LASER WELDING OF ALUMINUM AND COPPER FOR BATTERY WELDING APPLICATIONS USING A 500W SINGLE MODE FIBER LASER

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Abstract

For conductive materials such as aluminum and copper the use of a single mode fiber presents some clear advantages of welding speed and cost effective welding solution. The ability to a focus to a sub 30 micron spot size enables the single mode fiber laser to achieve the necessary power densities required to couple into these reflective materials. In addition the heat conduction of the materials stabilizes the weld from over heating due to the highly localized power density and also spread the weld volume to ease the potential issues of seam tracking with such as small spot size. The paper provides experimental details of the welding and specific examples of welding aluminum welding battery cans and conductive tabs for battery pack manufacture.

Introduction

The welding performance of multi kilowatt multi mode fiber lasers has been well documented for automotive and general penetration welding [1,2]. In contrast to the multi mode laser that typically use feed fibers of 100-200 microns diameter the single mode lasers have core fiber diameters between 15-50 microns, and therefore can be imaged to very small spot diameters. For many weld applications this fine spot size presents issues with weld fit-up and seam tracking accommodation and weld stability. For high speed lap welding applications[3,4] however the single mode fiber laser offers a unique solution. One such application area is that of battery and battery pack manufacturing.

In battery and pack manufacture there are a number of materials joining requirements, two of the key welding applications shown in Figure 1 are seam sealing the aluminum cans to create a barrier for the internal electrolyte and welding tab material to negative and positive terminals to create the electrical contacts for the pack.

Figure 1 Two battery welding applications suited to fiber laser welding technology; seam sealing aluminum battery cans and tab attachment to terminals for pack manufacture

The seam sealing application is well established and is currently being achieved using pulsed Nd:YAG laser technology. This laser source welds using a pulsed output with high peak powers provides a cost effective solution for high quality high reliability welding with minimal heat input. However, for certain volume production needs there is a requirement for faster welding that cannot be met using the pulsed Nd:YAG laser, as due to its nature a limit exists set by the average power. With a maximum value of around 600W this determines how quickly the laser can be pulsed for a given weld schedule. This pulse frequency sets the speed limitation as the weld spot overlap for a barrier must be maintained at around 70%. Therefore to increase speed further a continuous wave laser is required. For multi mode fiber laser the power to overcome the reflectivity of the aluminum or copper is several kilowatts which increases the capital costs significantly. In contrast the single mode fiber laser source offers the potential to weld both aluminum and copper with several hundreds of watts to provide the high welding speeds required at a similar cost as the pulsed lasers.

Laser welding of tabs to terminals for pack manufacturer is a much more recent application and is being driven by increasing production requirements and the need to weld more conductive tabs for the larger cells. Resistance welding has been and remains a key joining technology for welding tab material to a wide range of cells, though the mechanical actuation of the electrodes limits weld speed and a physical welding limitation is reached when welding tab material beyond 0.015" thickness due to current shunting. Laser welding of all tab thicknesses is possible with the capability of welding materials up to and beyond 0.04" thickness. The non contact nature of the process also provides high speed welding. As the tab weld geometry is lap there is no requirement for seam tracking thus allowing a very small optical spot size to be used. The minimal spot size provides sufficient power density to weld both aluminum and copper at high speeds.

Experimental

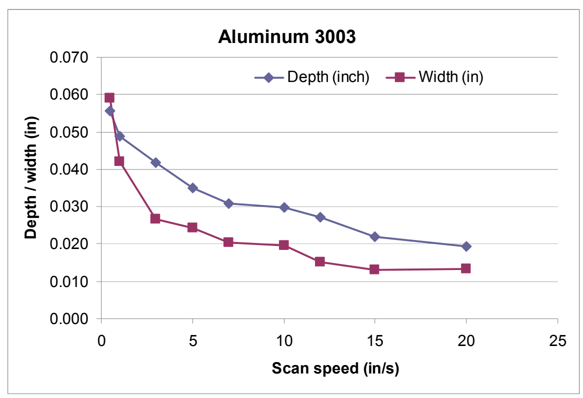
A 500W single mode fiber laser was used with an optical configuration that provided a spot size of 30 microns. The head was angled at 10º to avoid any back reflections, and off axis argon shielding gas was only used in the seam sealing trials. An initial benchmark test for the single mode laser bead on plate welds were performed on both aluminum 3003 and copper 110. All welds were completed on a high speed linear stage

For the seam sealing weld testing, battery can lids were welded to the body with a butt joint configuration. The thickness of the lid was 0.04". Both the body and lid material were Al 3003, with no pre weld treatment of the weld joint.

For the tab welding testing 0.012" thick 110 copper and nickel clad copper tab material (supplied by Technical Materials) was welded to a 0.018" thick cold rolled steel terminal. The lap welds were made across 0.5" wide coupons, with each weld examined for weld dimensions and peel strength.

Results

The benchmark results for penetration on bead on plate coupons of copper and aluminum exhibited penetration limits up to 0.02" and 0.06" respectively for 500W.



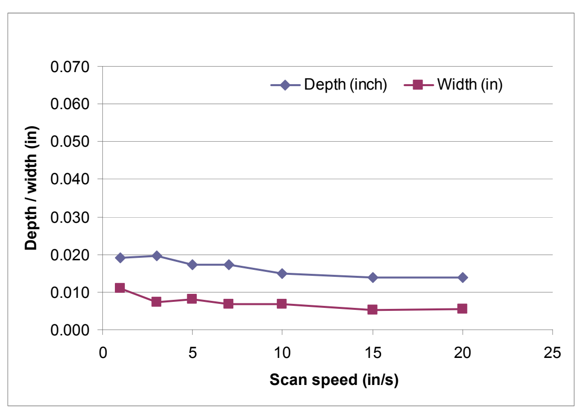


Figure 2 Bead on plate results of speed and penetration for a 500W single mode fiber laser with a

focus spot size of 30 microns for aluminum 3003 (top) and copper 110 (bottom).

With increasing speed it was interesting to note that aluminum penetration followed the usual reduction however copper exhibited a minor drop then flat line penetration response. With both materials impressive penetrations results were obtained, with even at 20”/s both showing around 0.02” depth for aluminum and 0.014” for copper.

The seam sealing trials were made on lithium ion battery cans for laptop computers. As the table needed to accommodate the weld path of the can lid the processing speed could not be maximized at 500W. Therefore the welding was completed at 300W.

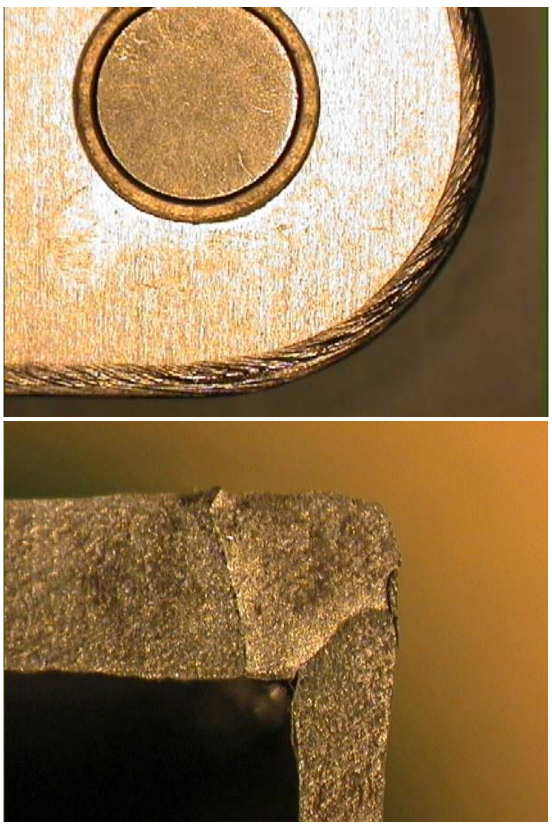


Figure 3 Top view of seam seal weld in aluminum 3003 completed at 300W and 2”/s. The cross section indicates that in this case too much penetration was achieved.

The weld results indicated fully penetrating butt weld of the 0.04” lid was possible at 300W and 2”/s. The weld surface was uniform without spitting and the cross sections indicated almost no porosity.

The tab welding speed and penetration results are shown in Figure 4 show the difference in material selection of tab material on penetration and speed. The copper shows an immediate fall off in penetration while the clad material exhibits almost twice the penetration at speeds beyond 2.5”/s. The peel strength results however indicated that although the clad material showed far greater peel strength at lower speeds (in excess of 150Ib peel), beyond 8”/s the copper peel strength was the same as the clad material, with 40Ib at 15”/s for the 0.5” wide weld strip. The failure mechanism of the copper material tended to be at the weld line as opposed to the clad material which failed away from the weld fusion line.

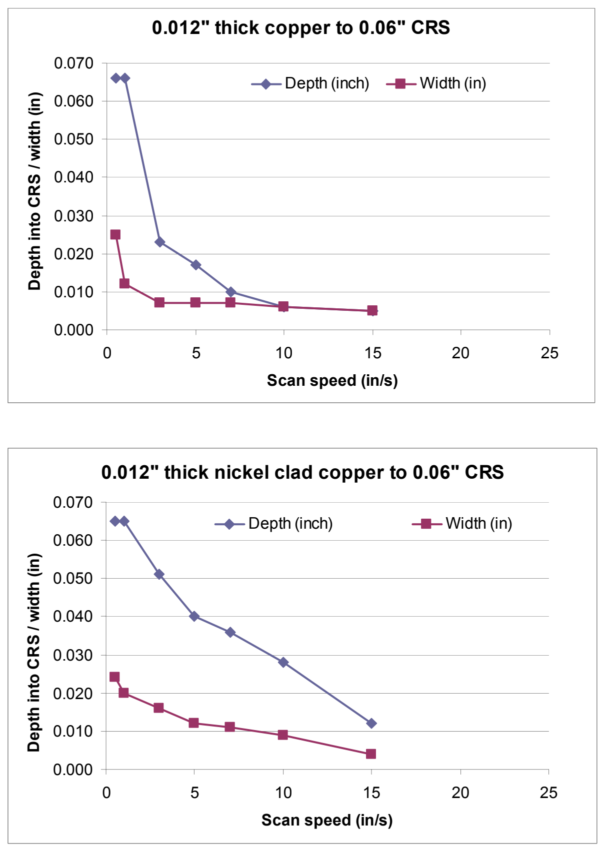


Figure 4 Penetration and speed for lap welding 0.012” thick copper and nickel clad copper into 0.06” thick cold rolled steel. Note the penetration on the graphs is shown into the cold rolled steel not total.

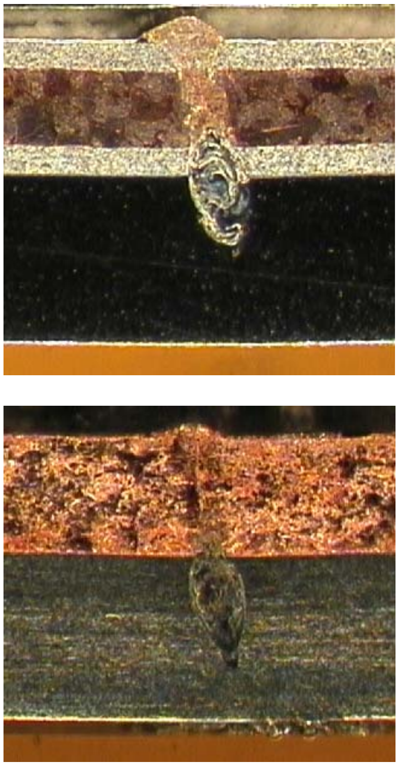


Figure 5 Cross sections of nickel clad copper (top) and copper (bottom) welded to cold rolled steel at 15"/s. Note slight angling of weld due to 10 degree head angle to prevent back reflection.

Discussion

Welding conductive materials such as aluminum and copper has always presented a challenge for lasers and many other welding techniques. For lasers the high reflectivity and thermal diffusivity produces inconsistent coupling and weld quality. The single mode fiber laser combines a 1064nm wavelength and sub 30 micron spot sizes to offer a unique laser source for seam welding aluminum and copper at high speed. To fully appreciate the extent of this a 30 micron spot size with 500W power provides a power density of 71×10^6 W/cm^2. At this level the reflectivity of both copper and aluminum can be overcome and welding occurs.

The preliminary results using a single mode laser on seam sealing cans indicate that the process is feasible and potentially offers rapid welding speeds. Applications that previously required 10s using pulsed Nd:YAG lasers can now be welded in 2-3s. The two key challenges that need determination for this high volume application are the level of welding consistency that a 30 micron spot size provides for a butt welding geometry and avoiding contamination of the internal battery jelly roll with weld metal. In addressing the weld tracking and gap tolerance accommodation it is worth noting that the aluminum welds exhibit a certain weld volume spreading that is not related to the focused spot size. Consider the cross sections shown in Figure 6 of bead on plate welds in stainless steel and aluminum at 2.5"/s and 500W with the same spot size of 30 microns. The steel cross section has a high aspect ratio of around 10, whereas the aluminum cross section has similar depth but a greatly increased weld volume with an aspect ratio of around 1.5.

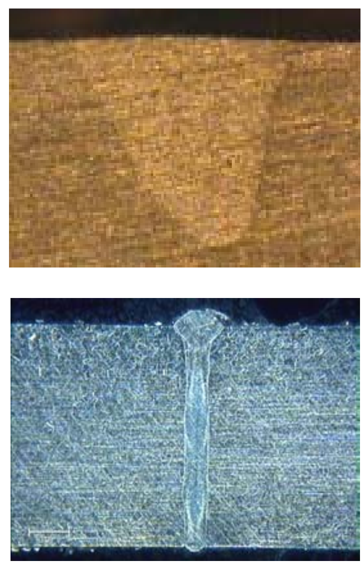


Figure 6 Comparison of the weld profiles for identical welding parameters with a 30 micron spot size in aluminum (top) and stainless steel (bottom). The aluminum exhibits far greater weld width due to increased thermal conductivity.

This effect can be very useful when butt welding as the weld tends to fill any gap or alleviate seam tracking issues. For the welding tests completed a sensitivity to weld gap was also investigated. Actual part fit-up for the butt weld had a gap of around 100 microns at the top with the sides tapering to meet at the base of the joint, the top view of the interface is shown in figure 7. However after welding the top of the weld is also shown in Figure 7 showing no underfill, and in sectioning the welds virtually no porosity.

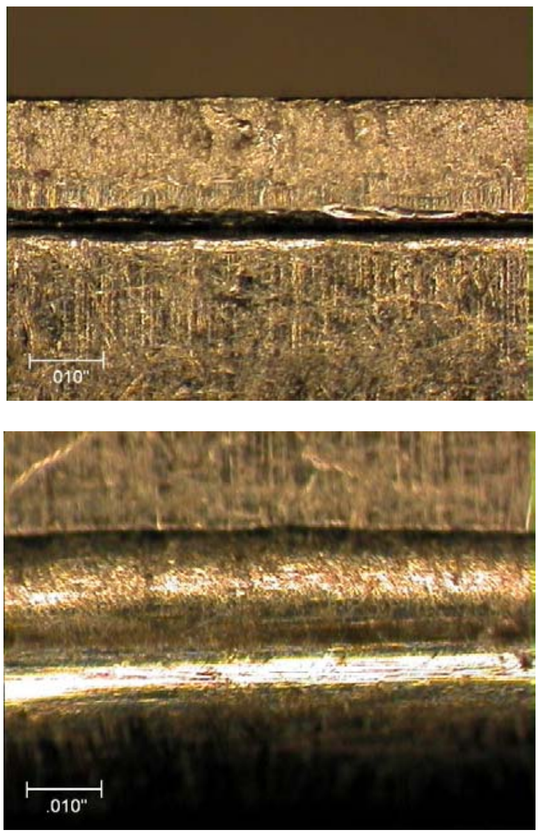


Figure 7 Indicates the top view of the butt weld interface with a 100 micron top gap, the after welded top view picture at the same point indicates no underfill or weld inconsistencies.

Following on from the work completed by Wagner [3] these results indicate that with 500W, and with an optical spot size of 30 microns, aluminum and copper with can be welded to around 0.06" and 0.02" depths respectively. More significantly these metals can be welded to depths of 0.015" at around 15-20"/s.

The welding results of the copper and nickel clad copper tabs to the CRS terminals aligns well with the requirements production welding, with good strength exhibited at high speeds. From the results the only anomaly lies in the relatively small drop in penetration of the copper with increasing speeds. A change is speed from 2.5 to 20"/s only resulted in a penetration change from 0.02" to 0.014". The possible explanations may be pre heating ahead of laser, minimal heat dissipation with increasing speeds, or that the power density is so high that the keyhole effect dominates until a point at which the weld simply fails completely.

There are a number of additional tab and terminal metals combinations that are required to be welded according to each battery and battery pack manufacturer. The most common metals for Lithium ion terminals are nickel plated CRS, nickel, nickel clad aluminum or aluminum. The tab materials are more diverse and are selected based upon cost, conductivity and weldability. One specific area of interest for cost reasons is the welding of aluminum to bare copper. While a bond between these two metals is possible and results in a joint that has initial strength the long term viability of the weld needs proving. With the bond comprised of brittle intermetallics and the mismatched thermal expansion coefficients of the base metals the weld lifetime subject to vibration and temperature cycling would appear questionable.

Summary

A 500W single mode fiber laser offers weld depths of 0.015" at speeds around 15-20"/s for both aluminum and copper. The two identified battery welding applications of aluminum can seam sealing and tab to terminal welding require both high speed and high quality welds. With its lap weld geometry the tab welding application appears well aligned to take advantage of the single mode fiber laser for high volume pack manufacture. The butt weld geometry of the can seam weld may be viable for fine spot welding though requires more testing.

Acknowledgements

To Technical Materials Inc for providing the nickel clad copper materials.

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Meet the Authors

Geoff Shannon completed his PhD in laser welding in 1993, since then has been involved in many aspects of laser materials processing. At Miyachi Unitek his role is Market & Application Development manager.

Hong Chen received his PhD in Mechanical Engineering from Columbia University in 2004 with research focused in laser processing. He worked at Quantronix Corp as application engineer and lab manager since 2004. Currently, he works as R&D Application Engineer at Miyachi Unitek.