

# Weldability of Aluminum to Mild Steel Using Friction Welding Process

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**Abstract**—Friction welding method is one of the most simple, economical and highly productive method in joining dissimilar materials. It is widely used in the automotive, medical and aerospace industrial applications. The purpose of this present work was to assess the development of solid state juncture of dissimilar materials of H30 aluminum and BS970 mild steel. The joints were obtained by Friction Welding (FW) process, which combines the heat generated from friction between two surfaces. The results were analyzed by means of tensile, Rockwell hardness test and metallographic tests. Solid state welding processes are characterized by the absence of melting and the formation of narrow heat affected zone (HAZ). The metallurgical properties are usually excellent and most of the processes can be mechanized or automated to be used as high production rate processes. The FW proves to be a great method for obtaining junctures between dissimilar materials which is not possible by fusion welding process.  
**Keywords**— Friction welding, aluminum, mild steel, dissimilar, tensile test, metallographic test.

## I. INTRODUCTION

In recent years, the use of joints between dissimilar metals has considerably increased. In the development of new technologies for the aerospace, medical and automotive industries, these junctures are of high importance, because they allows the systems, components manufactured in mild steel and aluminum to be structurally united. Even the fusion welding processes by presenting a heat affected zone (HAZ) well reduced.

Friction Welding (FW) is classified by the American welding society (AWS) as a solid state joining process in which bonding is produced at temperatures lower than the melting point of the base materials[3].

Fuji A et al.[2] studied mechanical properties of titanium - 5083 aluminum alloy friction joints. Ylbaz et al.[4]

investigated the mechanical and metallurgical properties of friction welded steel-aluminium and aluminium-copper. Fukumoto S et al.[1,5] studied the friction welding set up and the strength of the joints and investigated amorphization process between aluminium alloy and stainless steel by friction welding. Furthermore the cleanliness of the parts must be considered as important. Therefore, the ends of the parts were cleaned with acetone prior to the welding process to minimize the effect of organic contamination in the welding zone. Friction welding of aluminium and austenitic stainless steel has been studies experimentally.

FW Process is solid state joining process that produces a weld under the compressive force contact of one rotating and one stationary work piece, the heat is generated at the weld interface because of the continuous rubbing of contact surfaces, which in turn causes a temperature rise and subsequent softening of metals. In due course, the material at the interface starts to flow physically and forms an upset. When a certain amount of upsetting has occurred, the rotation stops and the compressive force is maintained or slightly increased to consolidate the weld. Friction time, friction pressure, forging time, upset time, forging pressure and rotation speed are the most important operational parameters in the FW process.

Figure 1 shows the phases of the process. (A) One side of the materials to make it join is fixed and the other material is rotated by rotational speed  $N$ ; (B) Pressure  $P_1$  and time  $t_1$  – heating phase; (C) Pressure  $P_2$  and  $t_2$  – forging phase.

Figure 2 shows the basic layout of FW equipment. Usually the structure is fairly rigid to provide stability to the equipment working at high speeds and is driven by high pressure forging. Modern equipment is automatic and allows all the parameters be adjusted and monitored directly on the control panel.

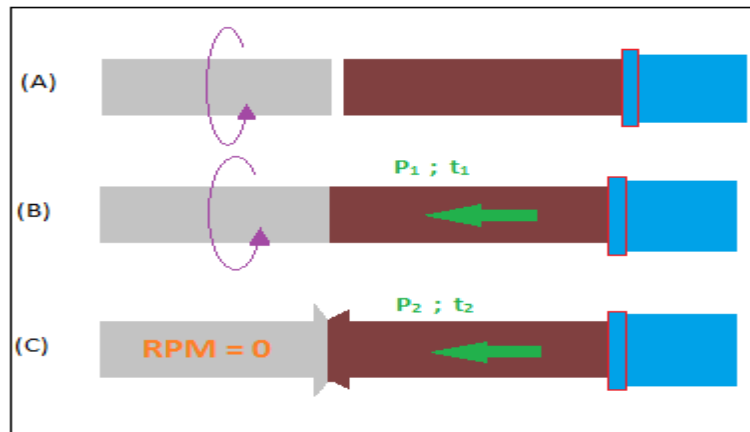


Fig.1: Phases of Friction Welding Process

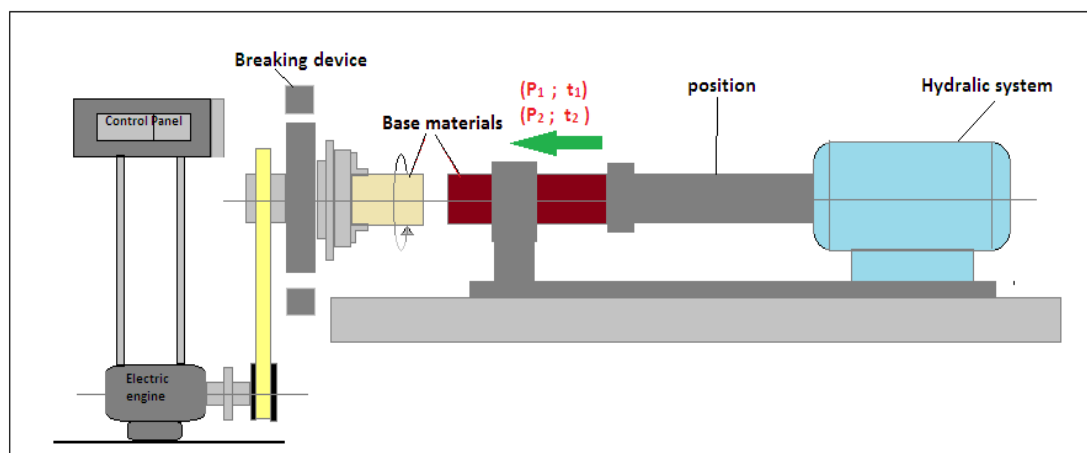


Fig.2: Equipment of Friction Welding

The difficulties in the welding of aluminum with mild steel by fusion welding processes have been a great challenge for engineering; because they result from hard and brittle inter metallic phases that formed between aluminum and steel at evaluated temperatures. In this study, the materials (H30 aluminum, BS970 mild steel) have been joined by FW and the results were analyzed and presented. Tensile and Rockwell Hardness tests were performed to define welding parameters and analyze the resistance of the weld.

## II. EXPERIMENTAL SAMPLE

The details of materials used, experimental setup, and tests conducted are discussed under the following subheadings.

**2.1 Materials:** The materials used in this study for dissimilar friction welding H30 aluminum – BS970 mild steel; each material were machined with a diameter of 8mm and length of 200 mm.

**2.2 Friction Welding Equipment:** A friction welding machine of brand UNITECH configured M250 was used with fixed speed 3000RPM, of H30 aluminum – BS970 mild steel dissimilar materials.

**2.3 Tensile Test:** After welding was performed, tensile tests were carried out to evaluate the mechanical properties of junctures, beside parameter settings, optimization and qualification of welding procedures and processes. The welded specimens were machined subjected to tensile tests on a machine brand UTK-4DE (2005/1281) with a capacity 400kN at room temperature of 25°C.

**2.4 Rockwell hardness tests:** The Rockwell hardness test method measures the permanent depth of indentation produced by a force or load on an indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. A conical diamond indenter with a round trip is used for hard materials and minor load is 10kgf and major load is 60-150kgf.

**2.5 Metallographic Analysis:** The junctures were cut in the transverse weld, embedded in an array of Bakelite, polished and examined in the region of the interfaces on aluminum to mild steel under a matascan metallurgical microscope (Jyothi Spectro Analysisn (P) Ltd., Hyderabad, INDIA)

The chemical composition of materials used in the present study is given in Table 1. The mechanical properties are given in Table 2.

Table.1: Chemical compositions of materials used in present study

Materials	Elements (%)				
H30 Aluminum	Cu		Mn		Mg
	0.1		1.0		0.6
BS970 Mild steel	C	Silicon	Mn	S	P
	0.17	0.3	0.08	≤0.05	≤0.04

Table.2: Mechanical properties of materials

Materials	Young's Modulus (E)		Tensile Strength Mpa	Yield Strength Mpa	Elongation (%)
	Psi	Gpa			
H30 Aluminum	10.0	69	110	95	5.00
BS970 Mild steel	29700ksi	205	440	370	15.0

### III. RESULTS

#### 3.1 Macrostructure:

In macrostructure level, it was observed the formation of flashes with circular symmetry, different formats, and also significant reductions in length of the cylindrical pin H30 aluminium in accordance with the adopted parameters. The BS970 mild steel side was not deformed because this material has higher strength than the aluminium alloy, and it thus provide more resistance to deformation. Hence the formation of flashes was restricted to H30 aluminium alloy. Figure 3 shows the interfaces that were bonded and specimens used for tensile test after machining.

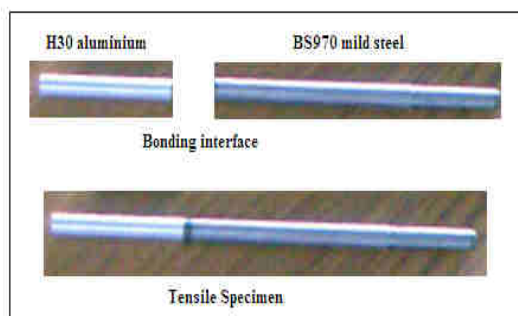


Fig.3: H30 aluminium, BS970 mild steel before bonding after bonding



Fig.4: H30 aluminium and BS970 mild steel after tensile test

#### 3.2 Mechanical strength of the junctures welded by friction:

The results of the tensile tests for different welding parameters ( $t_1$ ,  $t_2$ , and  $P_2$ ) are shown in Table 3. Effects of upset time and upset pressure on the strength of junctures were examined in welding of equal diameter parts, friction time was kept constant. The strength of junctures was determined by tensile tests, and the results were compared to those of fully machined specimens. Tensile strength of the junctures was estimated dividing the ultimate load by area of 8 mm diameter specimen. The fracture occurred at the interface of the dissimilar metal weld joint, strength of the weld joint was lesser than tensile strength of H30 aluminium 270 Mpa there was an unbounded region around the centre of the fracture surface, although the aluminium alloy was partially bonded to the mild steel. The unbounded region is defined as the region where the adhesion between the materials and inter diffusion of each element are insufficient, and elements are not metallurgically bonded to each other. i.e., insufficient upset pressure and upset time meant that the faying surfaces had not entirely reached up to the certain limit where the amount of axial forging pressure and the time required reaching the bonding temperature therefore, an unbounded region remained at the centre of the weld interface. Only the outer region was bonded because the temperature here was higher than that of the inner region in the forging stage. The obtained results are plotted between tensile strength versus upset pressure and upset time and are shown graphically in Figure 5 and Figure 6. As upset time and upset pressure for the junctures passes through a maximum, when upset time and upset pressure for the junctures are further increased, tensile strength of the joints decreases and finally fails due to high axial upset pressure in which just piercing of mild steel into the aluminium took place with zero mechanical locking or elemental bonding between two dissimilar metals. Thus, it is shown that upset time and upset pressure have a direct effect on joint y time and upset pressure affect cue of the metals the weld reduces the junctures quality, but it was slightly softened. The fracture mechanism of junctures

with a shorter time may be different from that of junctures with a longer upset time. The initial step was to examine fracture surfaces for any noticeable difference in fracture mechanism between unsound junctures with lesser and higher upset pressures and upset times. Figure 4 shows the specimens after tensile test.

Table.3: Tensile test values

Number of trails	Friction pressure (P <sub>1</sub> Mpa)	Friction time (t <sub>1</sub> )	Upset pressure (P <sub>2</sub> Mpa)	Upset time (t <sub>2</sub> )	Obtained tensile strengths
1	80	4	140	4	134.2
2	80	4	160	5	177.8
3	80	4	200	6	153.6
4	80	4	300	7	0

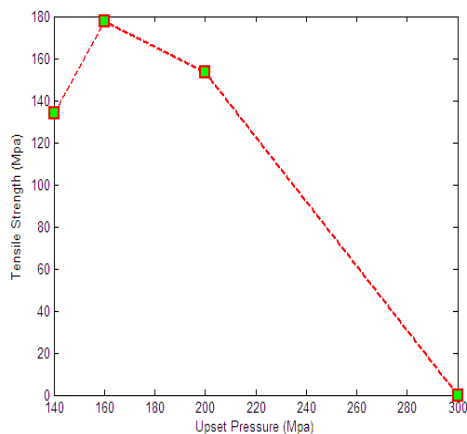


Fig.5: Relation between tensile strength and upset pressure

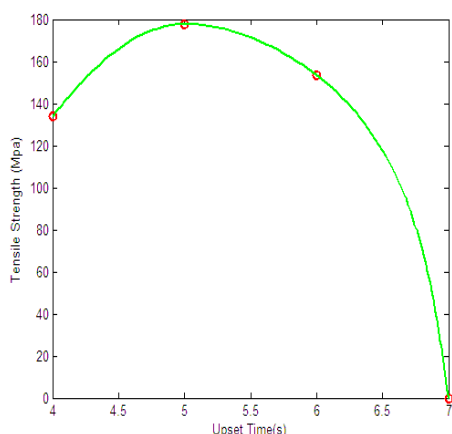


Fig.6: Relation between tensile strength and upset time.

### 3.3 Rockwell hardness test:

Rockwell number was calculated on B-scale of hardness machine values as shown in the Table 4. The variations in the hardness numbers different values of speed and feed rate values of hardness number was increasing and decreasing during testing. The Rockwell hardness test was conducted for measuring hardness along the weld zone.

From results of the hardness testing it is observed that maximum hardness number obtained for Rockwell for sample I, using cylindrical tool at speed 3000 rpm and feed 30 mm/sec.

Table.4: Rockwell hardness number

Speed (rpm)	Sample number	Feed (mm/sec)	Rockwell hardness number (B-Scale)
1500	A	20	18
	B	25	35
	C	30	16
2500	D	20	38
	E	25	22
	F	30	36
3000	G	20	25
	H	25	12
	I	30	46

### 3.4 Metallographic analysis of the bonding interface:

Figure 7 shows a photomicrograph of the junctures between H30 aluminum and BS970 mild steel taken in the central region of the sample with an increase of 100X. The interface region is characterized by a straight line with some imperfections under the friction welding process. Both in the aluminum and mild steel side's microstructural changes are not observed near the interface region as it occurs in fusion welding processes. All plastic deformation resulting from the parameters used in the process occurred in the H30 aluminium, due to the fact that this material has lower strength and lower hot forging temperature.

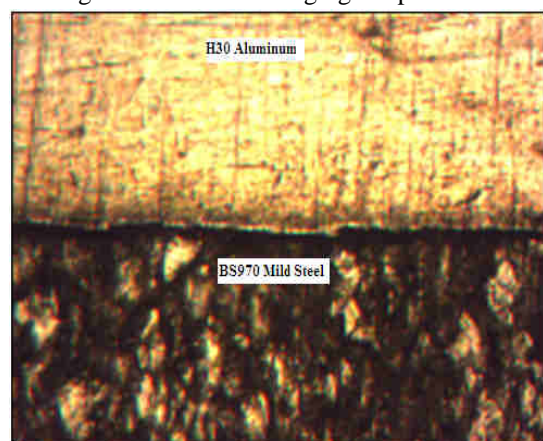


Fig.7: Photomicrograph of the interface bonding between the H30 aluminum and BS970 mild steel with an increase of 100 X.

## IV. CONCLUSION

The friction welding process was very efficient in the welding of dissimilar metals such as H30 aluminum and BS970 mild steel. It is showed by the results of tension mechanical tests that presented mechanical properties

which are not possible to achieve by means of fusion welding processes. Among the parameters used for testing the welding, the one that showed the best results in tensile tests. The HAZ is well fused and free from non metallic defects. Hence we can extend this work to the various residual stresses acting during the process.

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