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MICROSTRUTURE AND MECHANICAL PROPERTIES OF ALUMINIUM/STEEL FRICTION WELDED COMPONENTS

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Abstract. *Welding of dissimilar materials is possible through friction welding, which is a solid-state bonding process. Friction welding is as an interesting option as it generates less residual stress, less distortion and crack formation when compared to the fusion welding process. The characteristics of this process also allow satisfactory welding of dissimilar materials, with good results in terms of mechanical strength. In this work, the butt-welding of aluminum ASTM A6351 T6 and SAE 1020 steel was carried out aiming at evaluating the effects of the initial contact geometry on the mechanical properties and structure of the welded joint. The methodology consisted of friction weld aluminum bars with different initial contact geometry with steel bars in a machine specially developed for the application. The results indicated the influence of this parameter on the mechanical properties of the welded joint.*

Keywords: *welding, friction, dissimilar materials, geometry*

1. INTRODUCTION

The Friction welding is a solid-state bonding process consisting of the microscopic joining of the contact surfaces of the parts at temperatures below their melting points. The main bonding mechanism of materials in friction welding is diffusion.

These processes, as Fuji et al(1997) and Fukumoto et(1997), in the absence of melting and solidification, are characterized by the formation of a narrow thermally affected zone, which results in good metallurgical and mechanical properties, as well as advantages such as reduction of residual stresses, distortions and cracking, consequently joints of high quality and excellent mechanical results.

Yamamoto et al(2005), Yilbas(2014) e Sammaiah(2010) affirm that the process can be used to weld similar or dissimilar materials, as where very often the behavior of such materials and the formation of intermetallic compounds may be unpredictable and damaging to the weld. Guo(2017) Affirms that despite technological challenges, there is a crescent demand for industrial applications of dissimilar materials.

The friction welding process consists of the generation of friction between two surfaces, the generation of heat because of this friction and subsequently the deformation. The variables of the friction welding process related to the machine are the rotation, or speed of contact between the two surfaces, contact force and the force of forging, besides the times of application of the respective forces (NARAYANAN, 2013) and (ALVES, 2016). The variables that do not belong to the machine are type of materials, geometry and diameter of the specimens.

Ambroziak (2003), made friction welding experiments on the alloys Magnesium AlMg3 and Austenitic steel X10CrNiTi189, studied the initial contact geometry and the formation of intermetallic compounds that had a detrimental effect on the strength of the weld evaluated in tensile and folding tests was observed. Several attempts were made by altering the geometries of the pins. It was observed that the geometry of the pins influenced the formation of intermetallic compounds and the results of mechanical resistance of welded joints.

Alves (2016) used ASMT A 6351 T6 and AISI 304L stainless steel dissimilar welds to use flat and conical geometry and found that there was influence of geometry. The conic geometry made possible better removal of oxides, impurities and other contaminants on the surfaces, result of the plastic deformation and the elevation of the temperature in the central region of the weld interface, providing a better dynamic flow of the material, consequently provided a better physical and chemical adhesion and greater atomic diffusion.

Narayanan et al (2013) also carried out researches with changes in the geometry of the contact face and concluded that significant changes occur in the results of mechanical resistance. The research with pins with conical geometry presented superior mechanical resistance to those manufactured with flat geometry in approximately 7%.

Khan (2011) also conducted experiments with friction welding of dissimilar materials Aluminum 6061 and stainless steel AISI 304, were also welded pins of pure aluminum and copper, also aluminum 6061 and copper, all with flat and conical geometry. The conic geometry obtained better results in all weld dissimilar materials with higher mechanical strength and more uniformity along the bond line.

The objective of this work was to study the effect of initial contact geometry of welds produced by conventional rotary friction of ASTM A6351-T6 and SAE 1020 carbon steel in the tensile strength limit.

2. MATERIAL AND METHODS

The materials used in this research were SAE 1020 steel and ASTM A6351-T6 aluminum bars. The choice of those two materials is due to the wide use of them in several applications in the automobile industry, aeronautics, and industries in general. The application of dissimilar materials allows taking better advantage of the properties of each material. Table 1 shows the nominal chemical composition of the materials used and the table 2 shows the mechanical properties steel.

Table 1: Chemical composition of the materials used.

Material	**Elements (% weight)**							
A6351-T6 Aluminium	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
	1.30	0.50	0.10	0.80	0.08	-	-	0.22
SAE 1020 steel	C	Mn	Si	P	S	Mo	Al	Ni
	0.19	0.48	0.07	0.01	0.01	0.00	0.02	0.01

Table 2: Mechanical Properties of A6351-T6 Aluminum and SAE 1020 Steel.

Alloy	**Hardening**	**Tensile Strength Limit MPa (N/mm²)**	**Yield Limit MPa (N/mm²) Mín.**	**Minimum Elongating (%)**	**Brinell Hardness (HB)**
Al 6351	T6	290	255	8	95
STEEL	-	420	350	15	121

The proof-bodies/specimens have a diameter of 9.53 mm (3/8 "). The lengths used were 55mm for the aluminum parts and 50mm for the steel parts. The length of the aluminum bars is slightly higher than the steel bars to compensate for the length reduction during welding. Figure 1 shows the variation of the initial geometry of the aluminum contact points used to make the welding.

The steel bars contact surface were machined, which during the tests were used flat surfaces. It is important to emphasize that machining on the contact surfaces is fundamental to ensure similar roughness and a better distribution of forces of contact during the friction.

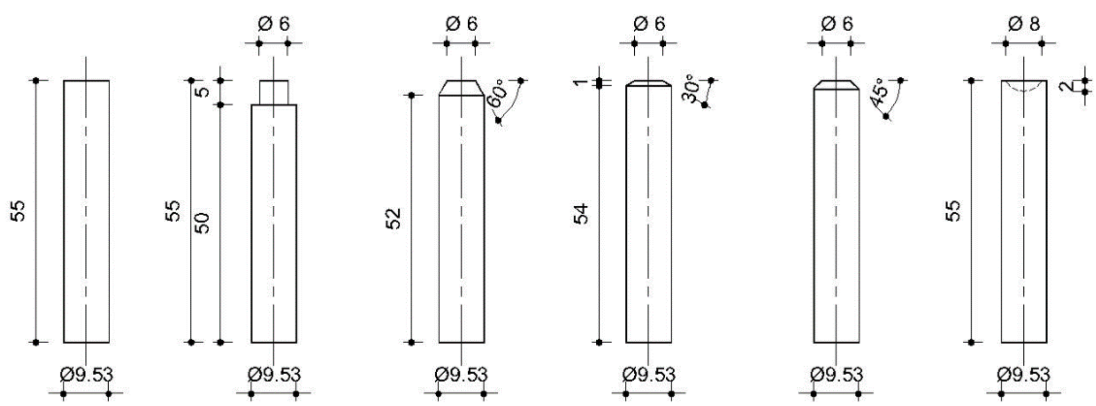


Figure 1: Variation of the initial geometry of contact point of the aluminum bars.

For the accomplishment of the studies the machine shown in Figure 2 was developed.

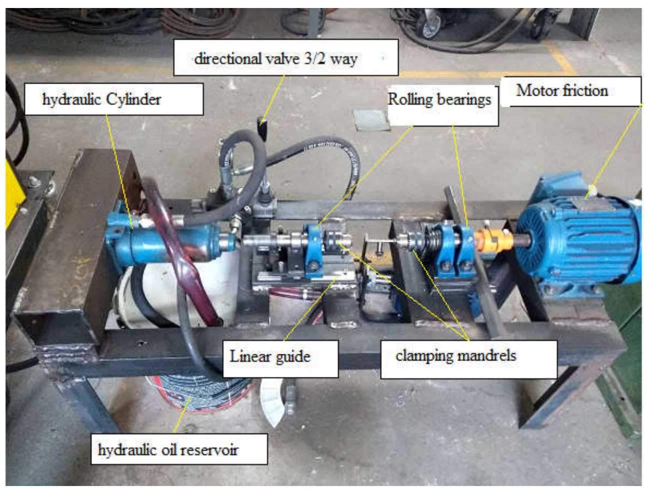


Figure 2: Friction Welding Machine

Initially minimum values of important parameters for carrying out the welding, such as welding force, welding time, forging time and forging force were defined. Those parameters were based on the literature applied in the welding of dissimilar aluminum and steel materials. Table 2 shows the parameters used.

Table 3: Initial Test Parameters

Welding time	4s, 7s e 10 s
Welding Pressure	21.63MPa; 43.33 MPa; 64.90MPa
Forging Pressure	The same of the welding pressure
Temperature	Room temperature (without preheating)
Rotation	1750 RPM(Fixed)
Forging time	6 s (Fixed)
Diameter	3/8” =9.53 mm (fixed)

3. RESULTS AND DISCUSSION

3.1 Joint appearance

Figure 3 shows the main difference between the aspects of the edges obtained, resulting from the welding using conical tip and bulged tip. It is observed that when the aluminum tip used is the bulged, the edge obtained is rounded.

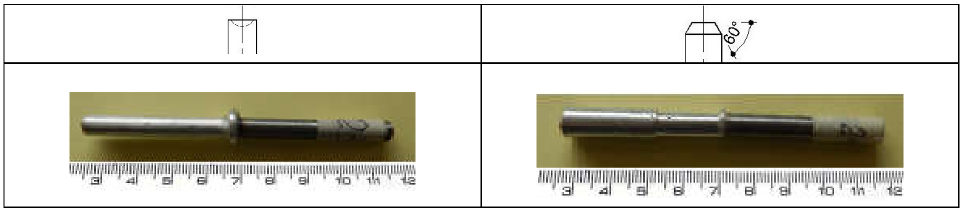


Figure 3: difference between the aspects of the edges obtained

3.2 Tensile Test of the joint

Figure 4 shows the test speciment, according to ASTM E 8. This test was important to verify the mechanical tensile strength of the welded joint, according to the parameters used.

Figure 4: Machined test body for tensile testing

Figure 5 shows the results of the tensile strength limits, as a function of the initial contact geometry, of the aluminum pins obtained in the process. The figure 6 shows the specimens after rupture in the tensile test.

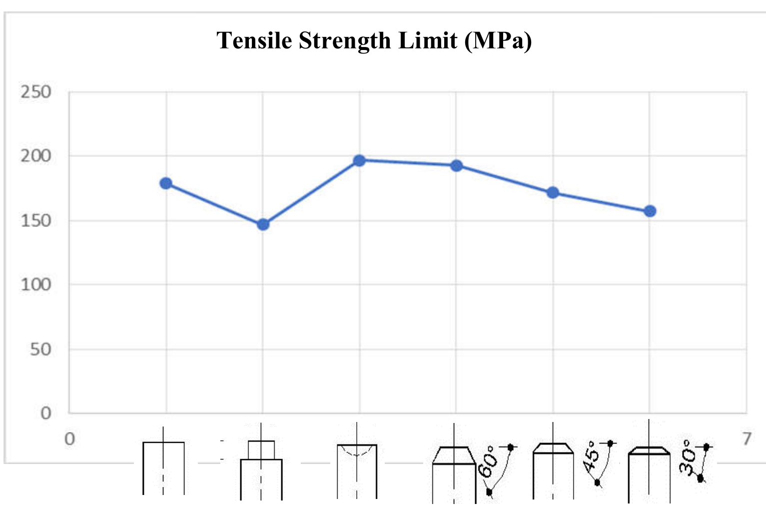


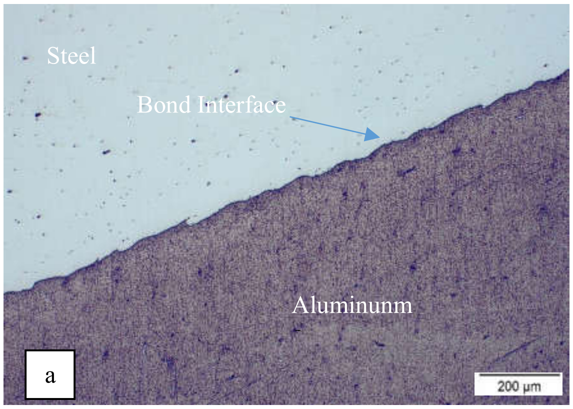
Figure 5: Tensile Strength Limit obtained with aluminum pins with altered geometries

By analyzing the results, the influence of the initial contact geometry on friction welding is observed. This influence can be seen in the results of the tensile strength limit of the welded parts. It is observed that the bulged tip (196,84 MPa) and the conical tip with 60ºinclination (192,82MPa) presented better tensile strength results.

Figure 6: Specimens ruptured after the tensile test

3.3 Microsturuture of the joint

Analyzes of the structure were performed, initially in the optical microscope. In this analysis, it was possible to evaluate and verify the aluminum-bonding interface with steel, aspects of the thermally affected zone, structural changes, granular structure, and aspects of mechanical contact, under pressure, between two parts with relative movement. Figure 7 shows the welded joint microscopy consisting of two images of the junction sample, of the peripheral region of the specimen,



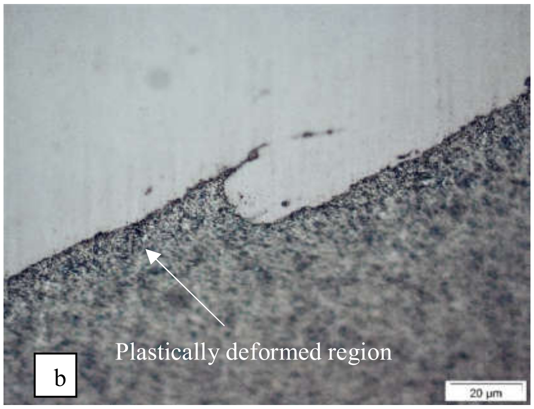


Figure 7: Metallographic images of welded joint a) 100x magnification, b) 1000x magnification

Figure 7 shows the imperfections of the bonding interface in the welded joint, characteristic of the friction welding process. More specifically due to the occurrence of Intense rotating contact between two parts of aluminum and steel. The Figure 7 (b) shows the occurrence of an intermediate line in the welded joint and the occurrence of deformation of the aluminum grains in the joint.

The Figure 8, obtained by Scanning Electron Microscope, confirms what was observed in the analysis using the optical microscope that the deformations resulting from the friction welding process.

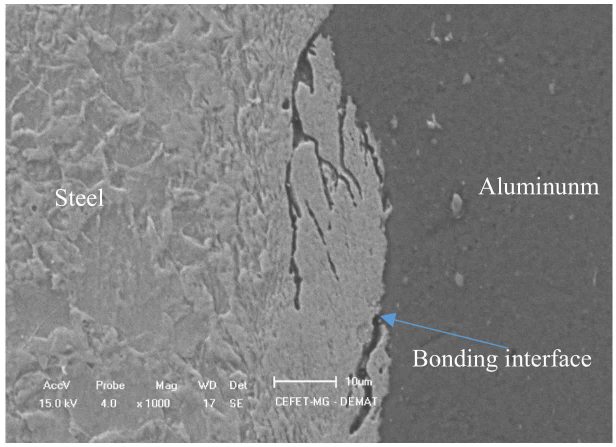


Figure 8: Welded joint (Scanning Electron Microscope magnification 1000x)

It was also performed semi quantitative analysis by EDS (Dispersive Energy Spectroscopy), shown in Figure 9. It is evident that in the interface region of the weld, on the side of the aluminum, the presence of iron occurs and on the side of the steel, the presence of aluminum occurs, that is, as the weld junction is exceeded, it is possible to verify the occurrence of interdiffusion between aluminum and steel.

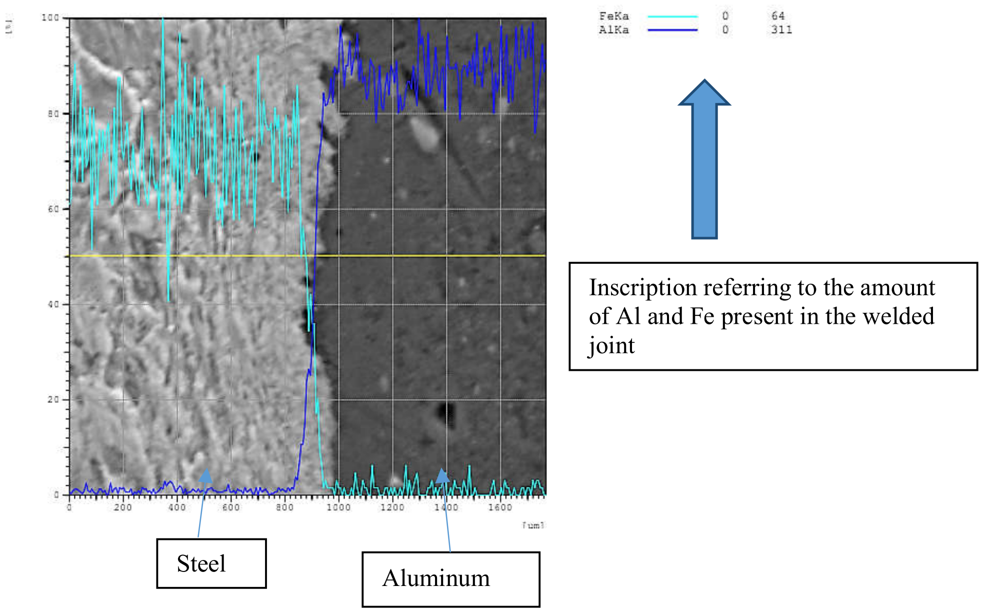


Figure 9: Semiquantitative analysis performed by EDS at the junction Aluminum and steel

In order to reach the proposed objectives, the welds were made using aluminum pins with tips with modified geometries as shown in Figure 1. The following parameters were used, using the best parameters, which resulted in a higher mechanical tensile strength, when the welds were performed with flat surfaces, ie, Welding Pressure and Forging Pressure equal to 21.63 MPa; welding time equal to 4s and forging time equal to 6s.

During the welding, it was verified that the conical and bulged tips provided a smoother displacement, with less vibration, besides formation of less flash.

Subsequently, they followed the machining procedures and preparation of the test specimens to perform the tensile tests, according to ASTM E 8 [15].

The structures obtained in the welding, using the tapered pins 60 ° and bulged, were also analyzed and obtained in the Scanning Electron Microscope and compared with the flat pins. Figure 9 shows that the main structural difference was the formation of intermetallic compounds (IM). Identified, through a contrast existing at the junction, by an intermediate layer formed between aluminum and steel. Fe and Al, in this case form these compounds, and their distribution shape and thickness have negative influence of the mechanical resistance of the welded joint.

Five measurements were made of the layers, 1 in the center and 4 in the periphery of the welded joints. Figure 10 shows the difference in joint aspects and thickness values of the intermetallic layers obtained.

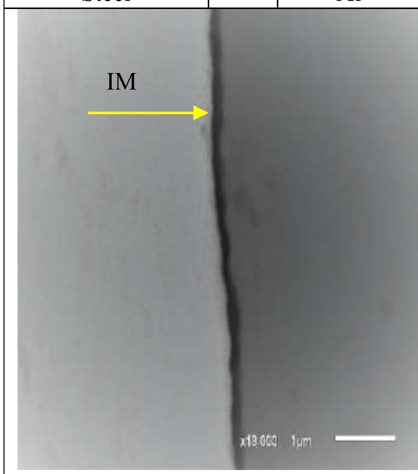
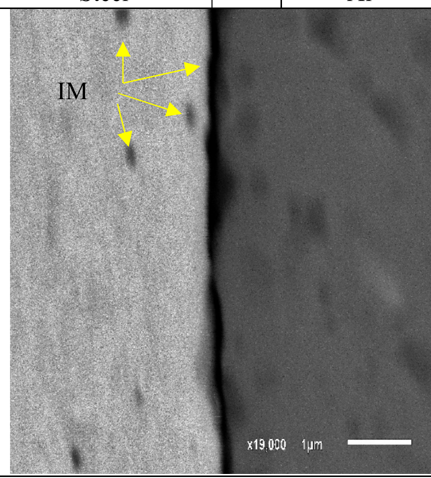
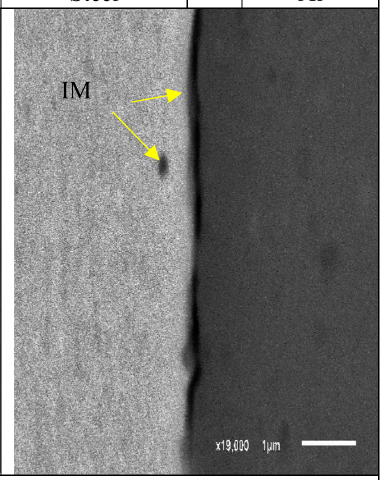
Conical Tip			Plan tip			Bulged tip		
Steel		Al	Steel		Al	Steel		Al
								
Thickness of intemetallic layer(µm)								
0.168;0.168;0.158;0.137; 0.158. Average:0.158 Standard deviation: 0.011321			0.137;0.126;0.221;0.147; 0.084 Average:0.143 Standard deviation: 0.044511			0.127;0.116;0.105;0.053; 0.116 Average:0.103 Standard deviation: 0.026143		

Figure 10: Intermetallic Layer formed in the friction welding

It is observed that the conical tips presented a higher average thickness of intermetallic layers; however, the distribution is uniform, whereas the flat tips have great thicknesses and an irregular distribution. This different formation of intermetallic compounds is caused by the distribution of heat generated during and friction.

4. CONCLUSIONS

By analyzing the results, it can be seen that actually occurs influence the initial contact geometry for carrying out the welding rotating friction. This influence can be seen in the results of resistance tensile limit of the welded parts. It is observed that the bulged tip and the conical tip with 60º slope, presented higher tensile strength results. During the welding, it was also verified that the conical and bulged tips provided a smoother displacement, with less vibration, besides formation of less flash.

There is influence of the initial contact geometry on the tensile strength of the welded joints. The conical point of 60º showed an increase in tensile strength in relation to the flat surface around 7.9% and the bulged tip presented an increase of about of 10.2% increase in tensile strength.

An interesting aspect is that flat geometry does not provide uniform force at the interface of the joint, which is lower in the internal region compared with the outside region. This can be the can cause entrapment of oxides and other contaminants.

Another important aspect is that the altered geometries changed the generation and distribution of heat on the friction surface.

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