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Heat Affected Zone (HAZ) – caught in the middle

Heat affected zone, as the name implies, is the region near the weld that is affected by the welding heat but not directly participating in the formation of the weld nugget; it is the region between the weld nugget and the un-affected parent metal. While the fusion nugget size/properties can be controlled directly, control of HAZ is indirect and hence a bit more challenging. In this report, we will review the many ways that properties of the HAZ can be affected and their implications for performance of the overall weld.

Size of the HAZ depends on rate of heating/cooling, alloy metallurgy, and part geometry. A quick burst of weld energy, as with a 2-msec laser weld pulse, produces practically no HAZ in a laser spot weld. Similar results are seen with laser or electron beam seam weld at rapid linear travel speeds. In contrast arc welding process with slow travel speed such as submerged arc welding will produce much larger HAZ volume. The second factor that affects size is thermal diffusivity. Materials with high thermal diffusivity, such as copper (111 mm^2/sec), rapidly dissipate the weld heat producing an extended HAZ, while stainless steels have much lower thermal diffusivity (4.2 mm^2/sec) leading to larger weld pool but relatively narrow HAZ. The third factor that affects HAZ size is the physical dimensions of the part in the vicinity of the weld; larger the surrounding volume available to act like a heat sink, smaller the HAZ. Hence a spot weld at the junction of two plates will have a much smaller HAZ compared to a spot weld at the junction of two wires. And if those wires are dissimilar, the smaller diameter wire will have an even larger HAZ. The math required to estimate the HAZ size considering all the factors will be quite complex, and it is much easier to section/etch the welds and measure size of HAZ with an optical microscope and with hardness measurements. One edge of HAZ is easy to identify as it borders the weld nugget.

However, the outer edge where it blends into the parent metal may not be visually obvious in all alloy systems, and may have to be deciphered with other means such as hardness measurement and grain phase/size changes. Welds that are solid-state and do not have a fusion nugget will have HAZ that extends from the weld interface all the way to parent metal.

The first characteristic that may be obvious in polished and etched weld section is change in contrast between weld nugget, HAZ, and parent metal, as those regions will etch differently; see photograph of weld section below. The second discernible feature may be change in grain size; grains can grow rapidly in pure metals, and for small parts can reach dimensions of the part itself. Under action of residual stress or applied stress, adjacent large grains can separate easily and form a crack which can grow under additional cyclic stresses. The other obvious feature is presence of liquation cracks that emanate from the partially melted zone at the edge of the fusion nugget and extend into the HAZ. Liquation cracks form in alloys systems with a wide solidification range such as Inconel 718 and Aluminum 6061.

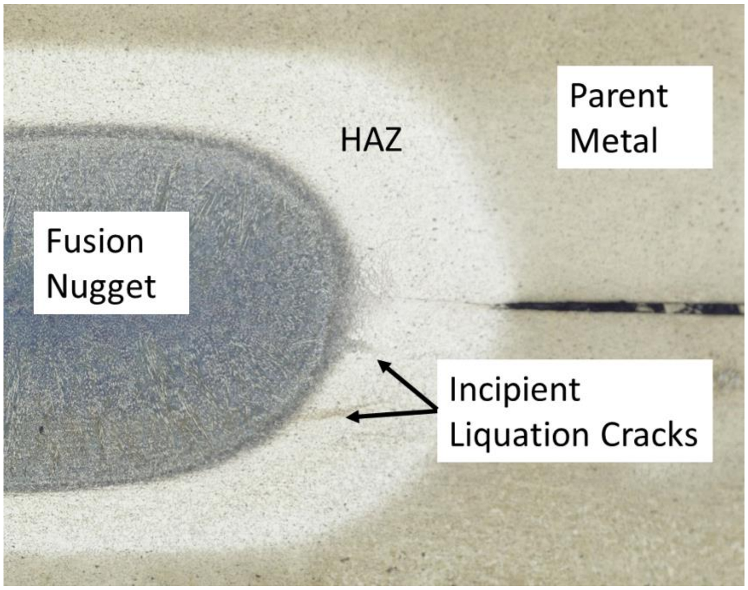

Photo above shows a weld section of a resistance weld in an Inconel alloy. Fusion nugget, HAZ, and parent metal are evident. Also shown are phase separation regions that indicate locations of potential liquation cracks under suitable stress conditions.

Some changes in HAZ properties are not visually obvious from a weld section. One of them is strength. Since HAZ is often quite a small volume of material, it is difficult to directly measure strength. In this case, hardness is used as a proxy for tensile strength. Micro-hardness scans across a weld section are a very informative tool and show a trend of change in hardness/strength from parent metal, HAZ, and the fusion nugget. In non-heat-treatable alloys, an increase in temperature in HAZ can lead to annealing in the HAZ with an associated reduction in strength. In heat-treatable alloys, strength in HAZ can increase or decrease depending on prior heat-treatment condition. For example, Al 6061 in T6 condition (46 ksi) can soften down to 24 ksi in the HAZ during arc-welding processes, leading to a much lower load carrying capacity in welded structures. On the other hand, an Al 6061 in T4 condition can exhibit a slight increase in hardness in HAZ under certain welding conditions. Strength can also increase in alloy systems that undergo phase transformations as in carbon steels. HAZ region in steels can be significantly stronger with formation of martensite during rapid cooling. Such strengthening is double-edged sword as the stronger martensite phase can be brittle (at higher carbon contents) and be susceptible to hydrogen embrittlement. Another aspect of HAZ that can lead to failure of welded part over extended period of time is corrosion in the HAZ. Sensitization, a common concern with stainless steels, where chromium carbides can precipitate along grain boundaries in HAZ at temperatures typically exposed to during welding, can lead to corrosion in aqueous environments.

Design engineers spend considerable time in selecting parent metal based on alloy systems (http://www.welding-consultant.com/Fall2018.html) and prior processing conditions, and are diligent in selecting proper filler alloy (http://www.welding-consultant.com/Fall2020.html), but may not always be aware of this third material, the HAZ, that can have unexpected properties that can scuttle all their brilliant plans for the weld. An engineer would be wise to conduct a thorough metallurgical evaluation of the weld including weld sections and hardness test so as not to be surprised by sudden failure in HAZ.

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.