

## Review in Friction Stud Welding of Aluminium to Steel

D.S. Samuvel Premkumar\*

### Abstract

*The demand for friction stud welded aluminum/steel joints has increased in many significant applications including cryogenics, structural engineering, spacecraft, rocket fuel tanks and high vacuum chambers owing to their superior properties. In automobile engineering, there is a requirement to join a mild steel earthing pin which is in the shape of a stud to an aluminum car body. Aluminum and steel was considered to join using friction stud welding. This review is about the material joining process in dissimilar materials. Mechanical properties, tensile strength of two materials and rotational speed, friction time, and friction pressure are considered as the input process parameters. Output parameters of hardness, impact strength, tensile strength, micro structure association of a welded joints has to be taken by conducting test method of micro-hardness, tensile, impact tests, optical microscopy respectively. The resulting joints made of friction stud welding are higher than the parent materials. Numerical investigation of heat flow in friction stud welding process was carried out for different combination. Results show that the heat dissipation is high at aluminum side whereas the heat dissipation is less in the mild steel side. This is due to the change in material properties of the two dissimilar metals. Since the thermal conductivity of aluminum is high the heat transfer is high in the aluminium side. Bonding mechanism and formation of intermetallic compound at joint interface during friction welding process is still least understood for different combination of materials especially in MMC/metal joints used in critical applications.*

**Keywords:** Friction stud welding, Aluminium and steel, Mechanical property, Rotational speed.

### INTRODUCTION

In the present scenario, aerospace and automobile industries depend on lightweight materials such as magnesium and aluminum alloys. Because of their low melting points, they are almost impossible the joining using conventional arc welding techniques [1, 2].

Friction stud welding (Figure 1) has been used to retro fit and to attach grating to offshore oil platform because of the risk of causing fire or explosion in arc welding [3]. Friction stud welding tool had previously been used to install anodes in some of the tanks during commissioning to avoid damage to the painted surfaces [4]

Rotational speed, friction time, and friction pressure are considered as the input process parameters.

The outcomes of the confirmation test show that good joining strength is accomplished by the optimal level of process parameters [4].

### APPLICATION

The demand for friction stud welded aluminum/steel joints has increased in many significant applications including cryogenics, structural engineering, spacecraft, rocket fuel tanks and high vacuum chambers owing to their superior properties. In automobile engineering, there is a requirement to join a mild steel earthing pin which is in the shape of a stud to an aluminum car body [5].

#### \*Author for Correspondence

D.S. Samuvel Premkumar

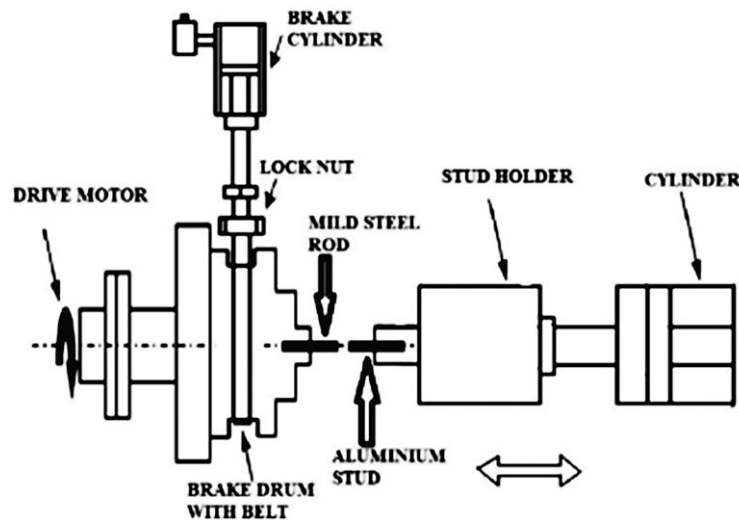
Research Scholar, Department of Mechanical Engineering,  
Mepco Schlenk Engineering College, Sivakasi, Tamilnadu,  
India

Received Date: January 06, 2022

Accepted Date: January 21, 2022

Published Date: January 31, 2022

**Citation:** D.S. Samuvel Premkumar. Review in Friction Stud Welding of Aluminium to Steel. Journal of Thermal Engineering and Applications. 2021; 8(3): 19–24p.



**Figure 1.** Schematic Representation of Friction Stud Welding Arrangement [4].

### ISSUES IN WELDING OF ALUMINIUM ALLOYS TO STEEL

The welding of aluminum based alloys and composites to steel are of particular interest to engineers, because the resulting products join the very different but favorable properties of each metal. The resulting products have a desirable combination of high thermal conductivity and low density of aluminium, and low thermal conductivity and the high tensile strength of steels [6].

Failure in these joints is a matter of great concern since that would result in massive losses. But, welding of dissimilar materials has great difficulties because of the formation of inter metallic compounds, presence of oxides at the interfacial region, inferior weld strength at the inner region of the joint interface, and more quantity of material consumption during the joining process [7]

Joining of aluminium alloys to steel by Friction Stud Welding is challenging due to the following reasons:

The physical, chemical, mechanical and thermal properties of aluminium alloy and steel are entirely different [8].

- Formation of intermetallic compounds in joining of aluminium alloy to steel is inevitable. Weld interface temperature determines the type of these intermetallic compounds. Formation of intermetallic compounds lead to brittle failure at the interface of the dissimilar joint.
- The melting point and hardness of Aluminium alloy and steel are different. So axial shortening of both the metals are different and oxides are formed during the joining process [9].
- During friction stud welding process, joining takes place from outer region to inner region and joint strength in the inner region is poor [10].
- The heat input to inner region is less. This is due to the relative velocity at the outer periphery when compared to the inner region [11].
- When the friction time is increased to increase the temperature at the interface, the chances for the formation of thick brittle intermetallic compound is higher [12].
- During friction stud welding of aluminium alloy and steel, aluminium alloy is softer and its flow stress is higher than steel. Hence, more flash formation and axial shortening take place at the aluminium side. More material is consumed in the aluminium alloy [13].
- Friction stud welding can also be used for welding in Zone 1 potentially explosive atmospheres using procedures that are properly tested and qualified [9].

### ISSUES IN WELDING OF ALUMINUM MATRIX COMPOSITES TO STEEL

The welding techniques fail because of the following reasons.

1. Thick intermetallic compound formation which is brittle in nature [14].
2. There exists a disparity between the chemical potential of the matrix and reinforcement and it results in thermodynamic imbalance between the matrix and reinforcement. This deteriorates the strength of the welded joint.
3. In fusion welding the solidification process is uncontrollable since the reinforcement phases are rejected by the solidification front. Consequently, there is inhomogeneous distribution of reinforcement material that leads to micro segregation. Micro segregation weakens the welded joint [7].
4. Since there are many difficulties encountered in the process of fusion welding, solid state joining process such as friction stud welding technique is found to be more appropriate for joining of aluminium matrix composites [15].

### INTERMETALLIC COMPOUNDS IN DISSIMILAR JOINTS

Joining of dissimilar metals such as aluminium and steel has many applications in the automotive engineering. But, the formation of brittle intermetallic phases is inevitable and it reduces the strength of the joints [16]

The formation of intermetallic compound depends on the peak temperature at the joint interface and the thermal cycle of the process. Together with the phase formation, an embrittlement of the joining zone can be observed [17].

In order to increase the strength and toughness of the dissimilar joints, the formation of intermetallic phases should be limited to a minimum size. Thus the major factors to be considered are the overall heat input and the reduction in the width of the heat affected zone [18–19].

It is found that high thermal gradients and the resulting rapid cooling could limit the formation of the intermetallic phases to a great extent at the joint interfacial region [1].

From the iron-aluminium phase diagram as shown in the Figure 2, it is evident that at least five stable inter metallic compounds are possible. There are two iron-rich intermetallic ( $\text{FeAl}$  and  $\text{Fe}_3\text{Al}$ ), two aluminium-rich intermetallic ( $\text{FeAl}_3$  and  $\text{Fe}_2\text{Al}_5$ ) and another intermetallic that has equal amount of iron and aluminium ( $\text{FeAl}_2$ ). Intermetallic compounds have a well-defined crystal structure and exist within narrow composition ranges. The chemical structure, composition, micro hardness and crystal structure of the stable intermetallic compounds are given in the Table 1 [12].

According to study the presence of  $\text{Fe}_3\text{Al}$  and  $\text{FeAl}$  during his experimentation on friction welding of AA 1050/AISI 304 steel joints. And the investigation on the microstructure and mechanical properties of friction welded aluminium-based MMC/AISI304 steel joints. It was reported that the tensile strength of the dissimilar joints deteriorates due to the formation of inter layer at the dissimilar joint interface. The interlayer comprised of a mixture of oxides such as  $\text{Fe}(\text{Al}, \text{Cr})_2\text{O}_4$  or  $\text{FeO}(\text{Al}, \text{Cr})_2\text{O}_3$  and  $\text{FeAl}_3$  intermetallic compound [14]

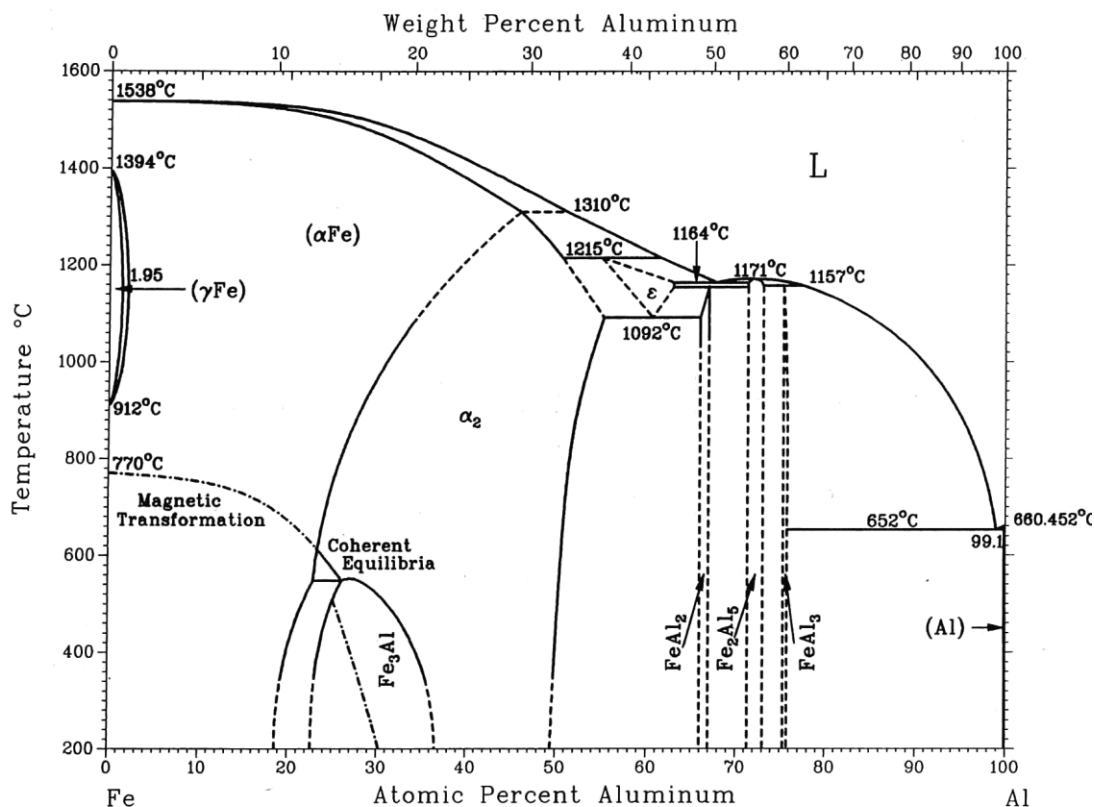
Owing to the difficulties many other process variants are also used in the present industrial scenario.

### NUMERICAL ANALYSIS

Thermal effects during friction stud welding of mild steel-Aluminium were investigated through numerical simulations using finite element analysis. The following conclusions can be drawn from the study [20].

- Online temperature measurement at weld interface of mild steel Aluminium combination is done using a non-contact Infrared thermometer and time-temperature profile is generated. Measured data is used for validation of numerical model [21–22].

- Numerical simulation of friction stud welding process using ANSYS has been carried out and the simulated results are compared with experimental results. The simulation results were in good agreement with the experimental values for friction stud welding of mild steel-aluminium combination [17].
- Using the non-linear numerical model, nodal temperature and heat flux during the continuous friction stud welding process are predicted [23].
- A simple mathematical model is developed based on finite element analysis of one dimensional heat flow. The analytical results are compared with that of the numerical results generated by ANSYS. A fair agreement is found between the analytical and numerical results [19].
- Numerical investigation of heat flow in friction stud welding process has been carried out with small time increments. Results show that the heat dissipation is high at aluminium side whereas the heat dissipation is less in the mild steel side. This is due to the change in material properties of the two dissimilar metals. Since the thermal conductivity of aluminium is high the heat transfer is high in the aluminium side [24].



**Figure 2.** Iron-aluminium phase diagram.

**Table 1.** Types of intermetallic phases [19].

| Intermetallic Phases            | Wt. (%) of Fe | Crystal structure | Micro hardness |
|---------------------------------|---------------|-------------------|----------------|
| Fe <sub>3</sub> Al              | 86.06         | FCC               | 250–350        |
| FeAl                            | 67.31         | Cubic             | 400–520        |
| FeAl <sub>2</sub>               | 50.72         | Triclinic         | 1000–1050      |
| Fe <sub>2</sub> Al <sub>5</sub> | 45.16         | Monoclinic        | 1050–1100      |
| FeAl <sub>3</sub>               | 40.70         | Monoclinic        | 820–890        |

## CONCLUSION

Some of the major limitations in the existing literature on friction welding of dissimilar materials are as discussed below:

1. The effect of friction pressure, friction time, rotational speed of the spindle and axial shortening distance on impact strength of the friction welded dissimilar joints had not been given due consideration in the previous works. All most all of them deal with the influence of process parameters on tensile strength of the welded joints.
2. Though it has been reported that the joint strength increases with interlayer, earlier studies have not considered the interlayer sheet thickness as a variable parameter in their experimental investigation. Hence, investigation on selection of optimum thickness of interlayer with superior joint properties was not carried out by the previous researchers.
3. The comprehensive study on joining of hybrid AA 6063 matrix composite to AISI 1030 steel using AA 1100 interlayer had not been carried out through friction stud welding process in the earlier studies.
4. Bonding mechanism and formation of intermetallic compound at joint interface during friction welding process is still least understood for different combination of materials especially in MMC/metal joints used in critical applications.

## REFERENCES

1. N. Rajesh Jesudoss Hynes, P. Nagaraj, J. Angela Jennifa Sujana "Investigation on Joining of Aluminum and Mild Steel by Friction Stud Welding" Materials and Manufacturing Processes Vol. 27, Issue. NIL, (2012), pp. 1409–1413.
2. N. Rajesh Jesudoss Hynes, P. Shenbaga Velu "Investigation on friction stud welded AMC/AISI 304 steel joints with ceramic intercoating" of the Brazilian Society of Mechanical Sciences and Engineering Vol. 42, Issue. 1, (2020), pp. 538–538.
3. Palanichamy, R, C.A.K. Arumugam, J. Angela Jennifa Sujana, et al. "Numerical Simulation of heat flow of Friction Stud Welding of Dissimilar metals" The Arabian for Science and Engineering Vol. 39, Issue. 4, (2014), pp. 3217–3224.
4. R. Kumar, P. Shenbaga Velu, J. Angela Jennifa Sujana, et al. "Optimization of friction stud welding process parameters by integrated Grey-Fuzzy logic approach" of applied research and technology Vol.16, Issue.4, (2018), pp. 276–286.
5. J. Angela Jennifa Sujana, R. Sankaranarayanan, et al. "Numerical simulation of axial shortening distance in friction stud welding of aluminium/mild steel joints" Materials Today: Proceedings (2021), pp. 1–6,
6. R. Meby Selvaraj, N. Rajesh Jesudoss Hynes "Finite Element Approach in Thermal Modelling of Friction Stud Welding" American Institute of Physics Publishing Vol. 2142, (2019), pp. 110006–110006.
7. N. Rajesh Jesudoss Hynes "Finite element based simulation on friction stud welding of metal matrix compos0069tes to steel" AIP Publishing Vol. 1728, Issue. 1728, (2016) pp. 205561–205564,
8. K. Anand Babu, P. Karuppasamy, et al. "Simulation Of Friction Stud Welding Process with an Intermetallic Layer" International of Applied Engineering Research Vol. 9, Issue. 26, (2016), pp. 9028–9030.
9. Vivek Prabhu, P. Nagaraj, et al. "Joining of hybrid AA6063-6SiCp-3Grp composite and AISI 1030 steel by friction welding" Defence Technology Vol. 13, Issue. 1, (2017), pp.338–345.
10. N. Rajesh Jesudoss Hynes "Simulation on friction taper plug welding of AA6063-20Gr metal matrix composite" AIP Publishing Vol. 1728, Issue. 1728, (2016), pp. 205561–205564.
11. T. Packiaraj Rajendran, Maria P. Nikolova, T. Christopher, et al. "Influence of heat treatment on friction welded joints made of high-carbon high chromium tool steel/low-carbon steel for tooling applications" of the Brazilian Society of Mechanical Sciences and Engineering Vol. 42, Issue. 42, (2020) pp.87–87.
12. T. Packiaraj Rajendran, N. Rajesh Jesudoss Hynes, T. Christopher "Characterization of high-carbon high chromium tool steel/low-carbon steel friction-welded joints for industrial tooling applications" of the Brazilian Society of Mechanical Sciences and Engineering Vol. 40, Issue. 6, (2018), pp. 1–8.

13. P. Nagaraj, J. Angela Jennifa Sujana, et al. "Ultrasonic evaluation of friction stud welded AA 6063/AISI 1030 steel joints" *Materials & Design* Vol. 62, Issue. NIL, (2014) pp. 118–123.
14. Shenbaga Velu P, N. Rajesh Jesudoss Hynes, "Effect of rotational speed on Ti-6Al-4V-AA 6061 friction welded joints" of *Manufacturing Processes* Vol. 30, (2018) pp. 288–297.
15. Shenbaga Velu P, Abeyram M Nithin, et al. "Friction push plug welding in airframe structures using Ti-6Al-4V plug" of the *Brazilian Society of Mechanical Sciences and Engineering* Vol. 40, Issue.3, (2018), pp. 158–165.
16. N. Rajesh Jesudoss Hynes, P. Nagaraj "Numerical Modeling of Temperature Distribution in Friction Stud Welding of Dissimilar Metals" *International of Applied Engineering Research (IJAER)*, Vol. 9, Issue. 26, (2015), pp. 9023–9027.
17. N. Rajesh Jesudoss Hynes "Analytical Modeling of Temperature profile in friction stud welding of dissimilar metals" *IEEE proceedings on Energy Efficient Technologies for sustainability* Vol. 1, Issue.1, (2013) pp. 827–829.
18. N. Rajesh Jesudoss Hynes, P. Nagaraj "Mathematical Model to Predict Heat Flow in Underwater Friction Stud Welding" *Advanced Materials Research* Vol. 984, Issue. 985, (2014), pp. 596–599.
19. Vivek Prabu, Shenbaga Velu, R. Kumar, et al. "An experimental insight of friction stir welding of dissimilar AA 6061/Mg AZ31 B joints" *Proceedings of the Institution of Mechanical Engineers, Part B: of Engineering Manufacture*, (2021)
20. N. Rajesh Jesudoss Hynes "Thermal Model for Heat Flow in Friction Stud Welding" of *Thermal Engineering and Applications* Vol. 2, Issue. 7, (2015), pp. 22–27.
21. N. Rajesh Jesudoss Hynes "Impact strength of Friction Stud Welded AA 1051/AISI 1030 Joints" *National on Advances in Mechanical Engineering* Vol. 1, Issue. 1, (April-2015)
22. N. Rajesh Jesudoss Hynes "Effect of Process Parameters on axial shortening distance in Friction Stud Welding" *International on Advances in Materials and Materials Processing* Vol. 1, Issue. 1, (2015,) pp. 132–135.
23. N. Rajesh Jesudoss Hynes, P. Nagaraj "Thermal Modeling of Friction Plug Welding" *International of Applied Engineering Research (IJAER)*, Vol. 9, Issue. 26, (2015), pp. 9031–9033,
24. P. Nagaraj, R. Tharmaraj, et al. "Mathematical modelling of friction plug welding with pre-heating effect" *Advanced Materials Research* Vol. 984, Issue. 985, (2014) pp. 600–603.