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Metallurgical Considerations in Selection of Filler Alloys

There are many welding processes that use a filler alloy to add metal into the weld pool for a variety of reasons including producing the desired metallurgy, allowing use of appropriate welding process configurations, generating a suitable weld profile, and creating a strong weld. While all issues are important and interrelated, in this newsletter we will focus on metallurgical considerations of controlling the weld chemistry to produce the desired fusion zone attributes.

Conventional arc welding processes such as GTAW, GMAW, and SMAW use a filler alloy in the form of wire or rod which is added to the weld puddle as the weld progresses along the seam. The filler alloy mixes with the fused base material in ratio that is determined by the weld geometry/process and produces a unique fusion zone chemistry. In laser welding, it is not typical to add a filler in form or a wire but is used as an option during laser brazing. If use of a filler is preferred in laser welding, the filler can be pre-placed along the welding seam in form a wire or a preformed insert. Surface plating can also act as a filler and should be given due consideration.

One of the key characteristics of the weld is that it should not produce cracks in the fusion zone as even small cracks have the potential to grow with time and lead to failure. The challenge with fusion welding when trying to avoid **crack formation** is that the base material which may appear to be homogenous prior to welding, segregates during melting and solidification process, and can push impurity elements along grain boundaries leading to cracking. Techniques used to avoid such defects depend on the alloy system being welded. For example, in austenitic stainless steels, the fusion nugget is susceptible to cracking if the weld solidifies in a fully austenitic phase. The solution is to add a filler that shifts the solidification behavior such that the weld metal has 3-5% ferrite; presence of ferrite mitigates cracking by a variety of mechanisms including higher solubility of impurity elements in ferrite and formation of torturous grain boundary profile that makes it difficult for cracks to grow.

Cracks can also form when impurities are inadvertently added through plating chemistry as happens when welding electroless Ni plated components. Electroless Ni plating has 3-15% phosphorous which forms a low melting eutectic and segregates to the grain boundaries as the weld cools. In such situations, electrolytic Ni plating is preferred as it is composed on pure Ni. A similar issue is dealt with in aluminum alloy systems but in their case the alloying elements are intentionally added in the base metal to provide certain material characteristics; however, most of these additions make the alloy prone to weld cracking. The solution is to add plenty of the second phase elements through the filler alloy to produce sufficient liquid phase that will fill all the cracks during solidification. A typical example is the use of 4043 filler alloy (4.5-6.0% Si) when welding 6061 Al (0.4-0.8% Si, 0.8-1.2% Mg). Excess Si added via the filler alloy allows formation of a lower melting eutectic liquid that has sufficient volume and fluidity to seal all the cracks.

In systems such as carbon steels that can have surface impurities such as mill scale oxides, the filler alloy has to do the job of bonding with the oxygen and rise to the surface so that the fusion zone itself is free of **oxide inclusions** that can affect toughness, strength, and ductility of the fusion zone. The elements that are added to the filler alloy for bonding with oxygen are called deoxidizers, and typically include manganese, silicon, and aluminum. Silicon provides the added benefit of enhanced weld metal fluidity that helps wetting of the toes of the fusion zone.

In dissimilar material welding applications such as welding a 304 stainless steel to a carbon steel, the two parent metals may not be brittle, but the mixture will likely be martensitic which lead to a **brittle fusion zone**. In this situation, the filler alloy used such as 309L, has to move the fusion mixture composition safely away from the martensitic region to an austenite/ferrite region. If a weld zone without ferrite is preferred, an alloy such as 307 can be used which has a higher percentage of manganese and resists cracking even in the absence of ferrite. Similar concerns of weld brittleness can occur when welding HSLA steels and may require use of filler alloy and welding conditions that avoid absorption of hydrogen into the fused metal. Hydrogen, if present in the fusion zone, can diffuse to any small defects and rapidly grow them to failure; referred to as **hydrogen embrittlement**.

Another aspect of the fusion zone is the gradient cooling that can lead to large elongated grains that can result in the weld zone being susceptible to grain separation during mechanical flexing. To avoid **excessive grain growth**, filler alloys usually have small amounts of added elements called grain refiners that produce smaller and more equiaxed grains. For example, 2319 Al is used as a filler for welding 2219 Al, and is practically identical to 2219 except for a slightly higher Ti content which acts as a grain refiner.

Visual appearance of welds after anodizing is common concern when welding 6061 Al, and in those situations a 5xxx series filler alloy better suited than 4043 to produce a good surface color match. Another benefit of 5xxx series alloys is that the welds are stronger than those made with 4043. However, there is potential drawback in that filler alloys with greater than 3% Mg are susceptible to SCC (**stress corrosion cracking**) if the welds are exposed to temperatures greater than 150 F for an extended period. A compromise option is to use 5554 that contains less than 3% Mg but is also a bit weaker.

It is evident that there are multiple metallurgical factors that need to be considered in evaluating suitability of filler metal alloys. The welding engineer would be wise to spend extra time on the proverbial drawing board during the selection process in order to avoid long hours spent in the QC lab diagnosing the problem in hindsight.

If you have any questions about the contents of this newsletter or any other question about welding, please contact us at WJM Technologies, www.welding-consultant.com.