

Self-Pierce Riveting of Magnesium to Aluminum Alloys

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ABSTRACT

Magnesium and aluminum alloys offer lightweighting opportunities in automotive applications. Joining of dissimilar materials, however, generally requires methods that do not involve fusion. This paper explores the use of self-pierce riveting (SPR) to join magnesium to aluminum alloys for structural and closure applications. The preliminary results indicate that SPR is a viable option for joining aluminum extrusions to magnesium die castings, as well as stamped sheet aluminum to quick-plastic-formed (QPF) sheet magnesium.

INTRODUCTION

Self-pierce riveting is a method of joining two or more pieces of material using a rivet. Unlike conventional riveting, self-pierce riveting does not require a pre-drilled hole because the rivet makes its own hole as it is being inserted. The self-piercing rivet is squeezed at high force into the material to be joined, piercing the top sheet(s) of material and spreading outwards into the bottom sheet of material, under the influence of an upsetting die, to form a strong joint [1].

The increasing use of coated, lightweight and high-strength materials, such as galvanized or pre-painted steel and aluminum has led industries to re-examine traditional methods of assembling components. Welding of these materials is difficult or impossible, especially for dissimilar materials such as steel-to-aluminum (steel/Al), steel-to-magnesium (steel/Mg), and aluminum-to-magnesium (Al/Mg). Assembly using conventional rivets is slow and costly, thus the benefits of a process like SPR that combines high joint integrity with rapid assembly times is being explored by many manufacturers. SPR, instead of resistance spot welding, is used by BMW to join Al/Al (aluminum front end

assembly) and Al/steel (aluminum front end to the steel body) in its 5- and 6-series body-in-white production [2]. SPR technology is also used in the production of aluminum-intensive vehicles such as Jaguar XJ and Audi A2/A8, to join various forms of aluminum (sheets, extrusions and castings), due to the superior fatigue and crash worthiness of SPR joints compared with spot welding [3]. Freightliner also makes extensive use of this technology for heavy-truck aluminum cabs [4].

Increasing use of lightweight Mg castings (instrument panel beams and radiator support structures) and Mg sheet applications (closure inner panels) promotes the need of joining Mg to other materials such as steel and Al. Friction stir welding of Al to Mg has been reported in the literature, but its joint strength was not fully characterized [5]. The objective of this paper was to explore the feasibility of using SPR technology to make Al/Mg joints for mechanical testing.

EXPERIMENTAL PROCEDURES

Two different joining applications were evaluated for this work. Application I replicates a structural aluminum extrusion joined to a die cast magnesium component; and Application II represents a stamped aluminum reinforcement joined to a QPF (quick plastic forming) magnesium inner panel. Two separate suppliers, Henrob Corporation (Novi, MI) and Emhart Technologies (Mt. Clemens, MI), were used for the above applications, respectively.

MATERIALS

For Application I, representative structural aluminum alloy 6063 and magnesium alloy AM50 were selected for this riveting study. The 6063 alloy was extruded into 2.5 mm thick plates and heat-treated to the T6 temper, which is often used in structural applications. The AM50 samples were die

Table 1. Nominal composition (wt.%) of the alloys [7, 8, 9]

Alloy	Al	Mg	Si	Mn	Fe	Cr	Cu	Zn	Ni
Extruded 6063-T6	Bal.	0.48	0.40	0.01	0.14	< 0.01	0.01	0.01	< 0.01
Die cast AM50	5.0	Bal.	< 0.1	0.30	< 0.005	N/A	< 0.003	< 0.01	< 0.003
Sheet 5754-O	Bal	3.1	< 0.4	< 0.5	< 0.4	< 0.3	< 0.1	< 0.2	< 0.05
Sheet AZ31B-O	3.0	Bal.	< 0.1	> 0.2	< 0.005	N/A	< 0.003	1.0	< 0.003

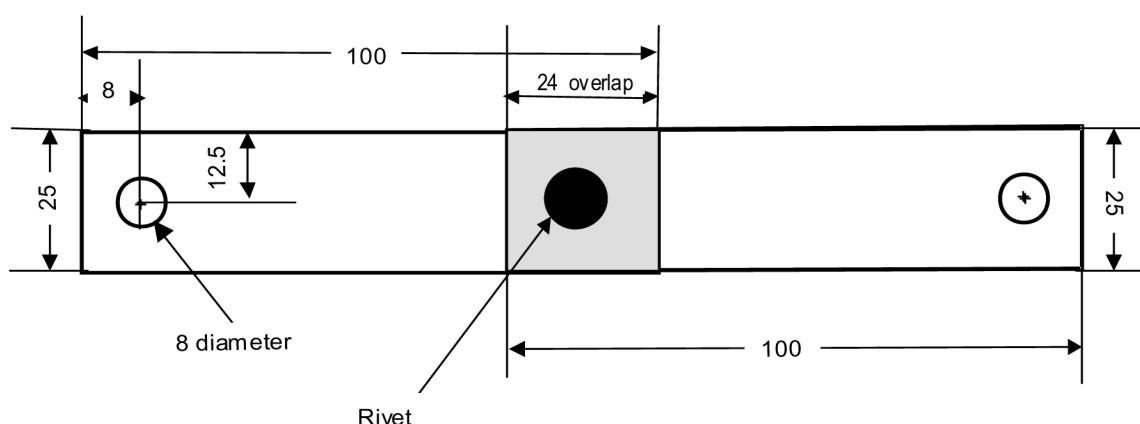


Figure 1. Lap shear joint for mechanical and corrosion testing (all dimensions in mm).

Table 2. Typical tensile properties of the alloys [7, 8, 9].

Alloy	Yield Strength, MPa	Tensile	Elongation,
Extruded 6063-T6	215	240	12
Die cast AM50	125	210	10
Sheet 5754-O	100	220	26
Sheet AZ31B-O	150	255	21

cast plates, 3 mm thick, and were used in the as-cast condition, as is done in many magnesium applications, such as instrument panel beams.

For Application II, representative 5754 aluminum and AZ31B magnesium alloys were used. 5754-O was chosen because it is commonly used for aluminum reinforcements. AZ31B has been used to form experimental inner panels by the QPF process [6]. Mg sheet samples were heat-treated to 450°C for 15 minutes, then air cooled, to simulate the forming process and to change its temper from H24 to O. The thickness of both types of sheet was 2.0 mm.

Alloy compositions and typical mechanical properties of the above materials are summarized in Tables 1 and 2, respectively [7, 8, 9]. The aluminum and magnesium specimens were machined and paired to make lap joints as shown in Figure 1.

JOINING

Application I: Extruded Aluminum/Die Cast Magnesium

Self-pierce riveting experiments of 6063-T6 and AM50 were conducted at Henrob, using different rivet sizes and upsetting dies. All specimens were produced using Henrob's hydraulic pre-clamping riveting equipment with a riveting pressure of 23 MPa and a clamping pressure of 12 MPa. The different rivet (coated steel rivets) and die combinations are listed in Table 3. Joining sequences of Al to Mg and Mg to Al were compared in this experiment.

Application II: Sheet Aluminum/Sheet Magnesium

SPR experiments of sheet specimens were done at Emhart, using rivets 5.3 mm in diameter and 6 mm long for all the experiments conducted. The rivets were cold formed, semi-tubular and made of carbon steel. The rivets were

Table 3. Application I (extruded Al/die cast Mg): Riveting parameters.

Experiment (# of specimens)	Joint Sequence	Rivet dimensions, mm		Die dimensions, mm		
		Diameter	Length	Diameter	Depth	Pip
A (50 specimens)	Mg/Al	5	8	10	2	2
B (5 specimen)	Al/Mg	5	8	10	2	2
C (1 specimen)	Al/Mg	5	7	9	2	2
D (1 specimen)	Al/Mg	5	7	10	1.5	2
E (1 specimen)	Al/Mg	5	7	11	1.2	0

Table 4. Application II (sheet Al/sheet Mg): Riveting set-up parameters.

Rivet	5.3 mm dia x 6.0 mm long
Setting Tool	80 kN
Emhart "C" Frame Number	M212 014
SPR Die	M260 021
Preclamp Force	6 kN
Maximum Force	53 kN
Head Penetration Setting	-0.8 mm

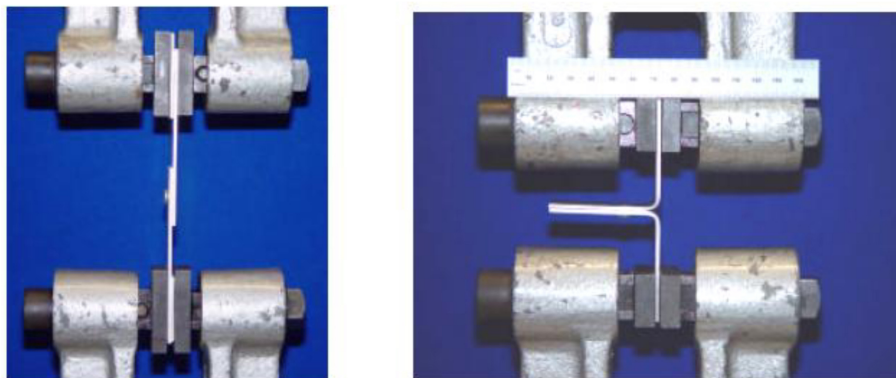


Figure 2. Typical (a) lap-shear and (b) coach-peel test samples and grips [15].

mechanically plated for corrosion resistance with ALMAC, which is a patented combination of aluminum and zinc [10]. Again, joining sequences of Al to Mg and Mg to Al were compared for sheet specimens. The equipment and basic technology used was the same as detailed in Application I. The set-up, dies, and rivets varied from those used in Application I, and are shown in Table 4. A standard (off the shelf) die was used for this work. No attempt was made at die or joint optimization. A specific Mg/Al die will need to be developed to improve the joint performance as this technology is developed further. All work was done under laboratory conditions.

CHARACTERIZATION

Lap shear (Figure 2a) and coach peel testing (Figure 2b) of the joined samples was carried out on a tensile test machine and the tested joints were examined visually to determine the failure mode (Figure 3). Optical metallography was used to characterize the joint sections.

RESULTS AND DISCUSSION

APPLICATION I: EXTRUDED ALUMINUM/DIE CAST MAGNESIUM

Results of the lap-shear tests and metallography for structural joints of Al extrusions and Mg die castings are shown in Table 5 and Figures 4, 5, 6, 7, 8, respectively. It is evident that the Mg to Al SPR joint shows about 20% higher lap shear strength than that of the Al to Mg joint. Figures 4, 5, 6, 7, 8 suggest that more plastic deformation is needed for the bottom part to be joined by SPR and all Mg parts were cracked when placed on the bottom, despite different rivet and die configurations used (Specimens B - E). For Experiments C - E, multiple samples were tried with no success; only one specimen was tested for each configuration and reported in Table 5. This is due to the slightly lower ductility of die cast AM50 Mg alloy (10%) compared with the 6063-T6 Al extrusion (12%). It is also seen that the Al to Mg joints failed by rivet "pullout", Figure 3a; and the failure