Laser Welding of Automotive Aluminum Alloys to Achieve Defect-Free, Structurally Sound and Reliable Welds

T. DebRoy
Department of Materials Science and Engineering
The Pennsylvania State University
University Park, PA 16802

I. TECHNICAL PROGRESS

The objective of this program was to seek improved process control and weldment reliability during laser welding of automotive aluminum alloys while retaining the high speed and accuracy of the laser beam welding process. In particular, we undertook a comprehensive experimental and theoretical research to understand the effects of various welding variables on the loss of alloying elements and the formation of porosity and other geometric weld defects such as underfill and overfill. The major achievements and findings from the work are summarized below:

I-1. Alloying elements loss

a) We developed a comprehensive model that can predict the weld pool geometry, vaporization rates, and weld metal compositional changes during conduction mode laser welding of aluminum alloys. The model can serve as a basis for the quantitative understanding of influences of various welding parameters on fluid flow and heat transfer, vaporization of alloying elements, and weld metal composition change during laser welding.

b) The vaporization rate of magnesium was found to be about two orders of magnitude greater than that of aluminum during conduction mode laser welding of aluminum alloy 5182. The significant magnesium loss from the weld pool resulted in a lower magnesium concentration in the weld metal than present in the base metals for all welding conditions. The vaporization rate increased with an increase in laser power. However, the higher loss was compensated by an equivalent increase in the melting rate and, as a result, the concentration of magnesium in the weld metal, although lower than found in the base metal, was not significantly affected by changes in the laser power. The

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weld metal composition was also unaffected by the variation of welding speed for conduction mode laser welding.

c) The peak temperature at the weld pool surface slightly exceeded the boiling point of the alloy and was not sensitive to changes in laser power or welding speed. The pressure in a small region near the center of the weld pool surface was higher than one atmosphere. Vaporization was most pronounced in this active region, which had a smaller cross section area than the laser beam. The vaporization here was mainly driven by the pressure gradient that existed between the weld pool surface and the atmosphere. The vaporization rate outside of the active region was much lower.

d) When the laser power density was higher than a threshold value for a specific alloy, the welding mode changed from conduction mode to keyhole mode, accompanied by a significant increase in the melting rate and a less significant increase in vaporization rate. As a result, the magnesium depletion problem was more pronounced for welding in the conduction mode than in the keyhole mode.

I-2. Porosity formation in aluminum alloys

a) Keyhole stability was found to play a major role in porosity formation during laser welding of aluminum alloys 5182 and 5754. Pores with diameters larger than 0.2 mm were observed in the weld metal when the welding parameters were close to those for the transition between the conduction and the keyhole modes. In this transition region, the keyhole was not stable. Very small disturbance would cause the collapse of the keyhole and consequently, the formation of large pores.

b) Pore formation can be minimized by using laser power densities that are either well above the for keyhole formation to obtain stable keyhole mode of welding or well below the threshold value to obtain conduction mode of welding. For a specific laser power density, the variation of welding speed can also change the welding mode. Therefore, welding speed needs to chosen appropriately to avoid the transition region between keyhole and conduction modes.

c) Porosity can also be formed by the rejection of hydrogen from the solidifying metal due to the significant hydrogen solubility difference in the liquid and solid aluminum alloys. However, due to the low hydrogen content in the base metal and the high cooling rate during the welding, hydrogen-induced porosity was rarely observed in laser welded aluminum alloys 5182 and 5754.

I-3. Reduction of porosity in the fusion zone of magnesium alloy AM60B

a) The porosity found in the fusion zone was much more pronounced than that existed in the base metal of this alloy. There were fewer pores in the fusion zone than in the base metal while the pores in the fusion zone were much larger. Therefore, significant coalescence of the pre-existing pores occurred during the welding. A model was developed to understand the mechanism of pore formation, considering pore coalescence and expansion. The pore expansion was considered to be due to the reduction in internal pressure when smaller pores combined to form larger ones. The temperature changes during the welding also were also considered to cause pore expansion. We estimated the total amount of porosity formed in the fusion zone using this model. The estimated values agreed well with the experimental results. The good agreement indicated that the most dominant mechanism of porosity formation in fusion zone was the coalescence and expansion of the pre-existing pores in the base metal.

b) The influence of keyhole stability on porosity formation was studied by using different laser power intensities. Due to the higher vapor pressure and lower surface tension of this alloy, the keyhole formed during laser welding of this alloy was more stable than the cases of aluminum alloys 5182 and 5754. We found the stability of the keyhole was not a major factor in the pore formation during laser welding of alloy AM60B.

c) The influences of various welding parameters including laser power and welding speed were studied. It was found that the porosity formed in the fusion zone decreased with decrease in laser power or increase in welding speed. The porosity levels similar to that in the base metal could be obtained when the heat input was low.

d) High levels of heat input are required to get full penetration for thick plates. The use of high heat input resulted in significant porosity in the welds. We found that well controlled remelting of the fusion zone allowed some of the pores to float out, resulting in reduced porosity in the fusion zone. The reduction in porosity also indicates that keyhole instability during laser welding of alloy AM60B was not important for pore formation.

I-4. Geometric defects

a) Underfill at the root of full penetration welds was a recurrent defect during laser welding of aluminum alloys 5182 and 5754. In welds with underfill, spattered metal particles were collected in the back-plate groove below the weld region, indicating that the underfill was caused by expulsion of the molten metal during the welding. The control of the laser power density by changing the extent of laser beam defocusing did not result in welds completely free of underfill. However, sharp or deep notches that are harmful to the mechanical properties of the weld were not observed in the weld cross sections.

b) Significant overfill was observed in autogenous welds of alloy AM60B. The formation of overfill was due to the displacement of liquid metal by the pores in the fusion zone. The extra volume of the metal over the top surface of the workpiece was found to almost equal the total volume of pores in the weld metal. When a weld did not contain a large amount of porosity, the upper surface of the weld had a smooth profile and no overfill was formed. Any measure that decreases porosity in the weld pool, such as decreasing heat input and remelting of the fusion zone, resulted in decreased overfill.

II. PUBLICATIONS

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