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Review of experimental investigation in friction welding process

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Abstract-Now a day the industries are in huge demand of new materials essential for their requirements for different applications such as aerospace, railways and automobile & chemical Industry. The joining of metals, which are not possible to weld with fusion welding , which has hard inter metallic compound which will leads to brittle joint, can be done with the friction welding process. In this Technology, the required heat to fuse two metals to join with each other without melting is caused by means of rotary friction. In this paper review of friction welding process for joining of various metals and the effect of parameters on the welding process has been discussed in brief.

Keywords – solid state joining, friction pressure, upset pressure, IMC layer

1. INTRODUCTION

Friction welding is a solid-state welding process that generates heat through mechanical friction between work pieces in relative motion to one another, with the addition of a lateral force called "upset" to plastically displace and fuse the materials. Because no melting occurs, friction welding is not a fusion welding process in the traditional sense, but more of a forge welding technique. But at the weld interface it generates inter metallic component (IMC) which will lead to brittle joint. The definition of friction welding in the American Welding Society (AWS) C6.1-89 standard is as follows: Friction welding is a solid-state joining process that produces coalescence of materials under compressive force contact of work pieces rotating or moving relative to one another to produce heat and plastically displace material from the faying surfaces. Under normal conditions, the faying surfaces do not melt. Filler metal, flux, and shielding gas are not required with this process. Practically there are two basic types of friction welding techniques; continuous drive friction welding and inertia friction welding. Here continuous drive friction welding is used in which two chucks are used to hold the work piece to be weld, one is fixed while the other one is rotating by the continuous drive motor in heating stage, the clutch is used to disconnect the chuck & motor and the brake is used to stop the rotation. Fig. shows the RFW.

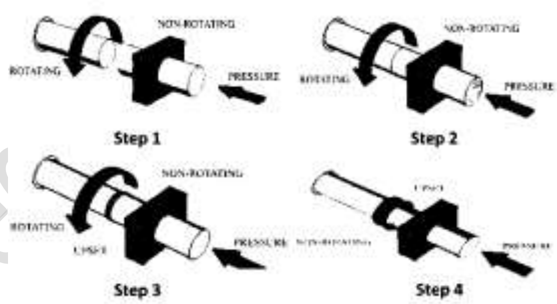

Fig. 1 Friction welding process

- It allows the joining of dissimilar materials.

- There is not any external heat or flux.

- Minimal or no defects found in joint.

- Speedy process and not required surface preparation.

In friction welding the five parameters control the weld characteristics which are friction speed, friction pressure, upset pressure, burn-off length and weld time.

Today there are various types of friction welding is available.

1.1 Continuous Induce Friction Welding/Rotary Friction Welding (RFW):

Rotary friction welding (RFW), for plastics also known as spin welding, uses machines that have two chucks for holding the materials to be welded, one of which is fixed and the other rotating.

In direct-drive friction welding (also called continuous drive friction welding) the drive motor and chuck are connected. The drive motor is continually driving the chuck during the heating stages. Usually, a clutch is used to disconnect the drive motor from the chuck, and a brake is then used to stop the chuck.

1.2 Linear Friction Welding (LFW):

Linear friction welding (LFW) is similar to spin welding, except that the moving chuck oscillates laterally instead of spinning. The speeds are much lower in general, which requires the pieces to be kept under pressure at all times. This also requires the parts to have high shear strength. Linear friction welding requires more complex machinery than spin welding, but has the advantage that parts of any shape can be joined, as opposed to parts with a circular meeting point. Another advantage is that in many instances quality of joint is better than that obtained using rotating technique. The most important parameters in the LFW process are Friction Pressure, Forging Pressure, burn-off, frequency, Amplitude, Stick out and perhaps their respective ramps or variation against time.

1.3 Linear Vibration Welding:

In linear vibration welding, the materials are placed in contact with each other and put under high pressure. An external vibration force is then applied to rub the pieces against each other, perpendicular to the pressure being applied. Both the work piece are vibrated at 200 Hz frequency. Mostly this technique is used in the automotive industry.

1.4 Friction Stir Welding (FSW):

Friction stir welding (FSW) is a solid-state joining process that uses a non-consumable tool to join two facing work pieces without melting the work piece material. Heat is generated by friction between the rotating tool and the work piece material, which leads to a softened region near the FSW tool. While the tool is traversed along the joint line, it mechanically intermixes the two pieces of metal, and forges the hot and softened metal by the mechanical pressure, which is applied by the tool, much like joining clay, or dough. A rotating cylindrical tool with a profiled probe is fed into a butt joint between two clamped work pieces, until the shoulder, which has a larger diameter than the pin, touches the surface of the work pieces. The probe is slightly shorter than the weld depth required, with the tool shoulder riding atop the work surface. After a short dwell time, the tool is moved forward along the joint line at the pre-set welding speed.

1.5 Friction Strip Spot Welding (FSSW):

Friction stir spot welding is one of the types of friction stir welding with one major difference. In friction stir welding, the tool is moved along the seam of the work pieces. However, in friction stir spot welding, the tool is rotated at a spot and not moved. It spins and creates a weld, and the tool is lifted up, creating an exit hole where the profiled pin was injected. The speed at which the relative motion occurs and the pressure applied on the work pieces depends on the magnitude of the heat needed to create the weld between the two metal parts. For steel, friction welding generates anywhere between **900** and **1300 Celsius**.

1.6 Inertia Friction Welding:

Many use inertia welding and friction welding synonymously. However, inertia welding is a type of friction welding. To be precise, inertia welding is a type of rotary friction welding. It gets the name inertia welding from the way the rotation takes place. In this joining technique, one of the work pieces is kept stationary while the other is mounted on a spindle. The spindle is made to rotate at high speed to generate friction between the two metallic surfaces. Here, the maximum rpm of the spindle is fixed and is based on the type of material that it holds and the temperature that it should reach to weld the two pieces together. Once the spindle reaches the top rpm, the drive disengages and the stationary work piece is trust into the rotating work piece. The work piece continues to rotate on its own due to the inertia force resulting from the kinetic energy.

1.7 Friction Surfacing:

This process is derived from a friction welding process where a coating material is applied to a substrate. Basically it is a surface coating process. A rod composed of the coating material which is called mechatrode. Then it is rotated under pressure, generating a plastic-type layer in the rod at the interface with the substrate. By moving a substrate across the face of the rotating rod a plastic-like layer is deposited.

2. LITERATURE REVIEW

Alex anandraj *et al* [1] investigated the mechanical and metallurgical properties of In718/SS410 friction welded joint. The welding has been carried out by the numerically control friction welding machine. For the mechanical and metallurgical properties tensile test and micro hardness test (Vickers micro hardness test) has been carried out.it has been found that the optimal joint for the tensile strength was found at 1300 rpm, friction pressure of 220MPa and forging time of 10 sec. the weld zone consist refined grain structure, the failure observed in higher hardness region of martensitic stain-less steel side due to sever hard phase martensite present with retained austenite structure.

Bkkiyaraj *et al* [2] used response surface methodology to evaluate the tensile strength of the friction welded joint of AA6061/AA7075-T6. The parameter for the joint was taken as trial base after getting the upper and lower limit, inter mediate parameters was found from the relation and they predicted the tensile strength from the Response empirical equation and the accuracy of the equation was checked by ANOVA method. It was observed that lower value of parameters leads to weak joint because of insufficient heat generation which result in poor consolidation material, on the other hand higher parameter leads to high heat generation which cause ejection of hot materials from the weld zone. Optimal parameter will leads to high tensile strength of the joint.

Ho Thy My Nu *et al* [3] studied the rotary friction welding of titanium alloy (Ti_6Al_4V).It was investigated by numerical analysis and experiments. The joint was found with higher tensile strength then the base metals. During the initial stage temperature of the interface is increased rapidly, while the temperature becomes constant or uniform during the steady friction stage.

Marian *et al* [4] Fully automated system for the friction welding of the pipeline system of diameter up to 400mm, it produces welding of API 5L X46 within 5 min defect free joint. With the use of ring ASTMA516, the welded region displayed over heated microstructure and highest hardness value oat the center ring. It has fracture toughness, the values in the HAZ and centers of the ring decreased as a result of the modification of the microstructure and the MnS inclusions imposed by the friction process.

Prandhaman *et al* [5] they studied analysis of friction welding on conventional lathe machine by joining the aluminum/mild steel on lathe, the quality of the joint and mechanical properties has been studied by taking various tests on weld (like-tensile test, micro-hardness test). The weld was successfully made by the lathe machine and with no defect like porosity, hot cracking. It has high static strength and concluded that conventional lathe has low cost than that of the friction welding machine.

Masaaki *et al* [6] they studied effect of parameters on the tensile strength of the friction welded joint of 5052 aluminum alloy/pure copper. It was found that the joint made with 30MPa fractured at weld zone because of non-joined fraction present at the interface. By increasing the forge pressure this non-joined region has been reduced. At the region near to the AA5052 it has mixed laminar structure of OFC/A5052 this layer influence the fracture point in the weld zone. The mechanically mixed layer can be reduced by decreasing friction time and increasing friction pressure after peak torque, Then, the joint, which had the same tensile strength as the A5052 base metal, the fracture on the A5052 base metal with no crack at the weld interface, and less mechanically mixed layer with no the intermetallic compound (IMC) interlayer on the weld interface, could be successfully achieved.

Ananthapadmanaban *et al* [7] studied the mechanism of friction and their correlation to the bond strength of the friction welded Ti_6Al_4V similar welds, low carbon steel/stainless-steel & Al/Cu dissimilar weld. Mechanism has different effect on various joints of dissimilar materials. The dominant effect on the tensile strength of the LCS/SS was thought to be recrystallization at weld and diffusion of chromium in weld zone. Effect on the weld of Al/Cu bond strength of the weld could be cold deformation due to high forge pressure without any recrystallization at moderate or high speed of rotation but a combination of high frictional heat generated at low speeds and high upset pressure, at low speeds. The mechanism having a major impact on the friction welding and bond strength of Ti-6Al-4V could predominantly be bond unsaturation.

Dusan *et al* [8] they studied the influence of parameters on the mechanical properties, microstructure and hardness of the friction welded joint of Al/cu joint, joining of the Al/Cu was made by friction welding by selecting the proper technical parameters for the process. Analyses of the experimental results have shown that the basic process parameters significantly influence joint's structural and mechanical characteristics. If the optimal welding conditions were applied, it is possible to achieve the joint's strength, which is at the level of the aluminum strength, which means that during the tensile test the break must occur outside the joint zone. If that was achieved, then the bimetal Al-Cu friction welded joint is considered as the high quality joint.

Muralimohan *et al* [9] has improved the mechanical properties of the joint Ti/SS by inserting the Al ring between the weld. The thickness of remaining insert metal decreasing with increasing upset pressure, due to the increasing of burn off rate of the insert metal which has come out as a weld flash. The strength of aluminum insert weld archived higher strength then direct joint. The strength of the joint is increased by increasing the upset pressure. SEM-EDS analysis confirmed that the presence of TiAl and Al3Ti intermetallic compounds formation which are more ductile than the FeTi and CrTi intermetallic compounds of direct joints.

Reddy *et al* [10] investigated the mechanical characterization of AA6061-T6 pipes by the continuous drive friction welding, they also studied the taguchi’s orthogonal arrays of L25 for the optimization of parameters and analysis has been done by ANOVA method. most of the joints failed at away from the weld region. From the micro hardness of samples understood that heat affected zone is not plays a vital role to fail the joint. From the analysis of mean effect plots it is transparent that burn off length of 3 mm, friction force of 0.6 Tons, upset force of 2.1 Tons, upset time of 0.75 sec and speed of 2000 rpm was the optimum parameter for maximizing the ultimate tensile strength of the joint By increasing the forge pressure causes more deformation on the metal. At the weld zone the size of the grains is closure to each other which is responsible for higher strength of the joint. hardness of the joint were degreases from weld region towards the parent metal comparatively. From the micro hardness it is found that the hardness value is at heat affected zone and weld zone is an average 8% greater than the hardness in base material.

Zhida Liang *et al* [11] has studied Continuous drive friction welding of 5A33 Al alloy to AZ31B Mg alloy The width of the FDRZ and TMAZ in Mg side was much larger than that in the Al side. A reaction layer formed in the friction interface between Al bar and Mg bar. The thickness of reaction layer increased as the friction time increased from 1 s to 3 s and then decreased gradually with increasing friction time from 3 s to 10 s. The micro hardness of Al/Mg friction interface was higher dramatically than that of the Mg base material. The thickness of hardened layer on the Mg side increased as friction time increased. On the Al alloy side, the micro hardness in the zone close to the friction interface was lower than that of the Al base material. The thickness of softened layer increased as friction time increased. When friction time was no less than 3 s, the micro hardness in the zone close to the friction interface of Al side had almost same value with that in the zone close to the friction interface of Mg side.

Koteswara *et al* [12] they studied the effect of speed on the hardness of the friction welding. It was observed that the hardness values were gradually increased from the weld zone. Where as in aluminum material it vice versa. The hardness value of brass was higher than the other welded joints and least value of hardness was for aluminum at welded zone. The hardness value was increases as the distance increases from the welded zone. Where as in copper and aluminum at weld zone hardness values were decreased. As the speed increases the hardness values were increases and higher values of hardness for the speed of 2700 rpm and least value of hardness for 1600 rpm.

Anantkirtay *et al* [13] investigated the effect of burn off length on the joint of friction welded material Inconel 718/SS304. The study discussed use of Design of Experiments by Taguchi Method. Here Orthogonal Array of L27 is used. Using multiple linear Regression and ANOVA effects on the burn-off of welding by Welding Parameters (Rotational Speed, Friction Pressure and Time) are analyzed using MINITAB 17. The experiment concluded that the Speed is the main factor for θ = 30 degree taper angle model that is affecting the Burn off Length. Other parameters such as Friction pressure, Time and Taper angle are contributing but not at a large scale so they can be neglected or can be taken as noise. For θ = 45 degree taper angle model, the factor which is maximum contribution is Time and then speed and Friction pressure. As the time increased burn off length also increased. For θ = 60 degree taper angle model, we can consider friction pressure as a main factor that is affecting the burn off length. And other parameter such as speed and Time are very less contributing so can be taken as noise.

Arun *et al* [14] they Design and Construct a Friction Welding Attachment on Lathe, Conduct Experiment and to Study about Mechanical Behavior of Friction Welded Joints of Aluminum Rods. Aluminum alloys (AA6061) were welded successfully. The welding process was investigated by tensile testing, SEM factography analysis, micro structure analysis and Rockwell hardness test

Shanjivii *et al* [15] investigated the effect of parameter on impact strength of friction welded joint of dissimilar metals. The impact test is conducted as per ASTM standard. The quality and the strength of the bond produced are also varied. Higher the burn-off length with low upset pressure decreases in impact toughness of friction-welded joint whereas with low burn-off and high upset pressure results in increase in toughness of welded joint. Due to temperature rise at the weld interface and presence of intermetallic layers, accumulation of alloying elements results with poor impact toughness of the welded joint. Fracture analysis was made in the impact tested sample with different magnifications result in ductile mode of fracture with dimple formation.

Kimura *et al* [16] studied Effect of friction welding condition on joining phenomena, tensile strength, and bend ductility of friction welded joint between pure aluminium and AISI 304 stainless steel. When joint were made at a friction pressure of 30 MPa with a friction speed of 27.5 s−1, the upsetting (deformation) occurred at the CP-Al base metal. CP-Al transferred to the half radius region of the weld interface on the 304SS side, and then it transferred towards the entire weld interface. The temperature on the weld interface increased with friction time, and it reached to 573 K or over at a friction time of 0.6 s or longer. When joints were made at a friction time of 0.6 s, i.e. the friction torque close to the initial peak, it had the joint efficiency of approximately 70% and fractured at the weld interface. Some joints, that were made at a friction time of 2.0 s or longer, had the mixed mode fracture (between the CP-Al side and the 304SSside) and the CP-Al side fracture. However, the joint efficiency of 100% was not obtained because the CP-Al side at the adjacent region of the weld interface softened. The joints, which were made at a friction time of 1.0 s with a forge pressure of 150 MPa, had the bend ductility of 90◦in a single direction with no crack at the weld interface. This joint had also the bend ductility of 90◦in reverse direction with no crack.

Zhao *et al* [17] investigated Realization of ODS-Cu/T91 Tube-to-tube Joining with Rotary Friction Welding. Tube-to-tube joining has been realized between ODS-Cu and T91 with RFW. They did not find any defect at the interfaces in all specimens. Asymmetric diffusion of elements has been detected by EDS. Very narrow soft regions were found in ODS-Cu at the vicinity of the interfaces in all specimens. All the tensile specimens have appreciable strengths but exhibit brittle characteristics. Both two as-received specimens were not broken after the scheduled rotary bending fatigue testing. The tensile brittleness can be explained by the existence of the very narrow soft regions, and the formation of the soft regions can be explained by high temperature softening of ODS-Cu induced by RFW. The asymmetric diffusion may be a factor that contributes to the abnormal hardening in the soft regions in ODS-Cu. Based on our discussion, in order to solve the problem of tensile brittleness, the RFW parameters should be further optimized to either enlarge the width of the soft region or completely eliminate it.

Masaaki *et al* [(18)] studied the characteristics of pure titanium and low carbon steel friction welded joint with post weld heat treatment. The joint efficiency was defined by the ratio of the joints tensile strength to the ultimate tensile strength and when the joint was made with 150 MPa friction pressure efficiency was 81% at friction time of 0.5 sec. The joint efficiency increased by increasing friction time and same joint had joint efficiency of 100% at friction time of 1.5 second more. Vickers hardness of the joint made with 0.5 sec has higher hardness value than that of made with 2 sec. However it did not have soften region. The characteristics of PWHT joint it shows that the joint efficiency decreased with increasing heating temperature. X-ray diffraction analysis shows that the PWHT joint has the void at weld interface. That is of the reason for the fracture of joint. It concludes that joint between the CP-Ti & LCS at elevated temperature of 1073K is undesirable.

Vankat kaushik *et al* [(19)] investigated the friction welding of H30 Al/BS970 MS. They performed tensile test, Rockwell hardness test and metallographic analysis. Flash was formed on Al side; MS restrict the formation of flash because it has higher strength. Upset pressure and Upset time has greater effect on joint strength, increase in upset pressure and upset time will increases the strength of the joint for some specific point after that the strength will decrease. Rockwell no .was calculated on the base of B-scale hardness M/c value and it was observed that max. Hardness no. obtained for Rockwell for sample using cylindrical tool at speed 3000 rpm, Feed 30 mm/s. microstructural changes was not observed near the interface region as it occurs in the fusion welding process.

Masaaki *et al* [(20)] studied the Joint properties of friction welded joint between 6061 Al alloy pipe and Al-Si12CuNi (AC8A) Al cast alloy pipe. They has made joint successfully and noticed that When joints were made with a friction pressure of 25 MPa, a friction speed of 27.5 rps, and a forge pressure of 30 MPa, the joint strength increased with increasing friction time, and it was approximately 40 % of the ultimate tensile strength of the AC8A base metal at a friction time of 2.0 s. all joints fractured at the weld interface between the AA6061 side and the AC8A side, which had an AC8A adhering to the weld interface on the AA6061 side (mixed-mode fracture). When joints were made at a friction time of 0.3 s with the same friction pressure and friction speed, the joint strength increased with increasing forge pressure, and it was approximately 60 % of the AC8A base metal at a forge pressure of 175 MPa. Many joints had the fracture at the AC8A side although one of the joints had at the mixed-mode fracture. Additionally Flash with friction time of 2 sec had more than 0.7sec.

Anusha *et al* [(21)] was investigated the weld-ability of Al with MS using friction welding process. They used H30 Aluminum and BS 970 Mild steel for the study. For the frition welding of the material they taken A friction welding machine of brand UNITECH configured M250 with fixed speed of 3000rpm, after welding was performed, tensile test was carried out to evaluate the mechanical properties of the juncture. For the metallographic test the junctures were cut in transvers weld, embedded in an array of Bakelite, polished and examined in the region of Al/MS interface. From the various test result it is possible to weld the dissimilar metals Al/MS by friction welding which will not made by fusion welding. The heat affected zone (HAZ) is wel fused and defect free from nonmetallic defects.

Nandhini Ravi *et al* [(22)] studied the effect of welding parameters in friction welding of hollow engine valves. They study the friction welding process to weld hollow engine valves by considering the optimum process parameter; Material of the valve was selected $X_{15}CrSi_{9\text{-}3}$(Martensitic stainless steel). To check for the efficient weld joint they tested sample for the tensile strength, micro hardness test and they optimized their parameters by Response surface methodology (RSM). They found 891.552MPa tensile strength. Hardness was measured and was found to be high at weld zone, low at heat affected zone and then low in base mate.

Kimura *et al* [23] studied Joint Properties of Friction Welded Joint between Pure Magnesium and Pure Aluminium with Post-Weld Heat Treatment. The joint properties of friction welded joint between pure magnesium (CP-Mg) and pure aluminium (CP-Al) with post-weld heat treatment (PWHT). The followings were concluded.1) The joint in as-welded condition, which was made with a friction speed of 25 s−1, a friction pressure of 50 MPa, a friction time of 1.0 s, and a forge pressure of 90 MPa, had approximately 100% joint efficiency. However, this joint fractured from the adjacent region of the weld interface. In addition, this joint had the intermediate layer (interlayer) consisting of intermetallic compound (IMC) on the weld interface, and its thickness was below approximately 1 μm. 2) Most of joints subjected to PWHT autogenously fractured at IMC interlayer and that mainly occurred between Mg2Al3 and Mg17Al12 although those layers had a little each other at the fractured surfaces. That is, this joint was approximately 0% joint efficiency, and the IMC interlayer was composed with mainly Mg2Al3 on CP-Mg side and Mg17Al12 on CP-Al side.

Sori won *et al* [24] studied Corrosion Behaviors Of Friction Welded Dissimilar Aluminum Alloys. The influence zone where galvanic effect gives an impact is revealed to be only near the interface, which seems to be ascribed to the slow ionic transport in the electrolyte. Analysis on the capacitance characteristics in Bode plots indicates that the degrading corrosion performances of the weld as well as AA2017 with immersion time would be ascribed to the formation of the micro-galvanic cell, while the improvement of the corrosion performance observed in AA6063 would be related to the growth of the passivation layer. As the main loss of the anodic metal occurs near the joint interface as a result of galvanic corrosion, the consideration on the dimension of the anodic metal that accommodates the dimension reduction occurring in the anodic metal near the interface should be conducted to maintain integrity of the joint.

3. CONCLUSION:

Friction welding is solid state welding process in which the require heat will generate due to friction between the metals by relative motion, the faying surfaces are in plastic zone which temperature is below the melting temperature of the base metals, and the joint are sufficiently made successful by applying optimum forge/axial force for the determined weld time. Due to the plastic deformation of the zone there is no intermetallic component (IMC) to brittle the joint. Friction welding enables joining dissimilar metals; there is no external application of heat or flux, Minimal or no defects, doesn't need much surface preparation, Very fast process, Does not need much surface preparation.

In this paper review of effect of various parameters on the friction welding of similar or dissimilar metals are discussed. Successful and quality joint are made by selecting the optimum value of the process parameters. Improper selection leads to the defects in the joint like porosity, non-joined area in weld zone, failure of joint. From the observation summarized that the friction pressure, friction time, forging pressure, forging time, rotational speed and burn off length are the most effective parameters for the friction welding process. Increase in friction time will increases impact strength of the joint, increase in rotational speed will minimizes the IMC formation; increase in burn off length will decrease impact toughness and increases ultimate tensile strength. Aluminum alloys, AL, MS, SS, Cu, LCS, Ti etc. Metals can be frictionally welded.

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