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Spot Welding of Aluminum and Cast Iron by Friction Bit Joining

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Dissimilar combinations of aluminum alloy A356 and grey cast iron were spot welded by friction bit joining. In order to facilitate bonding, an intermediate layer of interstitial free steel was placed between the aluminum and the cast iron. Welding development resulted in cycle times of approximately 5 seconds, and lap shear fracture loads of up to 6.8 kN.

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NOMENCLATURE

a = directional orientation of the system
h = strip thickness with strip thickness and strip thickness strip thickness

1. Introduction

The automotive industry is pursuing an increased use of lightweight materials in auto body structures, for reduced weight and improved vehicle fuel efficiency. The use of different material combinations presents a number of technical challenges, especially when light metals must be joined to steel or cast iron. Joining of different steel alloys has been done using standard methods like resistance spot welding (RSW) or laser welding (LW).[12-14] While some attempts have been made to use traditional fusion welding processes, like resistance spot welding (RSW), to join aluminum and steel,[3-6] this approach is usually not suitable for welding of dissimilar metals, because of the metallurgical incompatibility that occurs during melting and solidification. On the other hand, a mechanical fastening method like self-pierce riveting (SPR) can be used,[1-5] but this method is limited to the joining of relatively ductile metals like aluminum and mild steel. Friction stir spot welding (FSSW) has also been employed for spot joining of dissimilar metal combinations, like aluminum/steel and magnesium/steel.[1-3] This method is viable in some cases, but is limited in the amount of joint strength that can be produced.

Friction bit joining (FBJ) is another process with potential for joining of dissimilar alloys. This method has been used to join high strength steels[1] and dissimilar combinations of aluminum and steel,[1,2] and has been shown to achieve high levels of joint strength in these applications, with levels above produced by self-piercing riveting. The origin of the joint strength lies in the similar metal diffusion bond between the joining bit and the sheet material on the bottom of the joint, which in this case is steel. The bonding process between the bit and the steel sheet is similar to that of inertia friction welding.[1] This paper presents a study of friction bit joining (FBJ) applied to dissimilar combinations of cast iron and aluminum. The principal phenomenon that will be studied is the bonding between the steel joining bit and the cast iron, which is not usually amenable to friction joining processes, owing to the lubricity of the graphite flakes which prevent sufficient frictional heating from taking place. A modification to the normal FBJ method, where an intermediate layer of steel has been used to promote frictional heating, is described.

2. Experimental Methods

2.1 Spot joining

The FBJ process comprises two essential phases. It starts with an initial cutting phase, where the top layer of sheet material is penetrated by the cutting action of the rotating joining bit under applied axial load. After penetration of the top layer there is a transition to the second

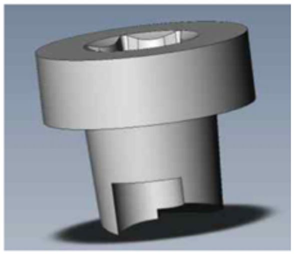

Fig. 1 Schematic representation of a joining bit. The bit has a cutting tip on one end and Torx head on the other end

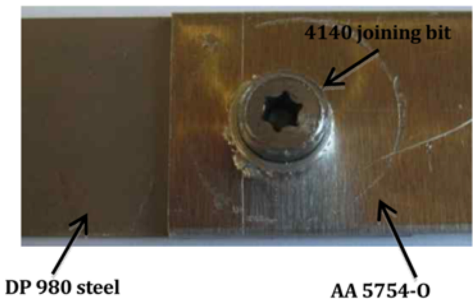

Fig. 2 Lap shear joint of AA 5754 (top sheet) and DP 980 steel (bottom sheet) using a 4140 steel joining bit

phase of the process, which involves frictional joining of the bit to the bottom layer of material. The joining bit is consumable, meaning that it is left in the workpiece at the end of the process and forms an integral part of the weld. A bit with a head driven by a standard Torx driver was employed, where a model is shown in Figure 1.

Prior work has been done with joining bits composed of alloy steel like 4140, with a hardness of about 30 R_c.[1] When joints are created by FBJ the light metal sheet is on top, and the steel sheet is on the bottom. As previously described, the bit cuts through the softer top layer of aluminum and then bonds by friction to the steel on the back, creating a diffusion bond between the steel sheet and the steel joining bit as shown in Figure 2, for a joint composed of 1.8 mm AA 5754 and 1.4 mm DP 980 steel.

In the present work, joints were composed of aluminum alloy A356 and grey cast iron. The frictional joining approach does not work well when a steel bit is rotated against a cast iron surface, because the lubricity of the graphite flakes in the cast iron prevents sufficient heating for creating a diffusion bond. Preliminary work showed that it was not possible to produce any bonding between the joining bits, which in this case were produced from steel alloy D2, and grey cast iron. Therefore, a thin intermediate layer of interstitial free (IF) steel was placed between the cast iron and the aluminum, in order to produce sufficient frictional heating to create a bond.

2.2 Mechanical testing

The strength of the welded joints was evaluated using lap shear tension testing. The application of the aluminum/cast iron joints was an aluminum hub/cast iron brake rotor assembly. As such, welding development was done on specimens that were cut from an aluminum hub and cast iron brake rotor. The aluminum specimens were 25 mm wide, 80 mm long, and either 4, 6, or 8 mm thick. Cast iron coupons were 25 mm wide, 80 mm long, and approximately 8 mm thick. Welds

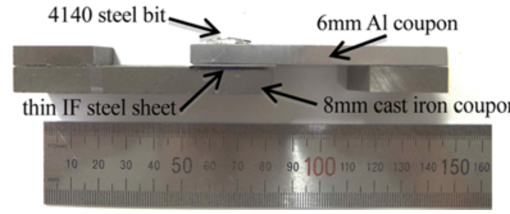

Fig. 3 Configuration of aluminum/cast iron lap shear specimen

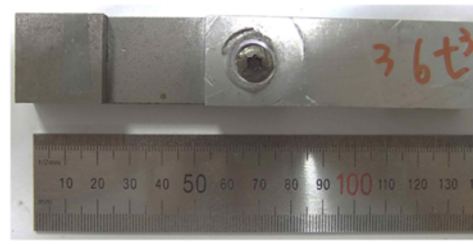

Fig. 4 Top view of lap shear specimen, with joining bit centered on overlap area

were produced in the center of an overlap area of 25 mm and spacers were added to each side in order to ensure proper alignment for testing. A thin layer of IF steel, with thickness of 0.85 mm, was placed between the aluminum and the cast iron, as shown in Figure 3 for a 6 mm aluminum specimen.

A thin layer of interstitial free steel was placed between the aluminum and the cast iron in order to facilitate bonding.

A view of the top of the lap shear test piece is shown in Figure 4, where the joining bit is seen to be in the center of the overlap.

Spacers were used to ensure that the specimen was centered along the tensile axis in the test frame, as can be seen in both Figures 3 and 4. The crosshead speed used for testing the specimens was 0.4 mm/min.

2.3 Analysis of joints

Line scans were done across the joint in different locations to verify bonding. Optical microscopy was also employed in order to study the joints that were produced by FBJ.

3. Results and Discussion

Various welding parameters were used during the development phase of the project, in order to achieve the best lap shear performance of the joints. The parameters that were found to provide the best results were as follows:

First bit speed:	3500 RPM
First plunge rate:	31.8 mm/min
First plunge depth:	-2.30 mm
Second bit speed:	3700 RPM
Second plunge rate:	31.8 mm/min
Second plunge depth:	-7.62 mm

Note that the plunge depth is the total distance traveled downward during the welding process, not the incremental distance. Lap shear fracture loads for specimens with 4 mm, 6 mm, and 8 mm aluminum coupons are shown in Table 1.

Table 1 Lap shear fracture loads for aluminum/cast iron joints.

Aluminum thickness	Lap shear fracture load (kN)
4 mm	2.65
6 mm	6.80
8 mm	5.63

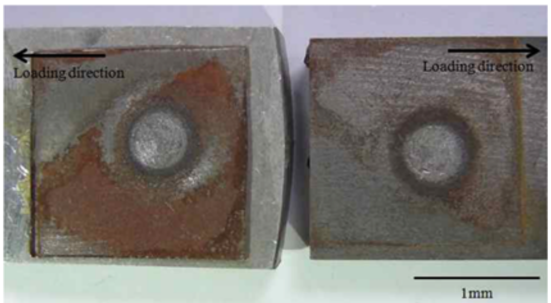

Fig. 5 A top view of aluminum/cast iron FBJ joint failed under a lap shear load

Fig. 6 Cross section of joint composed of A356 aluminum (top), grey cast iron (bottom), and a D2 steel joining bit (center). The intermediate layer of interstitial free steel can also be seen between the aluminum and the cast iron

The results in Table 1 are an average of two specimens for the 4 mm and 6 mm cases, and only one value for the 8 mm case. As expected the lap shear fracture load increases when the aluminum thickness is increased from 4 mm to 6 mm. However, there is a drop in lap shear fracture load from 6 mm to 8 mm. This may be attributed to a joining bit, which was not sufficiently long in the case of the 8 mm aluminum, and therefore the results will need to be verified by further testing. Overall the strength of the dissimilar metal welds is very good and can be viewed as a successful result, at least for the preliminary work that was done. Note that for all the tested lap shear specimens, separation occurred along the interface of the joining bit and the cast iron coupon as shown in Figure 5. This suggests that the joining bit penetrated the intermediate layer of steel and that direct bonding has occurred between the bit and the cast iron, even as the bonding was facilitated by heating from the intermediate layer.

As mentioned above, the bonding that occurred between the joining bit and the cast iron was facilitated by the intermediate layer of interstitial free steel. Without this layer there was not enough heating to create a diffusion bond. A cross section of one of the joints is shown in Figure 6.

The strength of the joint depends primarily on the diffusion bond between the joining bit and the cast iron. The micrograph in Figure 6 confirms that the joining bit has penetrated the intermediate layer of steel and bonded directly to the cast iron. It is likely that this bonding was facilitated by the frictional heating between the joining bit and the steel layer. A line scan across the bond interface between the steel joining bit and the cast iron is shown in Figure 7.

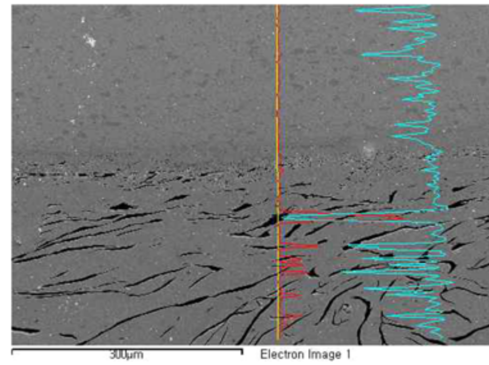

Fig. 7 Line scan across the bonded region of the joint, between the D2 steel joining bit (top) and the cast iron (bottom). The interface between the materials appears to show good bonding, and the amount of carbon is shown in red, while the iron composition is shown in blue. There is a clear transition from cast iron to steel and no apparent gaps or defects at the bond interface

4. Conclusions

Friction bit joining was used to successfully bond aluminum alloy A356 to grey cast iron, with lap shear fracture loads approaching 7 kN in the case of a 6 mm thick aluminum coupon welded to an 8 mm thick cast iron coupon. Bonding was facilitated by an intermediate layer of interstitial free steel, which promoted greater heating than is possible between the D2 steel joining bit and cast iron. The frictional heating appears to have created a metallurgical diffusion bond between the joining bit and the cast iron, and this was the source of the strength of the joints that were tested.

ACKNOWLEDGEMENT

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