strength bonds between the aluminum alloy and the alumina were achieved but there were problems with the cracking of the alumina. It was not possible to friction weld mild steel to alumina and copper to alumina. A mechanism was proposed for the friction welding of metals to ceramics.

Jolanta Zimmerman, Wladyslaw Wlosinski and Zdzislaw R. Lindemann [2009] [15] in a modeling of friction welding of elastic materials with elastic–plastic metals is presented by Jolanta Zimmerman et. al. This model has been practically verified in the process of friction welding of corundum ceramic of 97.5% Al2O3 content and aluminum alloy 6061-T6 as well as in the same ceramic and electrolytic copper of 99.9% Cu content. Mechanical strength of the acquired welded joints was around 30 MPa.

A simulation of the process was performed by means of the finite element method using two FEM systems, namely ADINA-T and ADINA. The simulations made it possible to observe the temperature distribution and thermo-mechanical fields that take place during the process. The obtained results show that the temperature, pressure and the deformation distribution near the contact surface are non-homogeneous. It causes not even conditions to create the bond and internal stresses generation. The agreement between the numerical geometry prediction and the experimental data proves the validity of the proposed model. The performed calculations and preliminary studies on the influence of the diffusion phenomena on the welding process showed that the diffusion depth is approximately 4 μm and the calculated diffusion coefficient of Al into Al2O3 is 1.8×10^{-13} m2/s. Numerical simulation of the friction welding process allows better understanding of the whole process, final products shape prediction and can be helpful during design of the process using other materials.

Koen Faes, Alfred Dhooge, Patrick De Baets, Eric Van Der Donckt and Wim De Waele [2009] [16] a new welding method for fully automatic welding of pipelines has been developed by Keon Faes et. al. The proposed welding procedure, called Friex, is a new variant of the well-known friction welding process. An intermediate ring is rotated in between the pipes to be welded to generate the heat necessary to realize the weld. In the first part of this paper, the working principles of the Friex welding process are briefly described. The influence of the rotation speed on the weld properties is discussed for welding 3 in. pipes in the pipeline steel API-5L X52. Two normalized fine-grained steels were used for the welding ring. The optimization of the thickness of the welding ring is also discussed in this paper.

L. D'Alvise , E. Massoni and S.J. Walløe [2002] [17] the development and experimental validation of a finite element code to simulate the inertia friction welding (IFW) process. The mechanical equations take into account, among others, the physics in terms of inertia, forces and friction. They are solved for velocity and pressure through the P1+/P1 formulation. Due to the rotational movement of the work piece, a third nodal unknown V_, the rotational velocity, is added to the variables Vr and Vz. The thermal calculation influences the rheological and tribological parameters and is coupled to the mechanical solution. Powerful contact algorithm and automatic remeshing are implemented to model the flash formation at the joint interface, its self-contact with the work piece and the multi-body contact between dissimilar materials. A novel formulation for the friction law is implemented to suitably represent the physical phenomena in IFW. A residual stress analysis is carried out.

P. Sathiya, S. Aravindan and A. Noorul Haq [2008] [27] emphasizes on joints of two types of industrially important stainless steels such as austenitic and ferritic stainless steels. The present study utilized a continuous drive friction welding machine to process similar joints. Cylindrical specimens of austenitic stainless steel and ferritic stainless steel of similar composition and shape (equal diameter and length) were used in this study. The processed joints were tested through uni axial tension test, impact test and hardness test. Microstructural studies were also carried out. The characteristics such as tensile strength, toughness, hardness across the joint zone and microstructural aspects exhibited by friction processed joints were compared to the respective parent materials. Joints processed by this method exhibited better properties when compared to the fusion processed joints.

R. E. Craine, A. Francis [1986] [28] in all types of friction welding the joining process is started by the generation at the rubbing interface of frictional heat arising from the relative motion of the components. In one form of orbital friction welding the two components to be joined are rotated about their longitudinal axes in the same sense with the same constant angular speed. The two longitudinal axes are being parallel but offset by a small distance. The interface rubbing velocity so created is particularly simple and in this paper a general expression for the rate of heat generation at the rubbing interface during the early stages of the orbital friction welding process is presented. The particular cases of a pair of rods of circular cross-section and two rods of square cross-section are considered in some detail.

Most of the research works regarding friction welding one done on the similar metals.Friction welding is a capable process of joining to dissimilar metal include study of joint of same metals with same ceramics likezirconium based metallic glass with steels were undertaken.the studies have also been made with copper and steels,stainless steel and mild steel. But limited data related to friction welding of aluminium and stainless steel-304 weld joint has been reported. The present work is objected to the study and temperature modeling of the Aluminium and Stainless steel-304 joint. The measurement and study of various mechanical properties like micro hardness tensile strength and also the metallographic behavior of the joint is also studied.

PROBLEM FORMULATION

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 into contact at high forging pressure to get upset. This approach is particularly useful in joining of dissimilar welds. The reason being the absences of any external filler material which may be further add in the heterogeneity of the weld structure.
From the literature survey, following limitation have been identified.

1. Limited data related to friction welding of aluminum and stainless steel-304 weld joints has been reported.
2. Not much studies work done have been reported on the microstructural evolution in friction welded joints and their relationship with variation of friction welding parameters.

These bimetallic welds impose a safety issue for the structural engineers. The bimetallic welds present a heterogeneous interface, which results in variation of micro-structural and mechanical properties across a very narrow zone. These welds also show thermal fatigue and residual stresses. The joining of Aluminium and Stainless Steel-304 is done by using Conventional welding procedure. This procedure generally uses a filler metal of similar nature as of stainless steel to weld the two pieces of aluminium and stainless steel-304 using conventional arc welding processes such as Gas Tungsten Arc Welding, Shielded Metal Arc Welding and Submerged Arc Welding. The joining of Aluminium and Stainless Steel-304 should be done in such a way so as to reduce the Residual stresses produced during joining process.

In this thesis an attempt was made to fulfill the limitation observed from the literature survey by attempting to carry out joining of aluminium and stainless steel-304 bars using friction welding and to understand the temperature modeling, micro-structural evolution and mechanical behavior of the friction welded joints. The friction welding parameters were to be varied and their effect was to be evaluated on the microscopic and macroscopic behavior. Temperature modeling will be done with the help of temperature torch to simulate the result.

For the achievement of the above objective an experimental setup was to be designed. The three parameters Weld time, Burn off length & Revolutions per Minute were to be varied.

EXPERIMENTAL SETUP

For doing friction welding Vertical Milling Machine was used. Two different materials were used, Stainless Steel – 304 and Aluminium.

The setup basically consists of following main elements:

1. **Vertical Milling Machine –** Vertical Milling Machine & Lathe both can be used for friction welding. Vertical Milling Machine (Fig. 1) was used for this purpose because of its stability & less vibration as compared to Lathe machine.

Figure 1 Vertical Milling Machine used for friction welding

2. **Temperature Torch-** Temperature torch was used to note down to temperature during friction welding.
3. **Stop watch-** Stop watch was also used to note down the weld time during friction welding.
4. **Dial Indicator –** A Dial Indicator with magnetic stand was used to note down burn off length during friction welding process.

SAMPLE PREPARATION

There are following steps for sample preparation:
Step1:
Input:

- Bandsaw, Lathe
- Aluminium & Stainless steel -304
- Cutting tools
- Vernier Calliper

Step2:
Cutting of aluminum, stainless steel-304 according to required length on bandsaw .
Step3:
Fix the cutting tool on tool post & fix the aluminum, stainless steel-304 in rotating chuck on lathe
Step4:
Turning of specimens to get the required diameter
Step5:
Checking of required diameter with the help of vernier caliper
Step6:
If required diameter is attained then go to step 7
else
go to step 4
Step7:
Sample is ready for welding.
Step8:
Finish

Firstly a rod of 12 mm diameter of Aluminium & Stainless Steel was cut into pieces of 70 mm length (each) on Bandsaw

After cutting operation 12mm diameter of Aluminium and Stainless Steel-304 having length 70mm each was to be joined. It was found that the pieces did not join even after running the setup for 6 minutes. So the pieces of 10 mm diameter were turned on Lathe and made 14 mm diameter. It was found that still the pieces could not be joined. Then the pieces of Aluminium and Stainless Steel was turned and made 12 mm diameter on Lathe. A hole of 2 mm depth and 3 mm diameter was made on 10 pieces of SS at a height of 10mm and on another 10 pieces of SS at a height of 15 mm from the top surface which was being welded on Drilling machine.

CHANGED PARAMETERS

The following are the three parameters which have been varied

Weld Time: Weld time is the overall time in which joint is obtained between the aluminum & stainless steel-304.

Burn off Length: Burn off length is the overall length loss of the specimens during the application of friction force & forge force. It can be original length minus length of welded component.

Revolutions per Minute: It is the revolutions of the rotating chuck in a minute.
Revolutions can be set according to the requirement.
Total of Eight experiments were done.

FIXED PARAMATERS

The following are the parameters that were kept constant throughout the experiment.

- **Diameter of the specimen:** 12mm
- **Total length of the specimen:** 140mm (70mm each)

RESULTS & DISCUSSION

MACROSCOPIC BEHAVIOUR

Tensile Result and discussion:

Table 1: Test matrix for UTM results

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	15	65.4	7.4
2	1400	2.5	15	67.2	7.6
3	1400	1.5	20	69	7.8
4	1400	2.5	20	65.4	7.4
5	1800	2.5	15	63.69	7.2
6	1800	1.5	15	72.5	8.2
7	1800	1.5	20	76	8.6
8	1800	2.5	20	67.2	7.6

Discussion on Tensile Strength: The effects of various parameters on the strength of the joints were examined in welding of equal diameter parts. From Table 5.1, It shows that maximum Ultimate Tensile Strength was observed for welded sample no.7 i.e. 76 N/mm2 and Ultimate Tensile Load 8.6KN. Lowest Ultimate Tensile Strength for sample no. 5 i.e. 63.69N/mm2 and UTL 7.2 KN. The values of Ultimate Tensile Strength for welded specimens were greater than that of aluminum bars in all cases. Since the friction welding process is characterized by a fast applied thermal and stress/strain cycle causing micro structural changes, it would be expected that the mechanical properties of welded joints would be quite different from those of the base materials. In all the cases sample is broken on Aluminium side.

Table 2: Test matrix for Temperature Measurement

No. of Experiment	Parameters			
	RPM (R)	Burn off Length (L) in mm	Weld time in sec.	Temperature
1	1400	1.5	15	78
2	1400	2.5	15	84
3	1400	1.5	20	82
4	1400	2.5	20	84
5	1800	2.5	15	80
6	1800	1.5	15	84
7	1800	1.5	20	84
8	1800	2.5	20	78

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.

Discussion of chemical composition results: The element percentage composition and element percentage change for AL, Interface and SS regions of friction welded joints. SS combine with AL at the interface, the percentage of Fe is then being 68.2% and 0.10% respectively. Then at the interface resulting from friction welding joint the percentage of Fe will be 34.15%. So that the percentage of Fe in AL is increased and percentage of Fe in SS is decreased at the interface due to the elemental diffusion takes place between two metals. Similiarly it is observed that the percentage Si, Mn, Cr, Ni, v is increased in aluminium and decrease the percentage Si, Mn, Cr, Ni, v in SS at the interface due to the elemental diffusion of the metals. In all the cases diffusion takes place in the interface.

CONCLUSIONS

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) Highest micro hardness values were observed in the specimen on the side of SS due to high friction and high heat at the welding zone. The reason for higher micro hardness was observed to be recrystalization.
4) 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.
5) 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.

REFERENCES

[1]. A.A. Essa, A. S. Bahrani, The friction joining of ceramics to metals, Journal of Materials Processing Technology, Volume 26, Pg 133-140, 1991.
[2]. A. Vairis, M. Frost, High frequency linear friction welding of a titanium alloy, Wear, Volume 217, Pg 117-131, January 1998.
[3]. Ahmet Hascalik, Nuri Orhan, Effect of particle size on the friction welding of Al2O3 reinforced 6160 Al alloy composite and SAE 1020 steel, Materials & Design, Volume 28, pg 313-317, June 2005.
[4]. Ahmet Z. Sahin, Bekir S. Yibas, M. Ahmed, J. Nickel, Analysis of the friction welding process in relation to the welding of copper and steel bars, Journal of Materials Processing Technology, Volume 82, Pg 127-136, March 1997.
[5]. Antonio A. M. da Silva, Axel Meyer, Jorge F. dos Santos, Carlos Eduardo Fortis Kwietniewski and Telmo R. Strohaecker, Mechanical & metallurgical properties of friction welded TiC particulate reinforced Ti-6AI-4V, Composites science & Technology, Pg 1495-1501, Volume 64, Issues 10-11, August 2004.
[6]. D. Ananthapadmanaban, V. Seshagiri Rao, Nikhil Abraham and K. Prasad Rao, A study of mechanical properties of friction welded mild steel to stainless steel joints, Materials & Design, Pg 2642-2646, Volume 30, Issue 7, August 2009.
[7]. Emel Taban, Jerry E. Gould, John C. lippold, Dissimilar friction welding of 6061-T6 aluminum and AISI 1018 steel: Properties and micro structural characterization, Materials & Design, Volume 31, Pg 2305-2311, December 2009.
[8]. F. Rotundo, L. Ceschini, A. Morri, T. S. Jun, A. M. Korsunsky, Mechanical and micro structural characterization of 2124Al/25 Vol.% SiCp joints obtained by linear friction welding (LFW), Composites, March 2010.
[9]. H.C. Dey, M. Ashfaq, A.K. Bhaduri and K. Prasad Rao, Joining of titanium to 304L stainless steel by friction welding, Journal of Materials Processing Technology, Volume 209, Issues 18-19, Pg 5862-5870, September 2009.
[10]. Hakan Ates, Mehmet Turker and Adem Kurt, Effect of friction pressure on the friction welded MA956 iron-based super alloy, Materials & Design, Volume 28, Issue 3, Pg 948-953, September 2007.
[11]. Hazman Seli, Ahmad Izani Md. Ismail, Endri Rachman, Zainal Arifin Ahmad, Mechanical evaluation and thermal modeling of friction welding of mild steel and aluminum, Journal of Materials Processing Technology, Volume 210, Pg 1209-1216, March 2010.
[12]. Hyung-Seop Shin, Jung-Soo Park, Yoon-Chul Jung, Jung-Ho Ahn, Yoshihiko Yokoyama, Akihisa Inoue, Similar and dissimilar friction welding of Zr-Cu-Al bulk glassy alloys, Journal of Alloys and Compounds, Volume 483, Pg 182-185, July 2008.
[13]. Hyung-Seop Shin, Young-Jin Jeong, Ho- Yeon Choi, Hidemi, Kato, Akihisa Inoue, Joining of Zr-based bulk metallic glasses using the friction welding method, Journal of Alloys and Compounds, Volume 434-435, Pg 102-105, October 2006.
[14]. I. Mitelea, C.M. Craciunescu, Parameter influence on friction welding of dissimilar surface-carburized/volume-hardened alloyed steels, Materials and Design, Volume 31, Pg 2181-2186, October 2009.
[15]. Jolanta Zimmerman, Wladyslaw Wlosinski and Zdzislaw R. Lindemann, Thermo-mechanical and thermal modelling in the process of ceramic-metal friction welding, Journal of Materials Processing Technology, Volume 209, Issue 4, Pg 1644-1653, February 2009.
[16]. Koen Faes, Alfred Dhooge, Patrick De Baets, Eric Van Der Donckt and Wim De Waele, Parameter Optimisation for automatic pipeline girth welding using a new friction welding method, Materials & Design, Volume 30, Issue 3, Pg 581-589, March 2009.
[17]. L. D'Alvise, E. Massoni and S.J. Walloe, Finite element modelling of the inertia friction welding process between dissimilar materials, Journal of Materials Processing Technology, Volume 125-126, Pg 387-391, September 2002.
[18]. M. Maalekian, E. Kozeschnik, H. P. Brantner, H. Ceriak, Comparative analysis of heat generation in friction welding of steel bars, Acta Materialia, Volume 56, Pg 2843-2855, February 2008.
[19]. Mumin Sahin, Characterization of properties in plastically deformed austenitic stainless steels joined by friction welding, Materials & Design, Volume 30, Issue 1, Pg 135-144, January 2009.
[20]. Mumin Sahin, Evaluation of the joint-interface properties of austenitic-stainless steels (AISI 304) joined by friction welding, Materials & Design, Volume 28, Issue 7, Pg 2244-2250, 2007.
[21]. Mumin Sahin, H. Erol Akata, Joining with friction welding of plastically deformed steel, Journal of Materials Processing Technology, volume 142, Pg 239-246, March 2003.
[22]. P. Sathiya, S. Aravindan and A. Noorul Haq, Some experimental investigations on friction welded stainless steel joints, Materials and Design, Volume 29, Issue 6, Pg 1099-1109, 2008.
[23]. R. E. Craine, A. Francis, Frictional heat generated in the early stages of an orbital friction welding process, Wear, Volume 114, Pg 355-365, June 1986.
[24]. www.ardindustries.com
[25]. www.frictionwelding.in
[26]. www.google.com
[27]. www.welding-technology-machines.info
[28]. www.wikipedia.com