Welding Mechanisms during Friction Welding of Aluminium with Steel

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ABSTRACT

Friction welding is a solid state welding technique for welding dissimilar metals. In this paper, some mechanisms of welding during friction welding of Aluminium to steel have been discussed with special reference to intermetallic formation. The possible difference in welding mechanisms in the case of Austenitic, Martensitic and Ferritic Stainless steel have been brought out and the main parameters affecting welding have been highlighted.

KEY WORDS: Friction welding, Intermetallics, Steel.

1. INTRODUCTION

Friction welding is a well-established technique to weld dissimilar metals, ceramics and polymers. Most of the research work has been done on welding of Aluminium alloys like 6061, 2029 and 5083 alloys. Different types of steels have also been friction welded, some of them being AISI 430 and 304.While welding dissimilar metals by fusion welding techniques, a lot of intermetallic compounds are formed. Formation of intermetallic can be substantially reduced by using solid state welding techniques.

Friction welding uses variation in parameters like friction pressure, upset pressure, burn off length and speed of rotation. In this paper, the challenges faced when welding Aluminium alloy Al6061 with Austenitic Stainless steel 304 are discussed. The main challenge is to reduce the intermetallic formation in the weld region. Another challenge is to choose a proper combination of welding parameters in order to get a sound, defect free weld. A simple mechanism of welding has been proposed for friction welding of Aluminium to steel, based on the various mechanisms of friction welding available in literature.

Literature: Aluminium welding with steel is not possible using conventional fusion welding techniques like TIG and MIG because of the formation of excessive intermetallics that make the welded joints brittle. Hence, solid state welding like friction welding and ultrasonic welding have to be resorted to. When these solid state welding techniques are used, the amount of intermetallics formed are considerably reduced.

Honda has reportedly had success in joining the steel yin to the aluminum yang using friction stir spot welding, which was first used in building the 2013 Accord. Automaker General Motors has claimed that they have developed a technique to weld Aluminium to steel in the year 2016.

Butt-welding of an aluminum alloy plate to a steel plate using friction stir welding was successfully performed by Watanabe (2006). The optimum tensile strength of the joint obtained was about 86% of that of the aluminum alloy base metal. Some intermetallics were observed at the weld interface. A continuous wave fibre laser has been used to join aluminium alloys to low carbon steel. Heat transfer mode was conduction mode.

Solid state welding of steel: While using Austenitic stainless steel the following negative metallurgical changes have been reported during fusion welding

- delta ferrite formation
- Sigma phase
- Stress-Corrosion cracking
- Chrome –Carbide precipitate between grain boundaries at 450-850° C of Cr-Ni Austenitic steels

Sathyanarayana (2005), have found that Dissimilar welding of austenitic stainless-steel with ferritic low carbon steel (A/F) is faced with the coarse grains phenomena in the weld zone and heat affected zone of fusion welds leading to low toughness and ductility due to the absence of phase transformation.

Table.1, shows Industrial applications of dissimilar steel welds.

Table.1. Industrial Applications of Dissimilar steel welds

S.No.	Product	User industry
1	EN19B To EN19B	Front Wheel Axle in Automobiles
2	EN354 To EN354	Main shaft in Automobiles
3	SAE 8620 to SAE 8620	Rocker arm shaft
4	High speed steel to medium carbon steel	Bimetal drill tools
5	SS316 to EN8	Pumps
6	SS316 to EN8	Nozzles
7	SS to Al	Nuclear and Cryogenics, Chemical

Mechanisms of Friction Welding: The surfaces of both steel and aluminium are very well prepared during friction welding. So, any impurities or oxide layers are more or less removed from the surface. If by any chance, a thin film of oxide layer remains on the Aluminium surface, it will be extruded out in the form of flash during the initial stages of friction welding itself.

The temperatures reached during friction welding are below the melting points of both metals and so the metal which is more ductile, in this case Aluminium will be cold deformed to a greater extent and it is expected that the flash on the Aluminium side is more. It is also expected that some elements from the steel side will diffuse into the Aluminium side. SEM-EDS studies are likely to give a better picture of the diffusion of elements.

Initially, friction pressureis applied in order to generate heat for welding to take place, some partial welding occurs. Then, when upset pressureis applied, the more ductile Aluminium is cold extruded and some of the Aluminium comes out as flash. Since, steel is harder than Aluminium, it is also expected that particles of steel gouge out the Aluminium during friction welding.

Thermal conductivity of Aluminium is 204W/mK and that of steel is 16 W/mK. So, difference in thermal conductivity is almost a factor of 10.Hence,it will be interesting to weld smaller diameter steel to larger diameter Aluminium alloy so that the surface area of Aluminium alloy is more and the weld cools faster when higher surface area of Aluminium alloy is used. If the reverse is done, then heat transfer through Aluminium alloy will take place through the longitudinal surface rather than the transverse surface. This may take more time and hence welding may be slower.

Friction welding of Ferritic Stainless steel with Aluminium alloy: Ferritic Stainless steel is soft. Aluminium alloy is also soft. So, it is expected that in order to get proper bonding friction pressure should be more .This is likely to give better heat generation and better bonding.

Friction welding of Martensitic Stainless steel with Aluminium alloy: Martensitic stainless steel are hard and Aluminium alloy is soft. So, during contact between the two while welding, the steel is expected to gouge out material from Aluminium alloy and bonds are expected to be good even with lower friction pressure.

Friction welding of Austenitic Stainless steel with Aluminium alloy: Austenitic stainless steel is moderately hard, so moderate friction pressure may be required to get good bonding with Aluminium alloy. Mumim Sahin (2009), has identified friction pressure and friction time as important parameters to join Austenitic Stainless steel 304 with Aluminium. Tensile strengths ranging from 75 MPa to 200 MPa were obtained when the friction pressure varied from 15MPa to 45 MPa.

Solute Diffusion in Aluminium: Al is trivalent and the diffusion of impurities in Al follows certain unique laws. Most transition metals (V, Ti, Cr, Mn, Fe) show very low diffusivities with respect to Al self-diffusion. Added to this, they have high activation enthalpies .Non-transition elements (Ge, Ga, Zn) have diffusivities similar or slightly higher than self-diffusion and the data show only small variations for the different elements. Their activation enthalpies are similar to those of Al selfdiffusion and almost independent of their valence. The reason for the deviation of diffusivities of transition metals from ‘normal’ impurity diffusion behaviour of other fcc metals very likely lies in the fairly strong interaction between vacancy and solute atoms. This can be seen from the calculations of vacancy-solute interaction energies for 3d and 4sp as well as 4d and 5sp element solutes performed by Hoshino (1996). Hence, during welding of Aluminium to steel, alloying elements like Chromium, Vanadium and Tungsten cannot be expectedto diffuse into the Aluminium. However, the weld region may contain some alloying elements and intermetallics. This may lead to higher hardness in the weld.

Intermetallics in the Aluminium-Steel System: Nanoscale intermetallics have been found to form when Aluminium and steel are fusion welded using welding-brazing processes. Solute diffusion in Fe-Al has been investigated by Peteline (2003). Investigations have been carried out in the intermetallic system Fe_3Al.

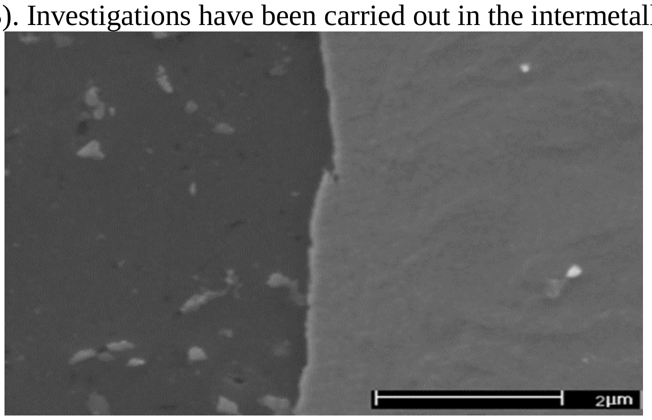

Figure.1. A typical inter-metallic formation at the junction of Fe and Al-light region aluminium, dark region-steel

Table below list the inter-metallic phases which are possible during welding of Aluminium to steel

Table.2. A list if inter-metallics found in different Aluminium alloy-Steel systems

S. No.	Method of welding	Dissimilar metal combination	Type of intermetallic	Authors and year of work
1	Friction welding	AISI 1040 Steel to 6082-T6 Aluminium	FeAl,Fe_2Al_5	Muralimohan, 2015
2	Spot weld	Steel to Aluminium	t5-Al8Fe2S	Chen, 2014
3	Friction welding	AL6061-T6 and SS304	$AL_{13}Fe_4$ and Al_5Fe_2	Chem, Kovacevie, 2004.
4	Friction welding	A1070 and S10C	Fe_2Al_5	Wallach, Elliott, 1981
5	Friction welding	A5052 and S10C	$Fe_2AL_5$and Fe_4AL_5	Naotsugu Yamamoto, Makoto Takahashi, Masatoshi Aritoshi, Kenji lkeuchi and 2007
6	Friction welding	A5083 and S10C	Fe_2Al_5, Fe_4AL_{13}, (Fe,Mn)Al_6	BelittS.Yilbas, Ahmet Sachin, Ali coban, AbdulAleem and 1994
7	Friction welding	A5083 and SS304	Al_5Fe_2 and Fe_4AL_5	Chandrasekaran, Batchelor, Jana 2015
8	Frictionwelding	AL6061-T6 and AISI 1018 Steel	FeAL and Fe_2AL_5	EmelTaban, Jerry Gould, John Lippold and 2010
9	Friction welding	AL6061 and AISI 4340	$Fe_2Al_5$and Mg found near the corner	Suresh Meshram, Madhusudhan Reddy and 2015

2. CONCLUSIONS

Strength of the friction welded joint depends on the type and thickness of intermetallic formed at the welded joint.

Important friction welding parameters that affect strength seem to be different when the type of steel used is changed. Friction pressure is an important parameter during welding of austenitic stainless steel.

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