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Advanced technology for light metals welding using a high-powered disc laser

Shigeki Saitoh

Laser Department, Trumpf Company Ltd, P.R. China

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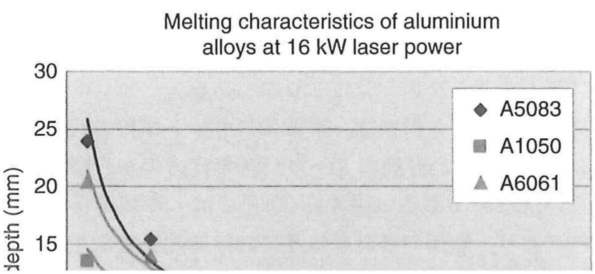
1. Introduction

The Trumpf Company supplies laser resonators and related equipment of all types, which range from micro to macro processes, in response to the needs of the manufacturing world. For macro processes, these include a CO_2 gas laser, with which it is possible to achieve a power of 20 kW, a CW disc laser resonator with a maximum power of 16 KW, and a lamp-pumped pulsed YAG laser.

In particular, the high luminance and high power of the disc laser are bringing about a major revolution in the welding of light metals. Below, there is a description of some examples of welding with a disc laser, exploiting its characteristic insensitivity to back reflection due to the resonator structure in a variety of working processes.

2. Melting characteristics of thick aluminium alloy sheet with high-power laser

Figure 1 shows the melting characteristics of a range of aluminium alloys when a 16 kW disc laser was used. The structure of the optical system was such that a silicon fibre with a 0.2 mm core was used to transmit the beam, the collimating lens had a focal length of f280 mm, and the welding was carried out using a work torch at a collimator focal length of f200 mm. The relationship between welding speed and melt depth was investigated using test specimens comprising two 12 mm thick sheets overlaid and fixed.



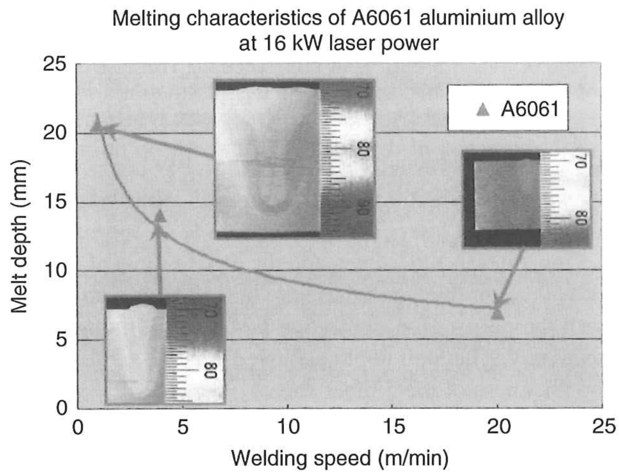


Figure 2. Melting characteristics of A6061 with 16 kW laser power. Beam spot diameter 0.28 mm, Ar 40 l/min.

When the welding speed was relatively low, 1–10 m/min for example, there was a tendency for welding speed and melt depth to vary. Once the welding speed was greater than 15 m/min, however, the differences between the melting characteristics of different alloys became less and the same melt depth was observed in all alloys.

Since, at low speeds, penetration was caused by a mix of thermal conduction and keyhole phenomena, it is thought that differences in the alloy components which control melting by thermal conduction affect the melting characteristics.

At higher welding speeds that give the same melting results, however, since melting due to the keyhole phenomenon becomes dominant, it is supposed that the formation of the molten layer is affected solely by the physical characteristics of aluminium which is the basic part of the alloy.

Figure 2 shows a cross-sectional photograph of the molten zone of A6061. At high welding speed, faster than

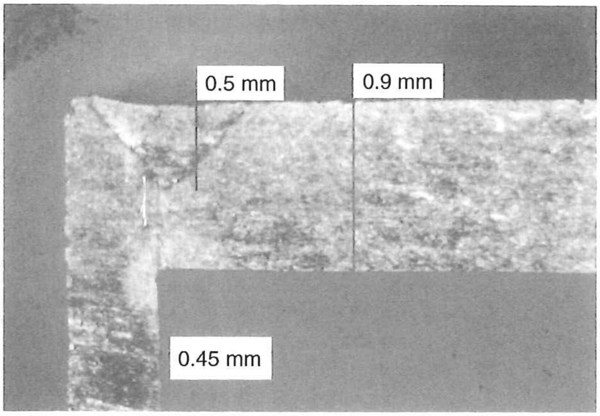


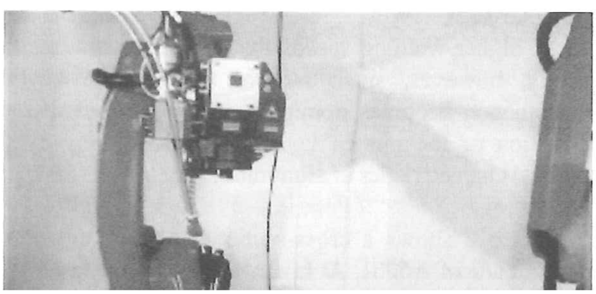
Figure 3. A3003 butt weld cross-section. TruPulse 304, Peak power 5 kw. Welding speed 13.3 mm/s (0.8 m/min).

sealing part was usually welded using a PW beam. Figure 3 shows a cross-sectional photograph of a butt weld made using a pulsed laser. The box was made of approximately 0.5 mm thick A3003 sheet, and the lid of a sheet of the same alloy 0.9 mm thick and these are butt-joined in an L-shape with the penetration depth that is generally thought to be necessary. The melt depth achieved was the same value as the thickness of the thinner sheet.

High-speed welding using a high-power CW beam is currently the main method. A remote welding technique incorporating an optical scanner is used in Japan in particular in the manufacture of Li-ion batteries (Figure 4). It is also widely used in the manufacture of vehicle bodies and increasingly used in motor vehicle manufacture in Europe.

One reason for which the remote welding was introduced into Japanese Li-ion battery manufacture is that it speeds up the manufacturing cycle, producing welded products at high-speed.

Even for thin-sheet welding at high-speed it tends to produce a marked reduction in spatter and internal defects. The appearance of the bead also shows a distinctive lustre so that the product gives a favourable impression.



3.1 A3003 melting characteristics with high-speed remote welding

Figure 5 shows the melting characteristics of A3003 aluminium alloy during remote welding. Due to the ease with which they are drawn, A3000 series alloys are widely used in battery cans.

A comparison was made of the melting characteristics and weld quality with laser powers of 2.5 and 4.0 kw. The experimental apparatus comprized a disc laser (TruDisk 4002) with a PFO33 (programmable focusing optics; focusing lens f255 mm). The beam spot diameter was 0.34 mm. B.O.P welding was performed with 1.5 mm thick A3003 sheet and the melt depth was measured and assessed. The shielding gas was argon, fed from a nozzle fixed to the jig.

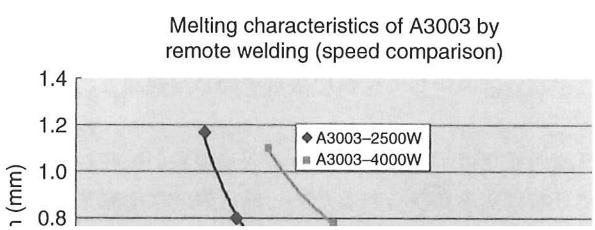
When the laser power was 4 kW, welding was of the total keyhole type and spatter was observed. In particular, when the welding speed was low, there was observable roughness of the bead and it was not possible to achieve a smooth metallic lustre. When the reverse surface was examined, it was found that the penetration was unstable.

When the laser power was 2.5 kW, however, there was a marked reduction in spatter and the appearance of the bead obtained was smooth. The melt depth was also constant. It was possible to achieve stable keyhole welding with relatively low power and high-speed.

It was found that it was possible to achieve the required weld quality with A3003 using a remote welding system with a constant power range. High-speed welding at speeds over 200 mm/s was successfully carried out with the relatively low laser power of 2.5 kW, which represents a welding speed of between 10- and 20-fold that of pulsed laser welding.

3.2 Characteristics of high-speed remote welding of aluminium alloys

In order to make the greatest use of remote welding by high-power disc laser into the battery manufacturing process, it must be used not only for the welding of batteries but also on other products.



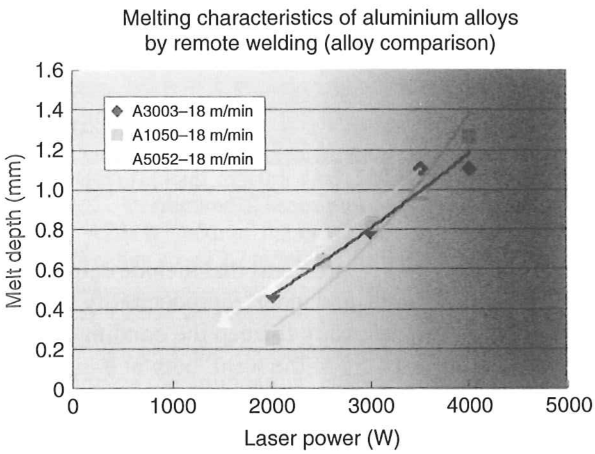


Figure 6. Melting characteristics of aluminium alloys. (alloy comparison).

Tests were carried out to examine the welding characteristics of three widely used aluminium alloys to determine whether they could be used in the assembly of Li-ion batteries using remote welding.

Figure 6 shows a comparative relationship of penetration depths and laser output at a constant welding speed of 300 mm/s (18 m/min). The three alloys were shown to have similar relationships between their melting characteristics and the laser output when they were welded at high-speed and in each case spatter became marked at a laser power of about 3 kW.

Figure 7 shows a comparative relationship of welding speeds and melting at a constant laser power of 2500 W. The relationship between welding speed and melt depth shows the same characteristics with A3003 and A1050 and the relationship seen with A5052 is not very different.

The relationship between spatter and welding speed for A1050 and A3003 was such that spatter started at a welding speed lower than 250 mm/s. On the other hand, spatter was observed with A5052 at welding speeds lower than 300 mm/s. Since, A5000 series aluminium alloys contain Mg, they have excellent melt characteristics but are liable to spatter and care must be taken when welding these for Li-ion battery parts.

As a result of these tests, it was clear that A1050, A3003, and A5052 produce almost the same penetration and weld quality under the same welding conditions, provided that the welding speed is set appropriately.

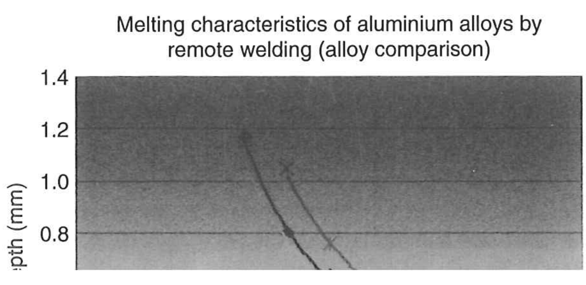
Since, the three alloys have approximately the same process window at a constant high welding speed, the same work conditions can be set for them all, which simplifies the process design.

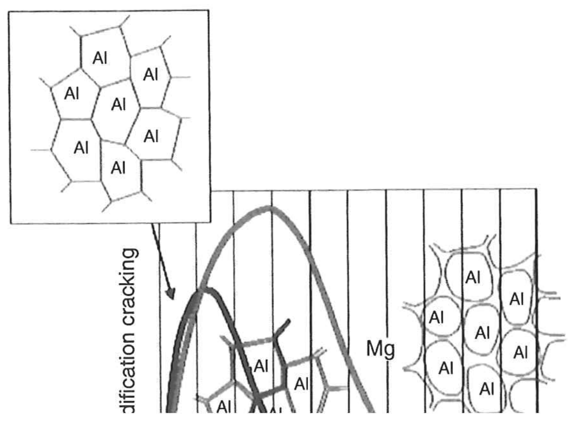
3.3 Measures against solidification cracking

One problem associated with the welding of aluminium alloys, particularly of dissimilar alloys, is solidification cracking.

When alloys are welded, care must be taken with the combination of alloys that are joined. In particular, when lap welding or butt welding the A1000 series with the A5000 series of alloys, the Mg element in the molten zone becomes diluted and there is a tendency for cracking to occur (Figure 8). When, for example, it is intended to weld A1050 and A5052 together, solidification cracking can be prevented by replacing A1050 with material such as A3004, which has similar work characteristics to A1050 and contains Mg.

Care must also be taken when welding aluminium alloys that contain much Si. A6000 series alloys are widely used in the structural members of motor vehicles and large motorcycles but when they are welded to other alloys, the Si content of the molten zone becomes diluted and cracking is liable to occur. An A4000 series filler wire should be used when an alloy of the A6000 series is welded to another alloy. It is thought that if MIG-laser hybrid welding were used, the cooling rate would have been moderate and the probability of solidification





cracking would have further reduced, making it possible to produce high-quality and high-strength structures.

4. Laser welding of dissimilar metals

Techniques of welding aluminium alloys to other metals are becoming indispensable.

In motor vehicle production, the increasing use of aluminium alloys in car bodies is now under consideration to achieve further large weight reductions. For reasons of cost, however, the 'component body concept', which combines aluminium alloy and steel plate, may well be a reasonable choice. There are actually production cars in which this body type is used, but the joining methods, which include rivets, caulking, and adhesives, are prohibitively costly.

On the other hand, the change of the drive system to electricity is a powerful means of improving the environmental load of transport, but since the batteries have to be connected in series, the joining of aluminium and the copper of the electrodes becomes an absolute requirement. There is thus a need for dissimilar metal welding to make it possible to join multiple electrodes rapidly and cheaply. Joining the dissimilar metals of copper and aluminium may be described as a production technology necessary for all industrial products required to convert their power source to batteries.

Trumpf would like to propose laser welding as one means of successfully carrying out dissimilar metal joining particularly involving aluminium.

4.1 Dissimilar laser welding: A5052 and SPCC

It is difficult to weld aluminium and iron. The melting points of the two metals are greatly different, and the production of brittle intermetallic compounds is a reason that it is impossible to achieve adequate mechanical strength.

The principal method of laser welding was previously solid-phase welding. A special solder such as Ag may be used, and the laser is radiated from the Fe side so that only the aluminium is melted and welding is thus achieved.

Figure 9 shows an example of solid-phase welding using a lamp-pumped YAG laser. This shows a sample that was solid phase welded by a laser radiated with a defocus distance of 20 mm (using an Fc200 mm/Fo200 mm beam focusing device). To obtain adequate weld strength using this method, it is necessary to limit the layer of intermetallic compounds of the dissimilar metals to no thicker than 8 μm.

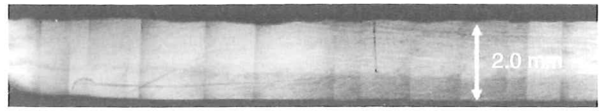


Figure 10. Microstructural micrograph of lap weld of SPCC (upper sheet) and A5052.(both 1.0 mm thick). (TruDisk 4002, laser power 2.0 kW, welding speed 2.7 m/min).

There are, however, problems that include deformation due to thermal strain and poor reproducibility of weld strength. It is also necessary to keep the bonding surfaces clean and apply pressure to the weld, both of which make the technique impractical.

Trumpf provides support to the Watanabe team at Chiba University who study usable techniques of high-speed keyhole welding for dissimilar materials. The results of their study of novel techniques of keyhole welding of A5052 and SPCC using disc lasers are shown in Figure 10.

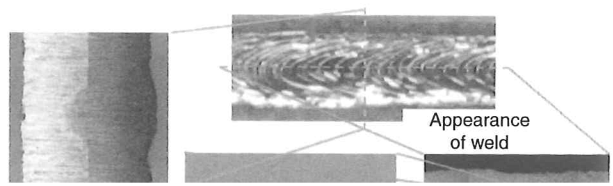
By optimizing the waveform control of the CW pulse modulation, defects such as cracking and porosities are inhibited and it becomes possible to achieve highly reproducible dissimilar metal welding. The tensile strength reaches 80% of the aluminium alloy base metal strength. Although there is a mixture of Al and Fe at the weld interface, no marked formation of intermetallic compounds could be observed.

Efforts continue to make further improvements in the mechanical strength and to validate the welding theory, with the aim of achieving a welding technique that can be put to practical use.

4.2 Dissimilar metal welding: A5052 and tough pitch copper

There are many obscure aspects of the theory of dissimilar metal welding by laser. However, good results were obtained by tuning the conditions for lap welding SPCC and A5052 to the welding of A5052 and tough pitch copper.

Figure 11 shows a vertical section of the bead parallel to the welding direction in a lap weld of A5052 and tough pitch copper using CW pulsed modulation. No cracks, porosities, or other defects are visible in the cross-section of the bead. In the future, it will be necessary to gain a better



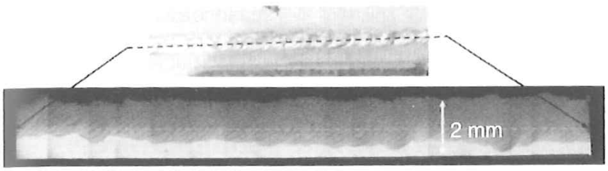


Figure 12. Vertical cross-section micrograph of bead of lap weld of AZ31B (1.0 mm thick). (TruDisk 4002, laser power 2.0 kW, welding speed 2.7 m/min). Tensile strength is 70% of the base metal.

understanding of the reproducibility, weld strength and, depending on the application, electrical resistance of this.

5. Laser welding of magnesium alloy AZ31B

Of the metals that are practically usable, magnesium alloy is the lightest and has the greatest specific strength. Since it shows high absorption of vibrations, it is used in the wheels of high-class passenger cars and for housing information terminals when portability is a requirement. However, working methods are limited to plastic working and casting, with grinding and welding being impossible.

Figure 12 shows the bead appearance and cross-section of AZ31B magnesium alloy welded with a disc laser. Magnesium was previously a material that is impossible to weld. It is possible, however, to weld it successfully by arranging the waveforms of CW pulse modulation and limiting heat input, reducing the penetration of the base metal.

Problems for the future include how to improve its mechanical strength and how to carry out butt welding.

6. Conclusion

Light metals are indispensable to the reduction in vehicle weight and the production of high-efficiency electrical power systems. The establishment of welding techniques for these metals is also vital to promote their wider use in industry. Trumpf's disc laser, due to its resonator design that makes it insensitive to back reflection, underpins research and development of a range of dissimilar metal welding and moves them on towards practical application.

Contributor

Shigeki Saitoh