

Comparing Laser Welding Technologies with Friction Stir Welding for Production of Aluminum Tailor-Welded Blanks

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ABSTRACT

A comparison of welding techniques was performed to determine the most effective method for producing aluminum tailor-welded blanks for high volume automotive applications. Aluminum sheet was joined with an emphasis on post weld formability, surface quality and weld speed. Comparative results from several laser based welding techniques along with friction stir welding are presented. The results of this study demonstrate a quantitative comparison of weld methodologies in preparing tailor-welded aluminum stampings for high volume production in the automotive industry. Evaluation of nearly a dozen welding variations ultimately led to down selecting a single process based on post-weld quality and performance.

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INTRODUCTION

The production of welded blanks for high volume automotive stampings is a core technology enabling the efficient use of materials throughout the body-in-white [1, 2, 3]. This approach of welding dissimilar thicknesses and alloys into a common sheet or coil aligns manufacturers with the type of lean engineering tools necessary to manage costs while simultaneously lowering weight and reducing material waste. While the effective use of laser welding technologies for producing welded blanks and coils in various steel alloys with unique coatings and properties is readily available for a wide range of applications [4], the implementation of the same techniques have lagged for applications in other metals such as aluminum and magnesium [5-6].

Research efforts in solid state welding technologies have greatly contributed to better understanding of welding light metals over the last decade, with significant strides being made in the development and commercialization of friction stir welding (FSW) [7, 8, 9]. Aluminum alloys benefit from being welded via solid state technologies, as they avoid the complexities associated with melt-solidification cycles. Aluminum's well characterized affinity for hydrogen in the molten state is problematic for traditional fusion technologies

that rely on locally managing a molten weld pool. Solid state processes like friction welding or FSW avoid the phenomenological complexities involved with managing light metals in their molten states.

EXPERIMENTAL DETAILS

Automotive aluminum sheet was used for all welding trials. Aluminum alloy 5182 with an "O" temper in thicknesses of 2.0-mm and 1.0-mm were welded together in a standard butt weld configuration. The AA5182-O materials used for this study exhibited a tensile strength of 306 MPa, a yield strength of 152 MPa, and elongations of 22% at failure. Material properties were evaluated in both the sheet rolling direction and transverse to the rolling direction without measurable distinction between properties. The AA5182-O sheets were bare without oil or lubricant on the surface.

Welding trials were performed on butt weld configurations of 2.0-mm and 1.0-mm sheets. The orientation of the welding was such that in all cases the bottom of each sheet was held flat, so that the entire offset due to thickness differences was present on the top side of the weld. All welding was performed from the top side of the sheets across the dissimilar thickness interface.

Weld coupons were rectangular specimens 125-mm wide by 230-mm in length by thickness. This size was designed to accommodate limited dome height (LDH) specimen geometries of 175-mm × 175-mm while avoiding any of the nonhomogeneous material at the start or finish of the welds. In some cases specimens were 460-mm in length accommodating two LDH specimens from each weld. LDH specimens were made with the weld line across the center of the 175-mm square panel, which centers the weld at the peak of the dome during the test initiation.

LDH testing was performed using a 101-mm diameter stainless steel punch, with a beveled stainless steel clamping ring. The clamping ring was fixed with a 1.0-mm shim over ½ the circumference of the circular ring to accommodate the 1.0-mm offset in the sheet thicknesses. AA5182-O welded blanks were isolated from the stainless punch with a 0.13-mm thick Teflon sheet to provide lubrication between the punch and welded aluminum sheet. The punch was operated at a fixed speed of 10-mm/min, and the stroke was stopped after a 10% reduction from peak load.

Laser Welding

All laser welding was performed with a with a 6 kW diode-pumped fiber. Individual variations in power, alignment and setup are discussed in detail within the following sections.

Single Spot

Laser welding with a single spot optic was performed characterizing the effects of beam spot size, welding speed, laser power, and beam offset relative to the weld joint centerline. Variations on the parameters explored as part of this study are shown in Table 1. Weld parameters that remained fixed for the study included: beam angle of 15°, a fixed in focus focal position, and a constant argon shield gas flow rate of 20 l/min.

Table 1. Variable Weld Parameters for Single Spot Laser

300 µm Spot Size	
Speed (m/min)	4.0, 6.0, 8.0
Offset (mm)	0.0, -0.3, -0.6
Power (kW)	2.5
600 µm Spot Size	
Speed (m/min)	4.0, 6.0, 8.0
Offset (mm)	0.0, -0.2, -0.4
Power (kW)	2.8, 3.0, 3.5, 3.8, 4.0, 4.5

Dual Spot

Laser welding of dissimilar thickness aluminum welded blanks utilizing a dual spot configuration was performed while holding the following weld parameters constant: spot size of 300 µm, a beam angle of 15°, a fixed focal position (in focus), and a constant argon shield gas rate of 20 l/min. Additional welding variables of spot size, beam intensity (the power ratio between the two beams), total laser power, and spot offset from the weld centerline were varied over the values displayed in Table 2. Two separate configurations were utilized to allow the greatest flexibility to the welder in preparing the welded blanks. This included a leading/trailing configuration along the weld centerline shown in Figure 1a, and a balancing beam approach having two lasers offset from the weld centerline across the centerline as shown in Figure 1b.

Table 2. Variable Weld Parameters for Dual Spot Laser

300 µm Spots Across the Weld Centerline	
Beam Intensity (%)	50-50, 40-60, 10-90
Distance Between Spots (mm)	0, 0.3, 0.6, 0.9
Offset (mm)	0.0, -0.1, -0.3, -0.5
Power (kW)	2.5, 2.8, 3.0, 3.2
300 µm Spots Along the Weld Centerline	
Beam Intensity (%)	50-50, 40-60, 20-80
Distance Between Spots (mm)	-0.9, 0, 0.9, 1.5, 3.0
Offset (mm)	0
Power (kW)	2.8, 3.2, 3.4, 3.6

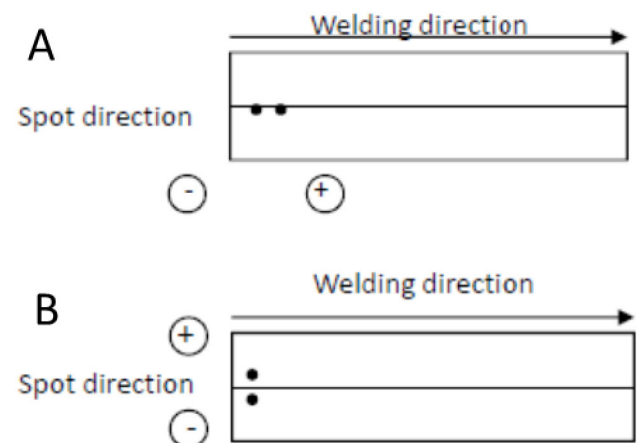


Figure 1. Beam Configurations for Dual Spot Laser Welding of Dissimilar Thickness Aluminum Blanks.

Hybrid Laser Plasma Welding

Table 3. Variable Weld Parameters for Laser Plasma Hybrid

Low Power (barely full penetration)	
Plasma Current (A)	15, 20, 28
Laser Power (kW)	2.3, 2.8, 3.7
Travel Speed (m/min)	4.0, 6.0, 8.0
High Power (full penetration)	
Plasma Current (A)	22, 23, 30
Laser Power (kW)	2.4, 3.0, 3.9
Travel Speed (m/min)	4.0, 6.0, 8.0

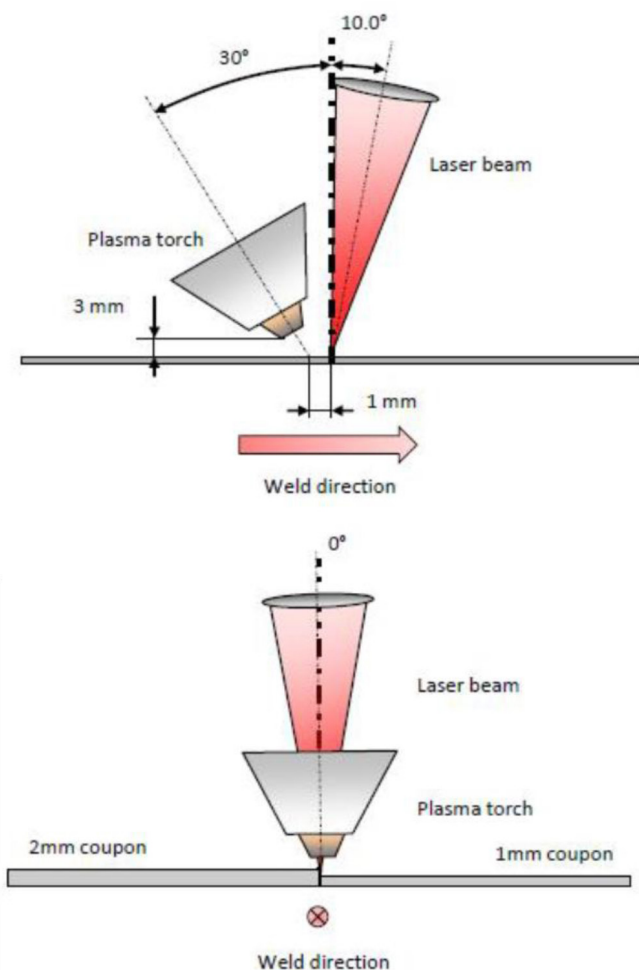


Figure 2. Schematic Representation of the Laser Plasma Hybrid Welding Process on Dissimilar Thickness Aluminum Blanks

A hybrid laser welding methodology was also applied for joining dissimilar thickness aluminum welded blanks. A schematic illustration of the process including weld variables is shown in Figure 2. Fixed parameters for the process included: spot size of 600 μm , beam angle of 0° , in focus focal position, a fixed offset of

0.4 mm, a fixed spacing of 1-mm between the focal position of the plasma and laser, and a constant argon cover gas feed rate for both the shield gas and plasma gas. These fixed parameters were set based on the results of screening tests ability to maintain consolidation. Parameters that were acceptably varied for the process include weld speed, plasma current and laser power, which were varied according to the details provided in Table 3.

Friction Stir Welding

Solid state FSW was also evaluated as a possible means of joining dissimilar thickness aluminum welded blanks. Welding parameters were varied according to conditions presented in Table 4. A schematic representation of the FSW tool used for these tests is shown in Figure 3. All tools were made of H-13 tool steel hardened to greater than 42 RC, and had a constant shoulder diameter of 12 mm with a fixed shoulder to pin diameter ratio of 3:1. Pins were tapered, 3-flat designs with pin length varying according to Table 4. The following fixed weld parameters were utilized: Tool tilt of 0.5° allowing the front shoulder to be slightly above the weld surface, a fixed material tilt with respect to the tool axis to accommodate the edges of the dissimilar thickness sheets. All welds were made on an anvil material made of H-13 tool steel with an as-machined surface finish.

Table 4. Variable Weld Parameters for FSW of Dissimilar Thickness Aluminum Blanks

Pin Length (mm)	1.5, 1.75
Rotational Velocity (RPM)	1100, 1500, 1950
Travel Speed (m/min)	1.9, 2.9
Plunge Depth (mm)	1.85, 1.88, 1.95
Number of Shoulder Flutes	1, 2

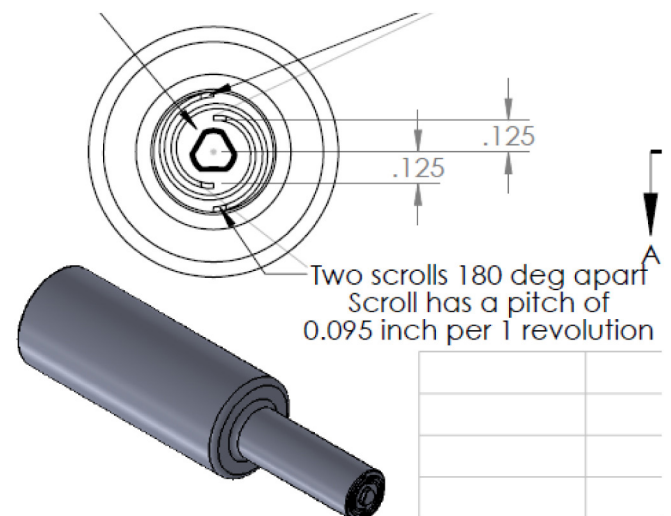


Figure 3. Schematic Representation of a FSW Tool used for welding dissimilar Aluminum Blanks Showing a Shoulder with Two Flutes.