BOND FORMATION IN LASER AND RESISTANCE WELDING

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Abstract

Laser and resistance welding are two processes that often compete for the same welding application and choosing between the two requires careful analysis. The processes are quite similar in their ability to make spot welds and their ability to weld dissimilar materials. On the other hand, they have differences such as location of heat generation, part geometry, and weld metallurgy that affects bond formation and consequently the weld performance. This paper compares and contrasts bond formation at the weld interface for laser and resistance welding and its effect on related factors such as part design and materials selection.

Keywords: Laser, Resistance, Welding, Fusion, Solid-State, Soldering, Brazing

Introduction

Of the commonly used welding processes, laser and resistance welding often compete since they have many similarities including ability to make spot welds, weld dissimilar materials, and join practically all types of metals and alloys. In resistance welding [1], the welding energy is provided by two welding electrodes that provide welding force and also provide a conduit for welding current. Heat produced by resistance to flow of current through the part stack produces welding heat. In laser welding [2], energy is supplied to the weld location in the form of a laser beam that interacts with the materials and produces heat. There are a lot of interesting similarities and differences in terms heat generation, shielding gas, types of bonds, and energy delivery that affect bond formation in these two processes. The issues need to be well understood before one can select between the two processes for a particular application and are discussed in this paper.

Weld Heat Generation

One of the key differences between the two processes is the location of heat generation. Laser energy interacts with the materials from an exposed surface; the molten metal pool then grows inwards till it achieves the desired size that includes the weld interface. The interface can be positioned away from the top surface as in lap welding but the fusion nugget still has to grow from the top exposed surface. On the other hand, a fusion weld produced by resistance welding grows from the inside at the weld interface towards the outer surfaces. The weld pool is trapped at the interface under pressure from the welding electrodes. Figure 1 shows a schematic of sections of laser and resistance welding.

Heat generation on an exposed surface produces challenges for laser welding. An exposed molten metal pool also has the potential to loose material by melt ejection (if the laser energy is not well controlled) or by loss of volatile or gaseous elements that can change weld chemistry. For example nitrogen bearing stainless steels can loose some of the nitrogen during laser welding. On the other hand, loss of Zn during welding of galvannealed/galvanized steels is actually good for the welds. However, laser welding also provides opportunities such as adding a filler metal in a manner similar to TIG

Shielding Gas

Since the laser weld metal is exposed to the environment, shielding gas plays an important role in laser welding. As the name implies, the shielding gas hovering above the molten metal, shields the molten metal from possible absorption of oxygen, nitrogen, and hydrogen (water vapor) from the air. The shielding gas also sweeps away any ionized gases and/or metal vapors formed during welding; the gases and vapors can absorb incoming laser radiation and reduces energy reaching the metal surface. Depending on the alloy being welded, the contamination can produce a cosmetic effect such as producing a layer of surface oxide. The color of the oxide can indicate the severity of oxidation. A light tan indicates minimal oxide formation. As the level of oxidation increases, the color changes to dark tan, blue and then black. Argon is the most common shielding gas used for pulsed YAG welding. Argon is heavier than air and with proper containment provides adequate flooding of the weld area. For high power CW (continuous wave) welding with CO2 lasers, gas plume formed above the keyhole can be highly ionized and use of Helium gas may be required to reduce ionization. A mixture of Argon and Helium can be used as well.

The most reactive of metals such as Ti and Al are also most susceptible to contamination and require special precautions. Most Ti welding for medical devices is done inside a glove box where oxygen levels can be maintained below 10 ppm and water vapor is controlled to a dew point of -60˚C; most hydrogen in air is in form of water vapor. Molten Ti can quickly pickup oxygen, nitrogen, and hydrogen to form oxides, nitrides, and hydrides that all work to increase brittleness of the welds. Molten Al has a high solubility for hydrogen but solid Al does not and hence as the metal cools, hydrogen is expelled and forms porosity in the welds.

As opposed to laser welding, resistance welds are self-shielding and contamination from environment is not an issue that affects weld strength. Since the parts being welded do become hot, the exterior surface of the welded components can become discolored and may require Ar shielding to produce cosmetic welds.

Types of bonds

There are primarily three types of bonds that can form in a weld: solder/braze. solid-state bond, and fusion bond. In all three types of bonds, a strong metallurgical bond is formed between the parts to be joined.

Solder/Braze Joint

Welding is frequently used where either one or both components have plating on the surface. The plating can be for improved corrosion resistance or to provide a good soldering surface. The plating alloy can act as solder/braze layer at the interface or just provide a good bonding agent to form a solid-state bond. A gold flash, with a Ni barrier layer underneath, is the most common variant. The gold layer can be easily welded to similar metals including Cu, Ni, Pt, and Pd. In automotive and electrical applications, copper conductors with tin plating are often joined to a copper or brass pad that also has tin plating. A resistance welding apparatus is used to heat the parts and forms a solder fillet which on cooling produces a solder joint. A laser power source is also being used for soldering individual components on a circuit board and for repair work.

There are situations where a braze joint is formed even though intent is to produce a conventional weld. Such a situation can occur when one of the metals/alloys has much higher melting point compared to the other. Figure 2 shows examples of laser and resistance welds where the lower melting component acts like a braze alloy to bond to the higher melting component.

Solid-State Bond

A unique aspect of resistance welding is that the parts do not have to melt to form a bond; they only have to soften and be forced together. Metal atoms on either side of the weld interface will form a bond as long as there are no contaminants on the surface and the atoms are brought in close proximity. A bond formed without melting of the constituents is called a solid-state bond. A bond line is visible at the interface, as is seen in Figure 3 in most cases except when welding similar materials where grain growth can occur across the interface. A solid-state bond is common when welding conductive alloys and refractory metals. Solid-state bond is also the preferred mode in welding dissimilar materials where a fusion bond can form a brittle weld. Formation of a solid-state bond is unique to resistance welding; the laser welding process cannot produce a solid-state bond.

Fusion Bond

A fusion bond is formed when material on either side of the interface melts, mixes, and solidifies to form a weld. Fusion bond is quite common during welding of metals and alloy from families of steels, stainless steels, Titanium, and Aluminum. Even though presence of fusion might be thought of as preferred bond type, it is not often the case when welding dissimilar metals/alloys. A fusion bond between dissimilar metals/alloys can result in formation of intermetallic compounds or brittle phases which can produce a brittle weld. For example, welding carbon steel to a stainless steel can produce a weld that forms martensite and will be very susceptible to cracking. Welding of Ti and steels is also not recommended since the weldment will have brittle intermetallics. Fusion is the most common type of bond in laser welding and is typical of steel and stainless steels welds in resistance welding.

Energy Delivery

One the greatest advantages of laser welding over resistance welding is the ability of the laser energy to be delivered without having to make physical contact with the parts being welded. Laser welds can be made quite successfully in relatively inaccessible locations, on part configurations such as battery lids where positioning of resistance welding electrodes would be very difficult, and through a quartz window where the part being welded is in a controlled environment. It is the non-contact nature of laser welding that has provided many new opportunities for producing medical device assemblies that would not be possible with any other welding process.

Summary

Resistance and laser welding provide some very unique options for the engineer when selecting a suitable process. Even though they have many features in common including ability to weld almost all metals, producing spot welds, and ability to weld dissimilar materials, the two processes also have some interesting differences. An exposed weld pool provides additional challenges with laser welding but at the same time the non-contact nature of the process provides opportunities. Even though both processes can produce solder/braze and fusion bonds, only resistance welding can produce solid-state bonds which are a powerful tool in bonding dissimilar materials that would other crack during fusion welding. An engineer choosing between the two processes has to be well aware of all the factors involved before making a selection.

Acknowledgements

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References

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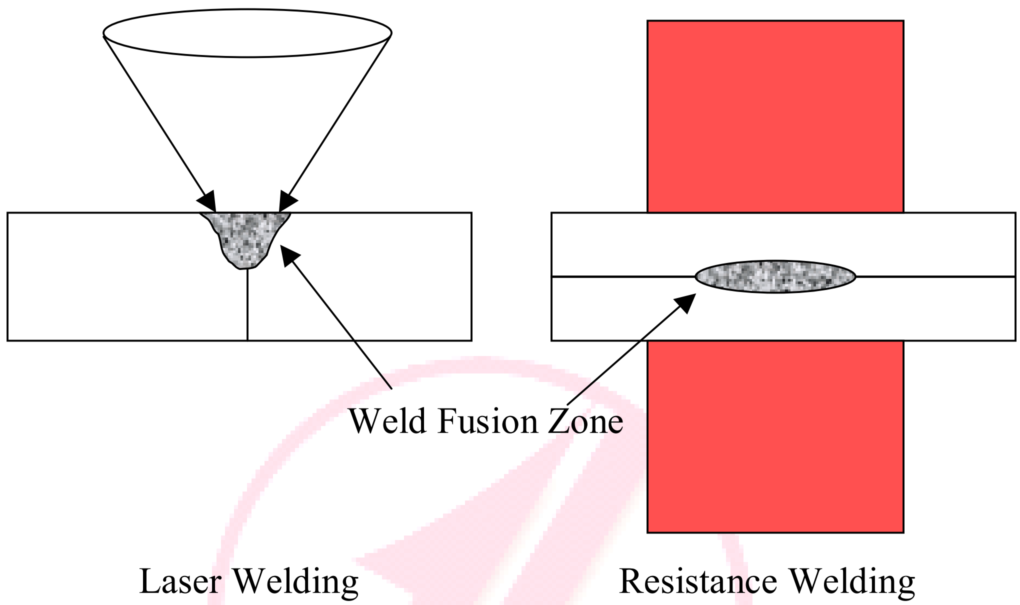

Figure 1. Schematic shows difference in heat generation between laser and resistance welding. The laser weld metal pool grows from the outer surface where as in resistance welding, the molten metal pool grows from inside out.

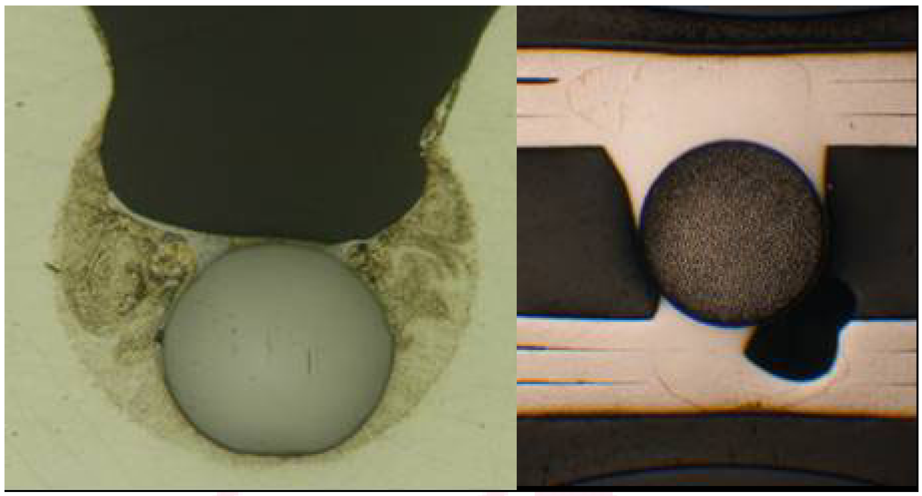

Figure 2. Photomicrographs of sections of joints formed by laser (left) and resistance welding (right) where one of the alloy is has much lower melting point and results in effectively forming a braze on the higher melting component.

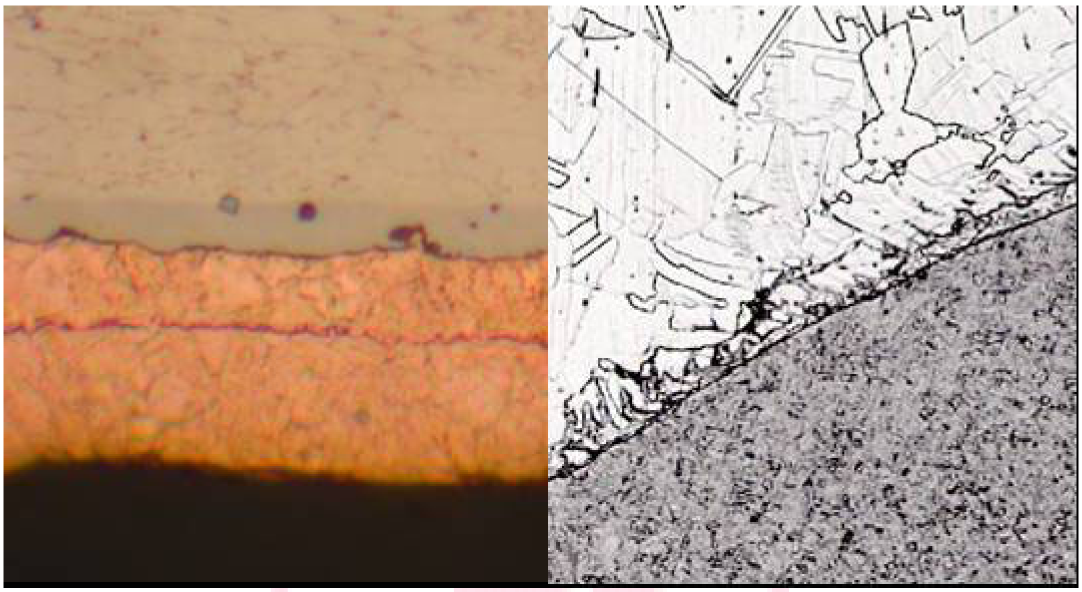

Figure 3. Photomicrographs of sections of solid-state bonds produced by resistance welding. Note the intact weld interface even after welding with no sign of fusion at the weld interface.

Figure 4. Photomicrographs of sections of fusion bonds produced by laser (left) and resistance welding (right).