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Laser & Resistance Welding – Metal Bond Types
By David Steinmeier

Metal Bonds
Metal bonding involves the transfer of electrons between one or more metal atoms. The metal atoms can be identical or different in atomic structure. Metal atoms tend to lose electrons from the outer shells. The "electron gas" produced by this separation holds the remaining positive ions together.

The resulting combination of metal atoms is typically called an "alloy". The physical properties of the new alloy are determined both by each metal's atomic structure and how their atoms are aligned to each other. This "alignment" structure is referred to as the crystalline structure of the alloy. Alloys are typically harder, less electrically conductive, stronger, and more brittle compared to the individual physical properties of each atom forming the alloy.

Bond Types
Bond types fall into four general categories, depending on the degree of alloy interaction and who is creating the definition. Fusion bonds involve the complete melting and mixing of both metals. Diffusion bonding can be viewed as a form of fusion bonding but with much less melting and mixing of both metals. With Solid State bonding, there is only a single layer atomic bond between the two metals. Finally, Reflow brazing or soldering utilizes a low temperature interface alloy to join two higher temperature metals. Each bond type will be discussed in more detail.

Fusion Bond
Fusion bonding involves the complete melting and mixing of two or more metals with similar thermal conductivity and melting temperatures.

Fusion bonding can be accomplished using Nd-YAG laser or resistance welding technology. The inner most melt area of a fusion bond is characterized by a fine crystalline grain structure. The area surrounding the melt zone is called the "Heat Affected Zone" or "HAZ" and contains a more course and brittle grain structure compared to the melt zone. Fusion bonds typically possess excellent tensile, shear, and peel strength.

Fusion Bond Structure – Nd-YAG Laser
Pulsed Nd-YAG laser technology employs very high peak power pulses of infrared light that are very short in duration, typically 0.5 to 2.0 milli-seconds. The laser beam can be focused to a diameter of less than 0.2 mm, thus creating a very high energy density spot capable of melting high temperature materials such as tungsten. This localized heat penetrates down through the top metal part and into the bottom metal part, causing both metals to melt and mix, creating a new alloy. This very mixing and melting action largely restricts the use of pulsed Nd-YAG laser welding to fusion bonding.

Figure 1 shows a typical laser fusion seam weld in a 304L stainless steel. The overlapping action of the seam weld creates the small penetration zone that appears at the top of the larger penetration weld pattern.

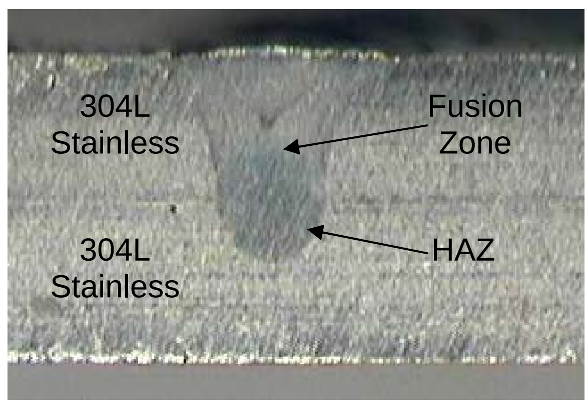

Figure 1 – Fusion bond created by a pulsed Nd-YAG laser welding technology.

Fusion Bond Structure – Resistance Weld
By passing a controlled electric current between two metals clamped together under pressure, resistance welding technology creates a fusion zone at the interface between two metals. The interface zone typically has a higher electrical resistance compared to the bulk resistance of the surrounding metals. Thus the electric current generates more heat in the interface zone, melting and mixing the top and bottom metals.

Resistance welding fusion bonding typically uses one or more high energy weld pulses that can range from 0.5 milli-seconds for a micro sized component to as long as 40 milli-seconds for a macro sized part. Figure 2 shows a fusion bond created by resistance welding two nickel wires together.

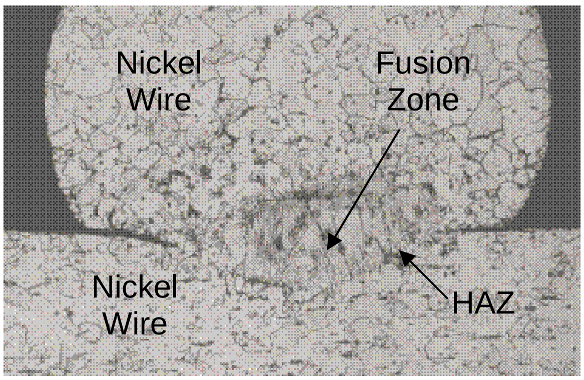

Figure 2 - Fusion bond created by resistance welding technology.

Diffusion Bond

Diffusion bonding involves very limited melting and mixing of two or more identical metals with high thermal conductivity characteristics. Compared to a fusion bond, diffusion bond joints are barely visible. Diffusion bonds typically possess excellent tensile and shear strength, but may exhibit poor peel strength in some cases.

Diffusion bonding uses lower weld energy over a longer time period to create the bond structure. In some cases, the weld pulse can last up to 300 or more milli-seconds. Figure 3 shows a diffusion bond created by joining two silver plated metals together. Note the tiny voids in the bond area.

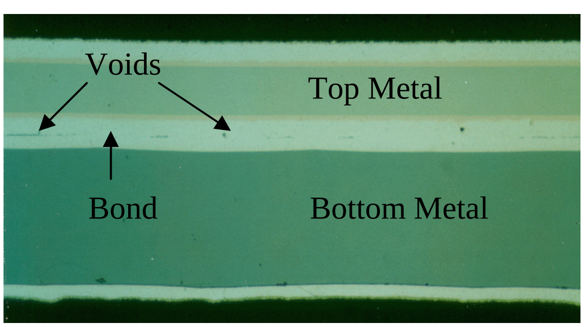

Figure 3 – Diffusion bond created by resistance welding technology.

Solid State Bond

Solid state bonding is excellent for joining hard, thermally resistive materials such as molybdenum, niobium, and tungsten. Bonding is terminated while both metals are in the plastic state. Solid state bonds possess excellent tensile and shear strength, but may exhibit poor peel strength. Figure 4 shows a solid state bond between a copper and nickel wire. Note the single joining line, a distinct characteristic of a solid state bond.

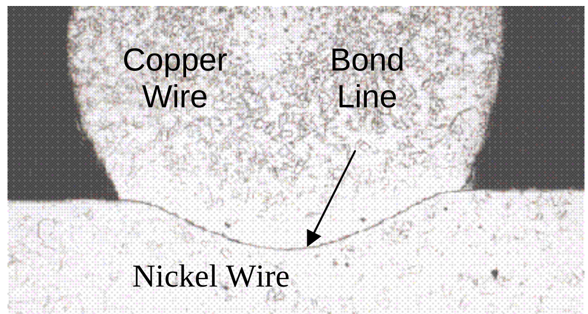

Figure 4 – Solid state bond created by resistance welding technology.

Reflow Brazing or Soldering

Reflow brazing or soldering utilizes a low temperature interface alloy to join two higher temperature metals. The braze or solder alloy wets to both metals, creating a visible bond line with minimum diffusion. These bonds have excellent tensile and peel strength, but weak shear strength. Figure 5 shows a copper wire engulfed in a tin/lead solder matrix, surrounded by two copper terminals.

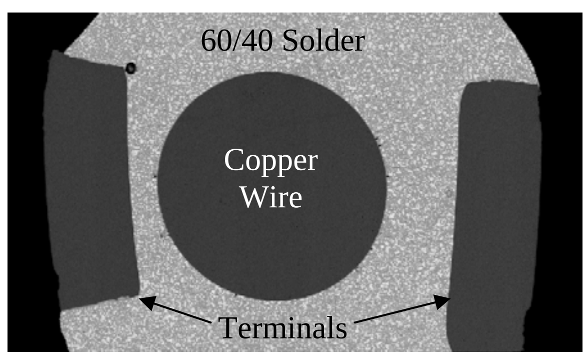

Figure 5 – Reflow solder bond created by resistance welding technology.

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