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Effect of Welding Process on Weld Metal Strength

A fusion weld, by definition, involves melting of material in the fusion zone during the welding process. Combination of high melt zone temperatures, aggressive interaction between metal atoms and shielding gas, and rapid cooling of the fusion zone affects weld metal strength in ways which are difficult to anticipate. In an earlier newsletter (https://www.welding-consultant.com/Fall2020.html), we have reviewed the effects of filler alloys on the weld. In this newsletter, we will review the various ways in which weld strength can be affected by the welding process.

In the simplest of the fusion welds, such as autogenous (no filler added) resistance welding where the fusion zone is not exposed to external environment (https://www.welding-consultant.com/Spring2021.html), the only interaction is between the metal atoms of parts being welded. If the alloys are dissimilar, the fusion zone will be mixture of the two and produce a third alloy that may be quite different in strength compared to the two being welded. For example, a weld between 304 SS to and 1008 carbon steel will produce a fusion zone mixture that will be martensitic and very strong and brittle. Similar situations can occur within other family of alloys as in Nickel, Titanium, and Aluminum alloys.

Electron beam welds are also typically autogenous fusion welds but a bit different than resistance welds since the molten metal surface is exposed to vacuum and there is potential for loss of some of the volatile constituents from the melt. Laser welds are also mostly autogenous, but typically have a shielding gas protecting the weld surface. Argon is the most common shielding gas for laser welding, but others such as Helium, Nitrogen, and even Air has been used quite effectively. Here again, volatile elements can evaporate from the melt and not only change the weld chemistry and strength, but can also coat the welding enclosure with a thin layer of metal dust. Nickel alloys are notorious for producing black soot, which is not to be confused with carbon black, that coats everything near the weld.

Some stainless steels have a small fraction of Nitrogen, an austenite stabilizer, with a strong contribution to Nickel equivalent (20 x N%, WRC-1992); ratio of Ni equivalent and Cr equivalent determines the type of stainless steel. Some of that nitrogen can be lost from the weld pool during welding in an inert gas, and conversely, nitrogen can also be added to the weld pool by welding with a shielding gas that contains nitrogen; any loss or gain will affect chemistry and strength of the weld. If specific nitrogen levels in a steel are critical, and have to be maintained during welding, an appropriate Argon-Nitrogen shielding gas mixture will have to be used.

The most interesting metal-gas interactions occur in arc welding applications as the arc ionizes reactive shielding gas components, and increase their ability to react with metal atoms. Shielding gases for welding steels can include CO_2 and O_2. Carbon steels can be welded with 100% CO_2; while stainless steels can be welded with Argon gas containing small fractions of O_2. Ionized oxygen, either from dissociation of CO_2 or O_2, can interact with constituents of the base metal and filler to change weld chemistry. Higher amount of ionized oxygen reacts with more of the scavengers in the filler metal such as Silicon and Manganese to produce oxide slag that can float to the surface and form silica islands. If amount of available oxygen in the shielding gas is reduced, then more of the Si and Mn will remain in solution in the fusion zone and produce weld bead with greater strength. A good example is welding of carbon steels with a 70S-6 filler alloy with different shielding gas mixtures. A 100% CO_2 shielding gas, which produces a lot of ionized oxygen, removes more of Si and Mn from the fusion zone in form of slag, and produces a weld metal of 75 ksi tensile strength. In comparison, a 75% Argon + 25% CO_2 mixture that has less oxygen in the shielding gas, produces a weld metal with greater amount of Si and Mn, and with 84 ksi tensile strength. Is a stronger weld metal always the better choice? Not necessarily, but that is a good subject for a future newsletter.

Weld strength can also be affected by stresses induced in a weld as it cools down. If both parts being welded are securely fixtured, then the cooling weld metal gets pulled towards the two parts and can induce tensile stresses in the weld. Such stresses can be further affected if it is multi-pass weld leading to more expansion and contraction of the previously deposited layers. Such stresses can have the effect equivalent of 10-20% cold working, and a corresponding increase in weld metal strength.

Weld metal strength can be measured in large size welds by machining out test samples from the fusion zone and testing for yield and tensile strengths. In situation where the welds are quite small and such direct measurements are not feasible, measurement of weld hardness can be used as a proxy for tensile strength.

A design engineer would do well to be aware of effect of various welding phenomena on the fusion zone, and not assume that weld metal strength provided by the filler metal manufacturer or parent metal strength (in autogenous welds) would be sufficient. The engineer should conduct thorough evaluation of welds including testing for strength, fatigue, and hardness to get a better understanding of welding process on weld strength.

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.
