WJM Technologies
*excellence in material joining*

Girish P. Kelkar, Ph.D.
(562) 743-7576
girish@welding-consultant.com
www.welding-consultant.com

The Weld Nugget™
a newsletter to inform, entertain, and educate
Publisher: WJM Technologies Volume 52, Fall 2021

## Welding or Casting?

When a fusion weld is made, the molten metal starts to solidify once the heat source is withdrawn or turned off. Solidification pattern in many ways is identical to solidification of molten metal in a casting. Volume of molten metal in the weld is akin to molten metal poured into a mold cavity, and the boundary between fused and solid metal behaves like the wall of the mold cavity. A good understanding of the casting process provides useful clues for weld solidification, and consequently any inputs to solving related problems.

During metal casting, the molten metal is poured into a mold cavity and allowed to cool. The mold itself is at room temperature and leads to rapid cooling and solidification of a thin layer of fine grains adjacent to the mold walls; this layer is referred to as the chill zone. From there on, grain size/shape/growth is a balance between heat loss to the mold, changes in composition of the remaining liquid metal, and related levels of undercooling. Based on these cooling dynamics, elongated grains start to grow from the thin surface layer and are oriented perpendicular to the mold walls as they grow in either columnar or dendritic fashion depending on the degree of undercooling. Cooling, solidification, and grain growth proceeds till a smaller volume of metal remains at the center of the mold which includes segregated impurities. The center region ends up having a more uniform temperature and finally solidifies with grains that are equiaxed; metallurgical term for grains that have about the same size in all three dimensions. A section of the cast metal is shown schematically in Figure 1 alongside a section of a typical fusion weld.

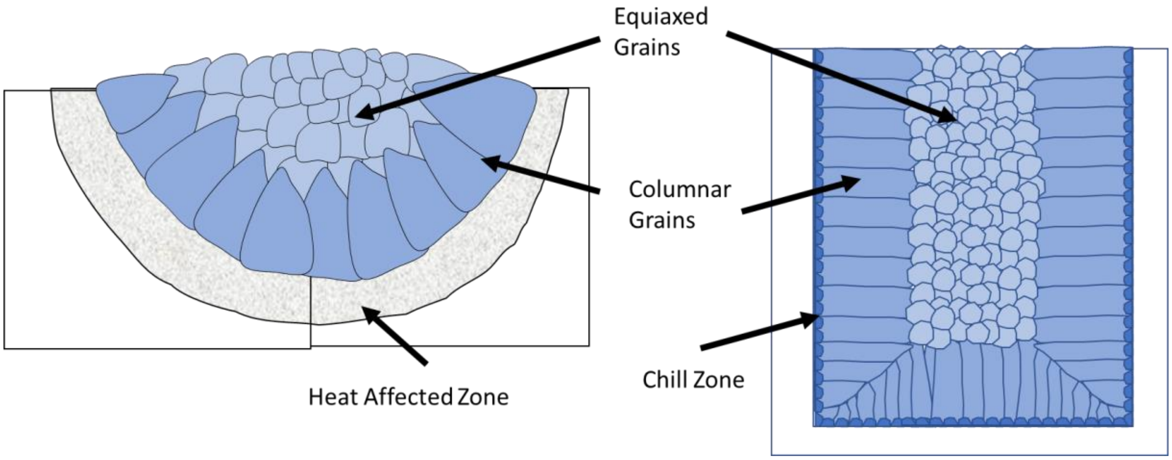


Figure 1. Schematic of grain structure in a typical fusion weld on the left and a cast metal on the right. Main difference is the presence of heat affected zone (HAZ) in a weld and the chill zone in the casting. Columnar grains and equiaxed grains are very similar in both.

There are remarkable similarities, and some differences, between casting and fusion welding. In fusion welding, instead of the molten metal being poured, the welding heat produces the molten metal in-situ; molten metal is a mixture of the two parts being welded and can include material from a filler alloy. Size of the fusion zone will depend on rate of heat input and thermal properties of the alloys being welded. At the edge of the fusion zone is a distinct boundary beyond which is the base metal that got quite hot but did not melt; referred to as the heat affected zone or HAZ. Beyond the HAZ is the parent material which was not affected by the welding heat. Boundary between the fusion zone and the HAZ is similar to the walls of the mold cavity with some important differences. The walls of a mold are typically at room temperature and usually made of a ceramic, sand, graphite, or a relatively high melting point metal; mold wall surfaces do not take part in the solidification process except for removing heat from the molten metal. In contrast, the walls of the fusion zone in a weld are practically at melting point and are of the same material (or very similar if a filler is used) as the fused metal. Similarity in temperature and metallurgy allows for the outer wall of the fusion zone to have a direct influence on the solidification process by providing nucleation sites for grain growth. As the melt starts to cool at the end of the weld, suitably oriented grains of solid metal that line up the weld cavity grow by adding atoms. Grains growing on the outer walls in the early stages of cooling end up looking like columns growing perpendicular to the weld cavity surface. Grain shape can be quite simple and look like columns, or can have a more complex shape with dendritic structure that looks like a tree; the word dendrite in Greek literally means treelike.  Grain structure depends on degree of undercooling from segregation of contaminants.  Examples of weld grain morphology are shown in Figure 2 below.

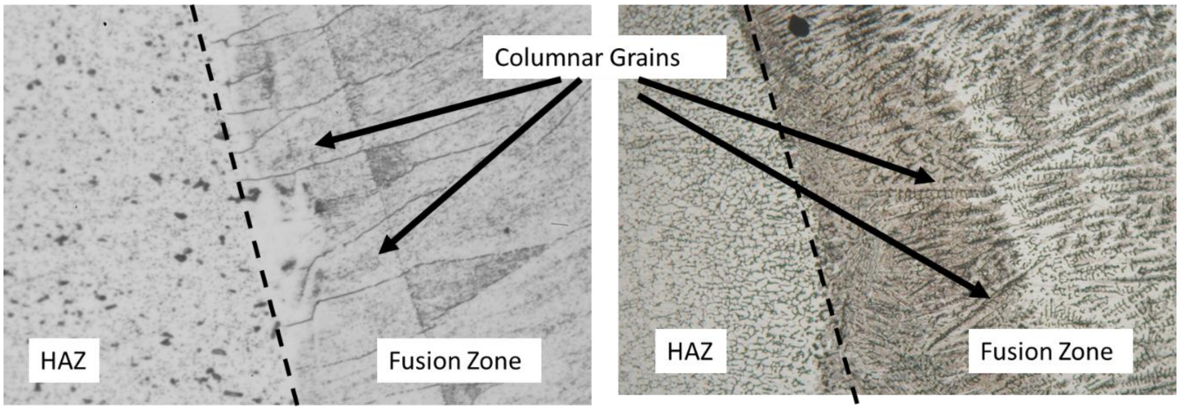


Figure 2.  Photomicrographs show weld microstructure at the interface between the HAZ and fusion zone.  Columnar grains growing towards center of the weld are evident and can be planar (left) or dendritic (right).

As the grains grow towards the center of the weld, they segregate increasing amounts of contaminants which further lower the melting point.  The lower melting phases can flow and fill any gaps that open up due to contractions in the weld from solidification and from external constraints on the weld.  However, the lower melting phases are sometimes unable to reach the gaps that are opening up if the dendritic structure is too intricate.  Lower melting phases also have weaker bonding strength and are often unable to hold the grains together leading to formation of solidification cracks in the welds.

Towards the end of the cooling process, the central region of the weld which is still liquid starts to solidify.  The temperature in this region is more uniform due to heat released from the solidifying columnar grains.  In the final mixture, there are a lot nucleation points including grain refiners typically present in filler alloys as well as broken shards of dendrites, thus resulting in formation of multiple equiaxed grains, unlike the columnar grains near the outer walls, as can be seen in Figure 3 below.

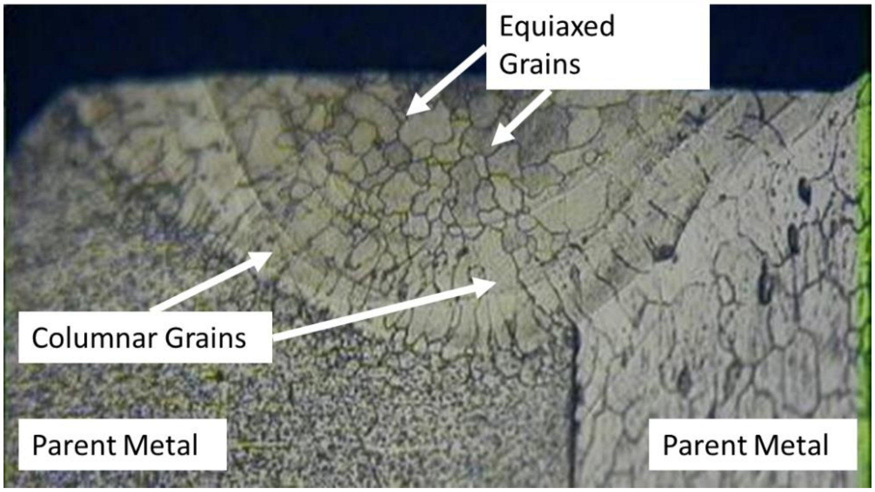


Figure 3. Photomicrograph of a weld showing columnar grains growing from the outer edge of the fusion zone and equiaxed grains towards the center of the weld.

In castings, a riser is usually added to the mold design which is essentially a reservoir of molten metal that fills in as the molten metal starts to cool and contract; without the riser there would shrinkage cavities in the mold. In a similar sense, the weld is often provided with excess metal via a filler to avoid cracks and porosities. In laser welds, which typically does not include a filler, the weld design should be selected such that the weld forms a convex profile on the surface. In resistance welding, closure of shrinkage pores and cracks can be achieved by applying a forging force towards the end of the weld.

Understanding weld metal solidification is critical in understanding weld properties and potential defects. Looking at a weld as a casting can help a user in thinking about how the fusion zone solidifies and what to expect in terms of grain morphology, phase segregation, and potential for formation of solidification cracks.

---

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.

---