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Effect of Process Parameters on Mechanical Behaviour and Micro Structure Evolution of Various Dissimilar Stainless Steel and Aluminium Alloys Welded by Friction Welded Joints by Using S.E.M.– A Review

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ABSTRACT

Generally, Friction welding has become well established producing high Quality welds of Aluminium Alloys compare to traditional fusion methods because of low distortion, low residual stresses, and eliminate porosity and solidification cracking. Friction welding has become a major joining process in aerospace, ship building, automotive, and railway industries especially in the fabrication of Aluminium alloys and also recently applicable for Stainless Steel – 304 and Aluminium based metal matrix composites. In this process parameters, micro structural evolution and effect of mechanical properties on Various Aluminium alloys and Stainless Steel – 304. Stainless Steel – 304 and Aluminium based Metal Matrix Composites have been discussed. Applications, future aspects, and several key problems are also described.

Keywords: Friction welding, Aluminium alloys, process parameters, micro structural evolution, Mechanical properties, SEM.

1. 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 [2, 8].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[3,4,6,7]. 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. (Figure 1.1)

STEP 2: These conditions are maintained for a pre-determined amount of time until desired temperatures and material conditions exist. (Figure 1.2)

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. (Figure 1.3)

Fig. 1.1 Step: 1[6],

Figure 1.2 Step: 2[6]

Figure 1.3 Step: 3[6]

2. LITERATURE REVIEW

Ahmet, J. Nickel [1] presented 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.

A. Vairis, M. Frost [2] presented a new hysteresis free linear friction welding machine is described, capable of welding at variable frequencies and amplitudes of oscillation with adjustable friction and forging pressures. Experiments were performed with Ti 6AI 4V up to a frequency of 119 Hz and for two amplitudes of oscillation (3 and 0.92mm).

Ahmet, Nuri [3] aim of this study was to investigate 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.

Mumin Sahin [4] in this study, an experimental set-up was designed and produced to achieve the friction welding of components having equal diameter.

Muhim Sahin, H. Erol [5] in the present study, 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.

Mumin Sahin [6] study was to 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.

Antonio A. M. da Silva , [7] aim of this paper was to investigate the feasibility of joining particle-reinforced composites by rotational friction welding.

Mumin , Gulmez [8] has to study 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.

Muhim Sahin[9] in this study, 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.

Mumin Sahin [10] 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.

Emel ,John [11] Joining of dissimilar materials is of increasing interest for a wide range of industrial applications.

Hazman Seli, Ahmad [12] in 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. **F.**

Rotundo, A. Morri, [13] h study is tas too evaluate the possibility of using the linear friction welding (LFW) technique to produce sound joints on a 2124Al/25 vol.% SiCp composite.

D. Ananthapadmanaban, V, Rao[14] has to study 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 .

According to H.C. Dey, M. Ashfaq,[15] the details of mechanical tests, microstructure analysis using optical and scanning electron microscopy.

3. PHASES OF FRICTION WELDING

3.1 The following are the main phases of friction welding.

3.1.1 First Friction Phase: The spindle begins to rotate and the parts are pressed in contact with each other with a force generally in range of 20.68-41.36 N/mm2 of weld area. Typically pre-heating of the weld interface occurs with no material displacement at this point. Friction duration is controlled by time. The purpose of the first friction phase is to burn off any light oils or light oxides at the weld interface.

3.1.2 Second Friction Phase: This phase controls the amount of material length loss. Approximately 2/3 of total material displacement occurs. Welding force of 41.36-82.73 N/mm2 of weld area is applied generally. The three methods of controlling the amount of material length loss in this friction phase are Time, Constant Distance and Position. With the Time method of controlling length loss, a simple timer is used to count the number of seconds when friction pressure is applied. When the pre-set time is achieved the machine rotation is stopped.

3.1.3 Forge Phase: The final phase in friction welding is the forge phase. The spindle is forced to a stop and both components are pressed against each other at extreme pressure and allowed to cool. Typically, approximately 1/3 of total material displacement occurs during this phase. There is no control as to how much material is displaced in the forge phase but it is dependent on the amount of heat generated in the Second Phase and the amount of pressure applied. Forge phase duration is controlled by time (typically only 5 to 15 seconds) and a forging force of 82.73-165.47 N/mm2 of weld area is applied generally[1].

3.3 Types / Methods of Friction Welding

The following are the different methods or types of friction welding.

3.3.1 Conventional / Continuous Drive Friction Welding: It is the most popular type of friction welding. In this process one of the parts is held stationary while other is rotated as a constant speed. The two parts are brought together under axial pressure for a certain friction time. In continuous drive friction welding the controlled parameter is:

- RPM
- Burn Off Length
- Forge Force
- Weld Time

3.3.2 Inertia / Spin / Rotational Welding: In this process two chucks are used for holding the materials to be weld. One of which is fixed and another is rotated. The flywheel and chuck rotated assembly is rotated to a certain speed to store required energy. Generally three parameters are controlled with the help of inertia welding. There are:

- Initial sliding velocity at the faying surface
- Moment of the inertia of the flywheel
- Axial thrust force at the welding interface

All these depend upon the combination of materials and the configuration of the weld.

3.3.3 Orbital Friction Welding: This method is substitute of the other friction welding. In this process one component is stationary and other move in a circular path with an orbit radius without rotating about its own axis. We have to reduce the orbit radius zero.A simple operating principle to achieve relative orbital motion involves rotating both the component in same direction with their axis offset. Axial friction force generate the heating[4].

3.3.4 Linear Vibration Welding: In linear vibration welding the materials are put under pressure and placed in contact. An external vibration force is applied to slip the pieces. Vibration the part is vibrating with small displacement known as amplitude. In this way the temperature of parts rises due to relative motion. When the temperature of layersrises to the required degree the vibration is stopped and axial pressure is increased. This technique is used automotive force.

3.4 Machine Parameters

The controlled variables also called machine parameters in friction welding are the speed of rotation, the amount of axial shortening or burn off length and weld time.

3.4.1 Peripheral Speed: The most widely used speed cycle is one where a constant speed is maintained during the friction heating phase followed by rapid heating. The rotation speed is often specified in terms of sliding speed at two third of the radius at the faying surface. In the welding of solid specimen, although the speed of rotation is kept constant, the rubbing speed across the interface varies linearly from zero at the centre to a maximum value at the outer radius. It is an important parameter in determining the maximum interface temperature and hence the final joint metallurgy. High speeds produce overheated structures whereas low speeds can produce insufficient heating.

3.4.2 Weld Time: Weld time is calculated with the help of stop watch during the joint of the two metals. Duration of heating welding of material is noted in sec.

3.4.3 Burn off Length: Burn off length is the overall length loss of the components during the application of friction force & forge force. The duration of the heating (Burn off) is selected so as to ensure that the faying surfaces are cleaned by friction and the weld zone temperature is raised to achieve the required plasticity for solid state pressure welding.

3.5 Metals and Metals Alloy Welded by Friction Welding

Friction welding have the advantage of joining similar metal and bi-metallic combinations not normally considered bondable (or "incompatible"), such as aluminium to steel, copper to aluminium, titanium to copper, titanium to stainless and nickel alloys to steel. As a general rule, all metallic engineered materials which are forgeable can be friction welded, including automotive valve alloys, tool steel, alloy steels, and tantalum. Many castings, powder metals (PM), and metal matrix composites are weld able. Bi-metallic designs allow engineers to use expensive material only where needed. Forgings and castings can be replaced with less expensive forgings or castings. They can be welded to bar stocks, tubes, plates and endless applications. [7,10].

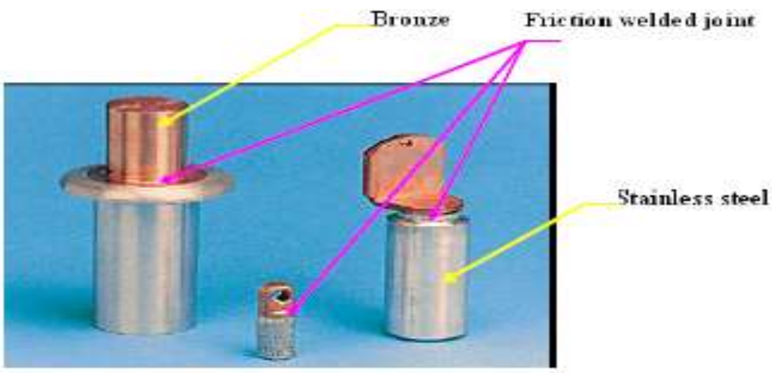

Figure 3.1 Friction welding of Bronze & Stainless steel [6].

3.6 Friction Welding of Bi-Metallic Materials:

Friction welding with dissimilar materials produces the same strength properties as parent materials and allows you to maximize and conserve your material expenditures where needed most. Hydraulic shaft is welded by using two different materials [1].A hydraulic actuator shaft for the Forestry Industry is friction welded. This bimetal weld joins a large, odd shape casting to a long. The bi-metallic materials weld by friction welding are shown in fig. 3.2.

Figure 3.2 Friction welding of aluminium and stainless steel – 304

3.7 Multiple Components Friction Welding:

Friction welding is not limited to two material types or sizes. Multiple materials and sizes are used for reduction in tooling costs and optimizing near final size.

Figure 3.3 Various materials joined by friction welding [1].

3.8 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.
- Production of pump shafts and control valve shafts, involving joints between plain carbon and corrosion resistant alloy steel (Oil and Gas Industries). Joining together dissimilar steel in the manufacture of bimetal fasteners that are used to support insulation covers for use in nuclear plant construction [5,7].
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3.9 Problem Formulation

Friction welding provides a solid state approach for joining the steels without adding any external filler material. This approach is particularly useful in joining of dissimilar welds. The reason being the absence 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.

The use of Aluminium and Stainless Steel-304 weld joints is in Nuclear Reactors. 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.

4. Eeffect of process parameters on micro structural evolution and mechanical properties of dissimilar Aluminium alloys and Stainless Steel composites.

For Microstructure examination round specimens were made flat from two opposite sides on lathe machine. After that flat sides were grinded on a disc which was attached to a belt grinder (Figure 4.1). After grinding on a rough emery paper polishing of the specimens were started[13, 14]. For this purpose different grades of emery papers were used. Specimens were polished on different grades of emery papers viz. 100, 220, 320, 400, 600, 800, and 1000. After polishing etching of the specimens were done with the help of etching liquid. Etching contains 98% of water plus 2% of HNO_3. After etching microstructure of the specimens was captured on an Optical Microscope (Figure 4.1) at 500X magnification with the help of a camera along the weld. Images were captured at different places along the weld, on interface, very near to the interface on Aluminium side, very near to the interface on Stainless Steel side, on Aluminium and on Stainless Steel.

 

Figure 4.1 Belt Grinder used for polishing & Optical Microscope used for Microstructure examination.

4.1 Micro hardness Measurements:

Micro hardness measurement of the specimens was done along the weld and at the cross section on Micro hardness Machine (Figure 4.5). stainless steel (Figure 4.4) and Aluminum (Figure 4.3) was taken along the weld hardness. On Aluminum 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, 4on Mild Steel side and 4 on Stainless Steel side..

Figure 4.2Optical microscope

4.2 Microstructure of Stainless steel-304:

The structure consists of austenite grains with annealing twins. No carbide observed within the grains & at grain boundaries.

Figure 4.3 Magnification 500x

4.2.1 Microstructure of Aluminium:
The structure consists of fine grains.

Figure 4.4Magnification 100x

4.3 Scanning Electron Microscope examination:

Figure 4.5Scanning Electron Microscope

4.4Macroscopic Behaviour

4.4.1 Microstructure Examination of Friction Welded Joints

On AL – Microstructure on Aluminium side, On SS-Microstructure on Stainless Steel side, NI SS- Microstructure near interface on Stainless Steel side, NI AL- Microstructure on Aluminium side.




Figure 4.6 on SS **Figure 4.7 on NI SS** **Figure4.8 on SS** **Figure 4.9 on Al**




Figure 4.10 on NI Al **Figure4.1 on SS** **Figure 4.12 on Al** **Figure 4.13 on NI Al**

4.4.2 Discussion of Microstructure of friction welded joint of AL & SS:

The microstructure of Aluminium base at magnifications of 100X is shown in Figure 4.4. The structure consist of fine grains. The microstructure of stainless steel base at magnification 500X is shown in figure 4.6-4.13. The large austenitic grains are clearly visible in the microstructure[11, 13].

Dendrite and reheat refined grains characterized the near interface region of the weld as shown in figure. The reheat refined region closed to the dendritic boundry develops comparatively coorser grain than the size observed in the reheat refine region away from the dendritic boundry of the interface. Therefore microstructure can be distribute in the weld of three different microstructure regions-

1) Dendritic region at interface (D)
2) Reheat refined coorse grains (RC)
3) Reheat refine grain region (RF)

The coarse grain reheat refined region (RC) primarily contains austenite and a mixture of acicular and chunky ferrite whereas, the fine grain reheat refined region AL contains fine grains. The microstructure at the different interface regions of weld metal in the friction weld.Thus, it may be concluded that the weld prepared varies within a broad range of coarseness as typically marked.

4.4.3 Micro hardness Measurements

4.4.3.1 Micro hardness measurement along the weld: The following are the table

Showing micro hardness on different specimens along the weld:

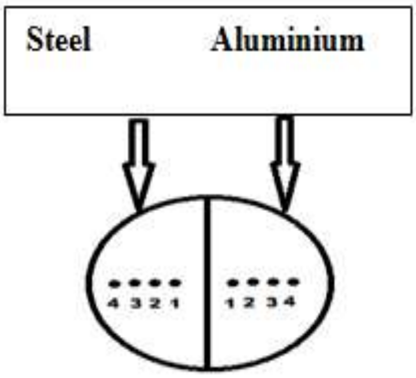

Figure 4.14 Micro hardness measurement along the weld

4.4.3.2 Discussion of Micro hardness measurement along the weld: Micro hardness measurements are taken at the base metal (Aluminium side),at interface, weld metal (Stainless Steel-304 side). Vickers micro hardness test was used and the micro harness measurements were done. Four readings at each location were taken & the average of the four readings was taken for analysis. Micro hardness variations have been studied. A maximum micro hardness of 330 has been obtained near the weld interface.

Studies on austenitic stainless steel joints using friction welding have reported a decrease in micro hardness at the interface zone of the joint.

The increase in micro hardness at the welding interface is probably due to friction and oxidation processes which took place during welding processes. This explanation is also corroborated by microscopic studies which revealed a plastically deformed zone at the weld interface. The highest micro hardness values are found to be at the weld interface and at the weld metal (Stainless Steel-304 side).

4.4.4 SEM Examination of Friction Welded Bimetallic Joints

The following are the images taken on SEM machine (Figure 4.15-4.19)

Figure 4.15 on SEM measurement

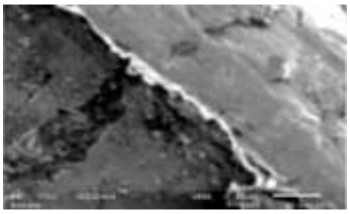

Figure 4.16 on SEM measurement

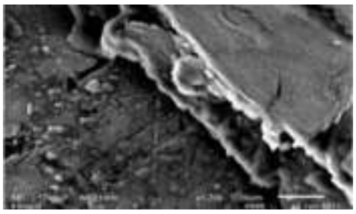

Figure 4.17 on SEM measurement

Figure 4.18 on SEM measurement

Figure 4.19 on SEM measurement

4.4.4.1Discussion on SEM: It is also observed that area fraction is increased by increasing the RPM and by decreasing the burn off length on Aluminium side. By increasing RPM burn off length keeping other parameters constant, area fraction is increasing on stainless steel side. Those undissolved regions result in increase in micro hardness values. At the interface area fraction of undissolved regions is maximum and minimum.

4.5 Major challenges in Friction stir welding of dissimilar metals

- The selection of tool materials of dissimilar metals is more difficult for friction stir welding.
- Value of Friction stir welding process variables such as tool speed, tool feed, tool shape and axial force for producing defect free welds.
- Design of fixture for holding work pieces during the welding process as high forces acting on the work pieces.
- Control the temperature at the weld zone which affects the type and nature of the intermetallics produce during the welding process.

4.6 Concern major areas of dissimilar materials are

- Characterization of Metallurgical and Mechanical properties of different welding zones.
- Magnitude of residual stresses. These stresses are responsible for crack imitation, crack propagation and fatigue crack propagation.
- Corrosion resistance susceptibility of the different weld zones.

CONCLUSIONS

In this review, a view of Friction welding of dissimilar metals focusing on Aluminium and Stainless steel based metal matrix composites has been discussed. This review presents study on effect of process parameters on microstructure evolution and mechanical properties of the Aluminium and Stainless steel based dissimilar welded joints. In this review many papers suggest that the fine grained friction welded Aluminium and Stainless steel alloys exhibits improve the strength as well as ductility of the welded joint. They were also observed that the best tensile and fatigue properties obtained many alloys placed on advancing side at low welding speeds. Friction welding has been successfully employed to weld dissimilar steels. Strength of the joints obtained was good. In UTM machine sample is broken on aluminium side so the values of Ultimate Tensile Strength for welded specimens were greater than that of aluminum bars in all cases. Microstructure evaluation of the friction welded joints revealed different zones namely, Reheat refined coarse grain region AL (RC), dendritic region Interface (D), Reheat refined fine grain region SS (RF).Highest micro hardness values are formed at the weld interface and SS regions for welded specimens. At interface and AL maximum area fraction of undissolved regions is formed through the SEM examination. These undissolved regions results in higher micro hardness values. Temperature modeling 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) Residual stress measurement can be carried out to relate with temperature profiles measured during friction welding.
3) Modeling 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 are 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) Modeling of residual stress generation during friction welding can also be carried out.

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