Literature Review on Friction Welding

J. Joshva[1], Prof.M.Deepak Kumar[2]
[1]*PG Scholar, Department of Metallurgical Engineering, Government college of Engineering, Salem.11*
[2] *Assistant professor, Department of Metallurgical Engineering, Government college of Engineering, Salem.11*

***Abstract*-Friction welding provides a solid state welding process without adding any external filler material. It is useful for joining of metallic and bimetallic welds. These metallic and bimetallic welds impose a safety issue for the structural engineers. The metallic and 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 stress. This paper the research review for metallic and bimetallic welds.**

Keywords: Friction Welding, Metallic Weld, Bimetallic Weld

I. INTRODUCTION

The friction welding is a Solid state welding process or the method of manufacturing for joining different types of metals, i.e., ferrous metals and non-ferrous metals (dissimilar metals). In friction welding, heat is generated by friction when the two materials joined together (one is rotate and another specimen is stationery) the temperature and pressure increase so the mechanical energy convert into thermal energy. Then it is (friction welding) so easy to join ferrous metal and non-ferrous metal, there are some parameter used in friction welding as forging (upset) time, forging (upset) pressure, friction time, friction pressure, temperature measurement, burn off length and rotation speed

II. LITERATURE REVIEW

Gaurav Verma et al., [1] have worked on different combinations of similar dissimilar friction welded joints. A horizontal lathe machine was used in this experiment. Friction welded joints between Mild steel-mild steel, Stainless steel-stainless steel, Mild steel-Stainless steel, were studied and their properties were reckoned. The specimens were 10 mm in diameter and 10 cm in length. Six experiments were conducted (two experiments for each combinations) with two varying rotational speeds. The result exhibited that the joints formed at higher RPM have higher strength compared to joints fabricated at a lower RPM.

P. Venkat Koushik et al., [2] have worked on dissimilar friction welding of H30 aluminium and BS970 mild steel. The specimen were both of 8 mm diameter and 200 mm length. The upset time and the upset pressure were varied, keeping the other process parameters constant. Four welded joints were formed between the specimens, and the observed results exhibited that when the upset time and upset pressure were further increased beyond the optimum level, the strength of the bond decreased and finally failed. The optimum levels were 200 Mpa (upset pressure) and 6 seconds (forging time). This was attributed to the cause that there was no elemental bonding between the two materials because of the high forging pressure. Thus proving a direct relationship of upset pressure and upset time with joints fabricated.

C. Shanjeevi et al., [3] conducted experiments on joining dissimilar materials namely, austenitic stainless steel (AISI 304) and copper. The specimens were 24 mm in diameter and 75 mm in length. The Taguchi Orthogonal array of 27 tests, 4 variables and 3 levels were used in this experiment. The four variables were friction and forging pressure, burn-off length and rotation speed. The combination of higher frictional pressure with low forging pressure tend to increase the soundness of the joints relative to the combination of lower frictional pressure with high forging pressure. And also it was noted that an intermetallic layer was developed at the bonded region due to high friction time. This also decreased the bond strength between the metals. (The optimum conditions were friction pressure of 33 Mpa, upset pressure of 108 Mpa, rotational speed of 1500 RPM and burn-off length of 1 mm).

R. N. Shubhavardhan et al., [4] analysed the friction-welded joints fabricated between AISI 304 and

AA6082 aluminium alloy. The specimen dimensions were of step cut bars of AISI 304, 18 mm outer diameter and extruded part 14 mm in diameter, and step cut bars of AA 6082 aluminium alloy, 17 mm outer diameter and 15 mm inner diameter. The operating parameters namely, rotational speed, upset time, upset pressure were kept constant and friction time, friction pressure were varied during this experiment. The observations made clearly indicated that the outer region was seen well bonded while at the middle, the weld interface was left unbonded. This is because, the temperature was higher at the outer region than the inner region during the friction stage. Thus when the friction time and friction pressure were increased, the strength of the friction-welded joints increased and on additional increase in the values, the strength was noted to be decreasing. The optimum levels were friction pressure of 104M pa, friction time 5 seconds, forging pressure 210 Mpa, forging time 6 seconds and 1400 RPM.

Jeswin Alphy James et al., [5] have worked on joining dissimilar steels such as Stainless steel 304 and AISI 1040. And, also analysed the properties of weld along with/ without inclusion of Nickel interlayer. The parameters such as rotational speed, upset pressure and burn-off were varied in this experiment. The specimens were AISI 1040 cylindrical rods, 75 mm length and diameter 10 mm and SS304 of length 55 mm, diameter 10 mm with holding side of diameter 20 mm. A 50±3 μm thick interlayer was used in this experiment. The maximum strength was obtained when nickel was used as an interlayer which reduced the inter metallic compound being formed at the weld interface. The optimum conditions were rotational speed (2200 RPM), upset pressure (1.570 ton) and burn-off length (8 mm).

B. Jeslin et al., [6] chose Aluminium Alloy 6082 T6 & Copper to fabricate friction welded joints. Both the specimens were 12mm in diameter and nine welded joints were fabricated using the Taguchi design of experiments. Three parameters namely friction pressure, upset pressure and friction time were varied and among these parameters, upset pressure was said to have major impact on the bond strength followed by friction time and friction pressure. The optimal conditions were found out to be friction pressure and upset pressure (43.6 Mpa), friction time (50 seconds) and upset time (2 seconds).

D. Ananthapadmanaban [7] has identified the errors for the case of friction-welded joints fabricated between Low carbon steel-Stainless steel, Aluminium to copper and similar Ti-6Al-4V welds. He concluded that in case of Aluminium-copper welds, lower the rotational speed, higher is the frictional heat generated which could lead to better bonding and higher tensile strength. And in case of weld joints of similar steels high upset and burn-off produced better results and diffusion of chromium at the weld interface was observed.

C. H. Muralimohan [8] have studied the significance of process parameters on the dissimilar welds between AISI 1040 (Medium carbon steel) and AA 6082-T6 aluminium rods (each of 10 mm diameter and 80 mm length). The friction time, upset pressure and friction pressure were varied keeping the others constant. The visual observations indicated flash formation at the interface and the density of the flash increased with an increase in upset pressure. And, thus they concluded that upset pressure is more vital than the friction pressure and the friction time.

P. Rombaut et al., [9] gave a clear summary on the friction-welded joints between steel and ceramics. He used Aluminium as an interlayer in this process and so classified his study based on two weld interfaces such as a steel/ aluminium weld interface and an aluminium/ alumina weld interface. The observed results clearly pointed out that the addition of interlayer was essential to reduce the residual stresses and also to increase the strength of the friction-welded joints. And in addition, the intermetallic compound (IMC) is another factor found to be influential on the bond strength. Although, intermetallic compound in small amounts produces sound welds but, thickness exceeding 1 μm is found to deplete the bond strength.

Y. Lekhana et al., [10] analysed the weldability of 316 stainless steel and AA1100 hollow tubes through friction welding process. The friction welding process was done through Finite element analysis. A 3D model of materials, each of 25.4 mm diameter and 100 mm in length was made using the ANSYS workbench. Taguchi design of experiments of L9 was selected for optimization of the process parameters. And, structural analysis was also conceded for bulk deformation, equivalent stress, penetration and sliding (responsible for the flash formation) at the weld interface. Friction and forging pressure tend to have great impact on the penetration levels and friction pressure, friction time tend to affect the sliding at the weld interface. The optimum conditions were friction pressure of 80 Mpa, rotational speed of 2000 RPM, friction time of 5 seconds and forging pressure of 160 Mpa.

Ozdemyr et al., [11] conducted experiments for optimization of friction parameters on the joints formed between AISI 304L and AISI 1040 steels. The specimens were 12 mm diameter rods each. 27 welded joints in total were fabricated, and the forging pressure is assumed to be twice that of the friction pressure in this study. The visual observation indicated the flash formation at the weld interface which corresponds with increasing the rotational speed, friction time and friction pressure. The combination of higher rotational speed with lower friction time tend to produce an excellent strength of the welded joints which in turn lead to a Fully Plasticized Deformed Zone (FPDZ) at the weld interface. The FPDZ and Deformed Zone width are mainly reliant on the friction time and rotational speed. The optimum conditions were rotational speed of 1700 RPM, friction time of 4 seconds, forging time of 2 seconds, friction pressure of 50 Mpa and forging pressure of 100 Mpa. M.

Azizieh et al., [12] investigated on the joint design on the faying surfaces. They selected ST37 steel and CK60 steel each of 15 mm diameter with two different joint designs namely flat and round heads. The visual observations showed that flash formation was more at the CK60 side, and had a higher temperature difference even higher than the weld interface leading to a higher flash volume. In general, the round head samples showed higher tensile strength, higher burn off and higher welding flash than the flat head samples.

G. Madhusudhan Reddy et al., [13] analysed the use of an interlayer on the friction welds between AISI 4340 and AA6061 (16mm diameter cylindrical rods each). Low burn-off length was initiated in this experiment to lower the heat input which results in less time for the intermetallics formation. A silver interlayer of 20 µm was electroplated on the AISI 4340 side. There was a clear indication that the presence of silver interlayer increased the strength and ductility of joints since the Fe-Al based intermetallics were partially replaced by Al-Ag based inter metallics which are naturally ductile.

Uday M. Basheer et al., [14] studied impact of rotational speeds on the alumina- 6061 aluminium alloy rod joints through continuous drive frictional welding. The specimens were 15 mm diameters each. Varying rotational speeds of 1250 RPM, 1800 RPM and 2500 RPM were used in this experiment with constant friction pressure and friction time. He concluded that the Heat affected zone (HAZ) was very thin, if not non existent in case of 1250 RPM welded joints and furthermore showed cracks and unjoined regions. The joints fabricated at 1800 RPM showed the presence of three different regions and visibly a good joint was achieved. At high speeds of 2500 RPM, the brittleness nature of alumina couldn’t withstand resulting in failure and a broad HAZ was formed due to large amount of specimen being pushed out of the weld zone.

Uday M. Basheer et al., [15] compared the bond strength of Alumina 0,25wt.% YSZ content to 6061 Aluminium alloy (16 mm diameter rods) through friction welding with varying rotational speeds. Since pure alumina lacks the fracture toughness, Zirconia stabilizer has been added to pure alumina to increase the toughness and zirconia also inhibits the alumina grain growth. The soundness of the weld was found through a four - point bend test. They concluded that the bending strength results of alumina-25 wt % YSZ composite joint were greater at lower rotational speeds. while, the results at joints with pure alumina were smaller at higher rotational speeds due to the higher thermal stress during the joining process. The optimum levels were friction pressure (7 Mpa), friction time (60 seconds), forging pressure (10 Mpa) with a forging time (45 seconds) and rotational speed of (630 RPM).

Radosław Winiczenko et al., [16] investigated on the effect of different interlayers on the friction welded joints between ductile iron. A ferritic, pearlitic, and bainitic matrix ductile iron was produced using different parameters of heat treatment. This experiment was carried out using 20 mm diameter and 100 mm length bars. Two different interlayers were used namely stainless steel and armco iron. The observed results were that the ferritic ductile irons welded with stainless steel as the interlayer showed the lowest tensile strength and the highest was for bainitic structure ductile iron with Armco iron as the interlayer.

G. Subhash Chander et al., [17] investigated on the joints between AISI 304-AISI 4140 through continuous drive friction welding with different rotational speeds keeping the friction force, upset force and burn off constant. The visual observations sighted the flash formation at the joint line and density of flash was larger on the AISI 4140 steel side. And, it was also observed that the deformation rate in the friction stage decreases with increase in values of rotational speed. And in forging stage, deformation rate increases with increase in values of rotational speed. Thus, the rotational speed had to be in optimum level so as to obtain better results and thus have a direct relationship with the deformation rate of the friction-welded joints.

Mumin Sahin [18] studied the effect of different diameter ratios on the plastically deformed austenitic stainless steels (AISI 304) through continuous drive friction welding. A prior plastic deformation was done on AISI 304, and parts of different or equal diameters were friction welded. Friction time and friction pressure were varied, keeping the other parameters constant. The optimum conditions were friction pressure of 60 Mpa, friction time of 9 seconds, upset time 20 seconds and upset pressure of 110 Mpa. It clearly indicated that the prior plastic deformation doesn't have any influence on the process variables or on the weld strength. And, the strength of the friction-welded joints decreased as the diameter ratio were increased in the plastically deformed parts.

N. Ozdemir [19] chose AISI 304L and AISI 4340 steels, each of 12mm diameter to study the bond strength of the friction-welded joints. Five weld joints were fabricated with varying rotational speed and all other parameters to be considered constant. The microstructural studies for AISI 304L/ AISI 4340 friction welded joints revealed that there were four different regions at the interface and the width of these regions change as a function of rotational speeds. The tensile strength tend to be greater in the samples which were welded at higher rotational speeds. And so, higher values of rotational speed, friction pressure and upset pressure, along with low values of friction time should be applied to obtain sufficient strength of the joints. The optimum levels were rotational speed of 2500 RPM, friction pressure of 40 Mpa, forging pressure of 60 Mpa, friction time of 5 seconds, forging time of 10 seconds with axial shortening of 4.8 mm.

Amit Handa et al., [20] conducted experiments on the friction-welded joints of plastically deformed AISI 304 steels (20 mm diameter and 100mm length). Five weld samples with different axial pressure were considered, keeping the other weld parameters constant. The samples that were weld at lower axial pressure tend to fail at the interface while the samples weld at higher axial pressure also tend to fail at the weld interface but showed necking behaviour before getting failed at the interface.

Radosław Winiczenko et al., [21] investigated on the different metal matrix of ductile iron friction welded with stainless steel as the interlayer. Both Ferritic Ductile Iron (FDI) and Bainitic Ductile Iron (BDI) were produced using different parameters of heat treatment method. The specimens were 20mm in diameter and 100 mm in length. The visual observations clearly indicated the flash formation and the density of flash increased with increase in friction time for the BDI joints and vice versa for the FDI joints. It clearly indicated that the strength of the BDI joints were more compared to FDI joints fabricated. There was diffusion of Cr and Ni atoms from stainless steel to ductile iron and Carbon from ductile iron to stainless steel. And, the range of diffusion of Ni and Cr atoms in the ductile iron doesn't exceed 50 μm.

K. Koundinya et al., [22] analysed on the specimen geometries namely square joint, vee-joint and plain joint on the dissimilar friction-welds between 405 ferritic stainless steel and 705 Zr alloy with an interface material between them. A 3D model of materials, 25 mm in diameter and 100 mm length, and a pure aluminium sheet was used as an interface material. Taguchi design of experiments, L9 was preferred and finite element analysis was employed for this experimentation. It clearly indicated that the introduction of an interface material enhanced the strength of the welded joint and the vee-joint is said to impart good weld strength due to mechanical interlocking.

G. Madhusudhan Reddy et al., [23] investigated on using nickel (Ni) as an interlayer between the friction-welded joints of maraging steel and low alloy steel. Six friction-welded joints were made by combining various conditions of post weld heat treatments (PWHT), presence of interlayer and under the As-Welded conditions. The specimens were of 18 mm in diameter and 65 mm in length with a 5mm length of an interlayer. It was observed that nickel was squeezed out of the tri-metal joint as flash. The result showed that weld samples with nickel as the interlayer exhibited higher tensile strength compared to those samples welded without nickel interlayer and, the post-weld heat treatment in further reduced the toughness in case, without interlayer. Thus, nickel when used as an interlayer acts as an effective barrier for diffusion of carban and manganese so as to overcome the problem of carbon migration.

A. Chennakesava Reddy [24] analysed on the joint design on the friction joints between Austenitic stainless steel and Mild steel. Three different joint designs namely, square joint, plain joint and vee joint were taken into consideration. The specimens were of length 300 mm and diameter 25 mm. The joints were welded at rotational speed of 4000 RPM, friction time 10 seconds, friction pressure 10 ton, upset pressure 20 ton and upset time of 30 seconds. The observed results showed, the vee-joint was found to have a higher tensile strength compared to the other two joint designs. Even though, square joints has a greater surface area compared to the other two designs, the distribution of forging pressure was not uniform throughout the friction welding process resulting in poor joint strength. In case of vee-joint, the pressure distribution was even, resulting in better weld quality.

V. Srija et al., [25] analysed the optimum friction parameters on joints between UNS C23000 Brass and 2024Al alloy. Finite element analysis was performed to model the friction welding process. A 3D model of the specimens each of 100 mm in length and 25.4 mm in diameter was made using the ANSYS workbench software. Taguchi design of experiments, L9 was preferred for this experimentation and contact analysis was also conceded to find out sliding of materials and the penetration depth. And, so the optimal conditions obtained were frictional pressure (40 Mpa), rotational speed (1500 RPM) , frictional time (4 seconds) and upset pressure (37.5 Mpa). In these particular welded joints, the forging pressure was lesser or almost equal to frictional pressure, since the generated heat during the friction stage was high enough for the materials to weld. The penetration and sliding of materials was good at these optimal levels.

Sachin Kumar et al., [26] conducted experiments on Aluminium and AISI 304 (12 mm diameter and 70 mm length) by friction welding. The joints were fabricated on a vertical milling machine because of its stability and less vibration in relative to the lathe machine. Eight joints were fabricated by varying parameters like the weld time, revolutions per minute and burn off length. The highest strength was witnessed in the specimen welded with a higher rotational speed due to the carbon migration from stainless steel to weld zone. The optimum conditions were rotational speed of 1800 RPM, burn-off length 1.5 mm and weld time 20 seconds.

Sangathoti Haribabu et al., [27] conducted experiments on the joints formed between dissimilar steels, AISI 304 and AISI D3 tool steel (16mm diameter and 100mm of length). A new combination of frictional pressure to upset pressure, upset pressure to frictional time and frictional pressure to frictional time were used for optimizing the parameters and also to achieve high quality joints. And the combination of frictional pressure to frictional time achieved higher efficiency than the other combinations.

Amit Handa et al., [28] conducted experiments on the friction-welded joints between similar steels AISI 1021. Twelve bars of 20 mm diameter and 100 mm length were used for the first set of readings and similarly for the next two sets were prepared for this experiment. An existing lathe machine was modified to suit the requirements of the friction welding process and the friction joints were prepared under varying rotational speeds and axial pressure keeping the other parameters constant. The results established that the highest strength was conceded at a higher rotational speed. And, thus the rotational speed and the axial pressure were primarily a determinant factor in the tensile strength of the joints between AISI 1021.

Sandeep Kumar et al., [29] fabricated friction welded joints between aluminium alloy and mild steel each of 12 mm in diameter and 75 mm in length. A vertical milling machine was used for this experimentation and eight joints in total were fabricated by altering the rotation speed, burn-off length and friction time. The maximum strength was achieved in the specimen where all the parameters were at a higher value. Burn off length and friction time were found to be more responsible for variation in bond strength

than the rotational speed, which was found to have very little impact on the tensile strength values. The optimum conditions were rotational speed of 1800 RPM, burn-off length of 2.5 mm and weld time of 30 seconds.

Amit Handa et al., [30] evaluated friction-welded joints between AISI 304 and AISI 1021 steels by varying the forging pressure. The visual observations of the five joints fabricated between the dissimilar steels revealed that the flash was seen greater towards the AISI 1021 steel for all the cases. And, the flash density tend to increase with rise in forging pressure values. This was attributed to the presence of Cr in

AISI 304 steels, and also due to greater hardness at higher temperatures as compared to the AISI 1021 steels. And the strength of the friction-welded joints tend to increase with rise in forging pressure levels.

III. CONCLUSION

It has been observed from the literature survey that friction welded material exhibit better mechanical properties than other techniques. The effect of various parameters varies on the quality of weld. Many researchers have investigated the properties of friction welded materials with rotational speed, axial force and/or friction time as variable parameters. But the effect of end preparation on weld quality has not been reported in open literature, so it reflects the gap in the research.

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