Welding Defects

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A weld discontinuity is defined by the American Welding Society as “an interruption of the typical structure of a material, such as a lack of homogeneity in its mechanical, metallurgical, or physical characteristics.” Welding defects are a type of discontinuity that compromises the usefulness of a weldment, which could render it unable meet minimum applicable acceptance standards/specifications. Welding defects can be welding process-/procedure-related, or related to the chemical composition or metallurgy of the alloy(s) being welded.

Weld metal porosity is a cavity-type of welding defect formed by gas entrapment during solidification as a result of contamination by certain gases, such as hydrogen, oxygen, or nitrogen. Porosity caused by hydrogen pickup can be minimized by keeping the weld joint area and filler metal free of hydrocarbon contaminants and moisture. To avoid porosity caused by oxygen and nitrogen, it is important that the weld pool is properly shielded through the use of high purity shielding gases, and sufficient shielding gas flow rates are being utilized. Although porosity can occur in HASTELLOY® and HAYNES® weldments, they are not particularly susceptible to porosity since most alloys contain a significant amount of Cr, which has a natural affinity for the gases that are formed during welding.

Weld metal inclusions can form as a result of oxides that become trapped in the weld pool. This can occur from the tenacious oxide film that forms on the surface of most alloys. Since the melting temperatures of surface oxides are usually much higher than the base metal, they are more likely to stay solid during welding and become trapped in the weld pool. Thus, it is especially important that surface oxides be removed prior to welding and between passes in multi-pass welds. During GTAW, if the tungsten electrode accidentally contacts the molten weld pool or if there is excessive weld current, tungsten inclusions can be produced in the weld metal. Elements with a strong affinity for oxygen, such as aluminum or magnesium, can combine with oxygen to form oxide inclusions in the weld metal. Slag inclusions are associated with flux-based processes such as SMAW, SAW, and FCAW. These inclusions form in the weld metal when residual slag becomes entrapped in cavities or pockets that form due to inadequate weld bead overlap, excessive undercut at the weld toe, or an uneven surface profile of the preceding weld bead. Thus, an important consideration in flux-based processes is the ease with which the slag can be removed between weld passes. Inclusions must be ground out from the weld or they will act to initiate fracture prematurely, which can have a detrimental effect on mechanical properties and service performance.

Other common process-related defects that are encountered are undercut, incomplete fusion/penetration, and distortion. These defects are generally attributed to improper welding technique and/or welding parameters. Undercut is a groove that is melted into the base metal, usually at the root or toes of the weld, and can occur due to excessive welding current. This discontinuity creates a notch at the periphery of the weld and can significantly weaken the strength of the weldment. Incomplete fusion defects are promoted by the “sluggish” nature of Ni-/Co-base molten weld metal and their poor weld penetration characteristics.

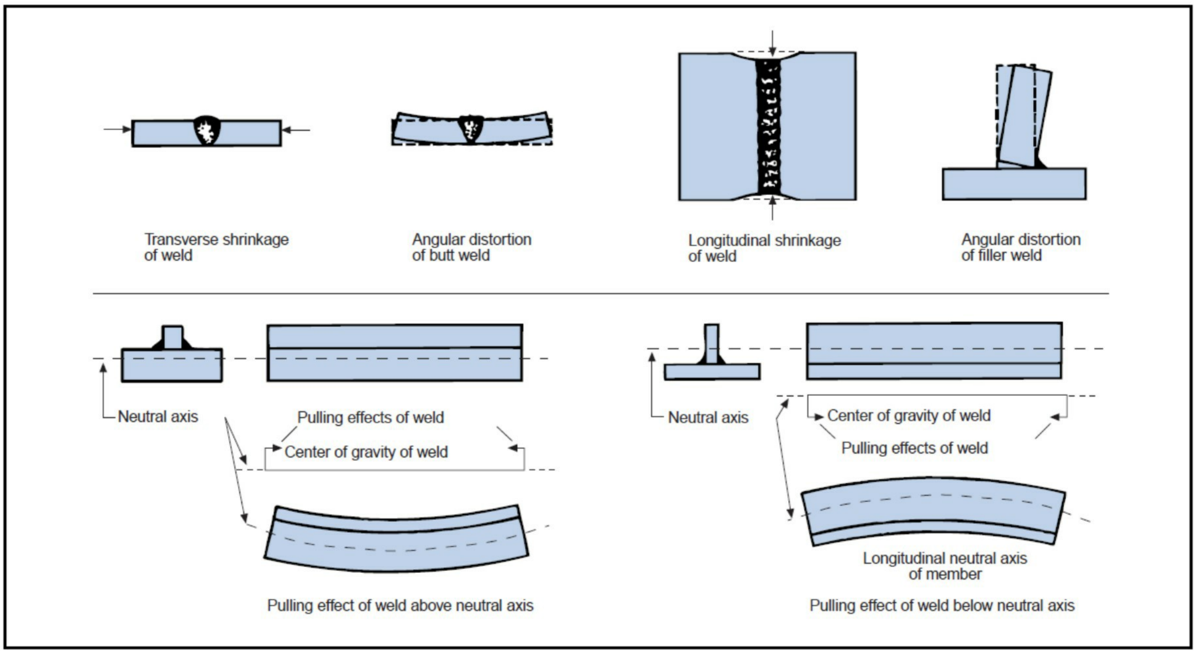
Distortion characteristics of the HASTELLOY® and HAYNES® alloys are similar to those of carbon steel, with less tendency to distort than austenitic stainless steel weldments due to their lower coefficient of thermal expansion. Jigs, fixturing, cross supports, bracing, and weld bead placement and sequence will help to hold distortion to a minimum. Where possible, balanced welding about the neutral axis will assist in keeping distortion to a minimum. Proper fixturing and clamping of the assembly makes the welding operation easier and minimizes buckling and warping of thin sections. It is suggested that, where possible, extra stock be allowed to the overall width and length. Excess material can then be removed in order to achieve final dimensions. Weld distortion for different joint designs are shown in Figure 3.

During normal fabrication of HASTELLOY® and HAYNES® alloys, weld-cracking is rare and one should expect to fabricate large, complex components with few instances of cracking. The most common type of weld-cracking encountered is hot-cracking, which is associated with the presence of liquid in the microstructure. Hot-cracking can occur in the weld metal and heat-affected zone of a weld, and usually results from liquid films along grain boundaries. These strain-intolerant microstructures temporarily occur at elevated temperatures within the melting and solidification range of all alloys. Due to their nominal chemical composition, certain alloys are more susceptible to hot-cracking than other alloys. In general, hot-cracking is a more common occurrence with high-temperature alloys due to their higher alloy content. Impurity elements, such as sulfur and phosphorus, and minor alloying additions, such as boron and zirconium, can have a strong influence on cracking susceptibility even though they are present in very low concentrations.

In addition to a susceptible microstructure, the level of tensile stress on the weld is a critical factor for hot-cracking. The development of stress is inevitable during welding because of the complex thermal stresses that are created when metal solidifies and cools. This is in part related to the inherent restraint placed on the weldment due to weld-joint geometry and thickness. In general, weldments with increased joint thickness are more susceptible to hot-cracking. Additionally, a “teardrop-shaped” weld pool created due to fast travel speed tends to increase cracking susceptibility since it produces a distinct weld centerline where elemental segregation is enhanced and transverse stresses can be high. Large concave weld beads that place the weld surface in tension tend to promote solidification cracking and should be avoided. Further information about weld-cracking mechanisms and welding metallurgy of Ni-base alloys can be found in the following textbook:

J.N. DuPont, J.C. Lippold, and S.D. Kiser, Welding Metallurgy and Weldability of Nickel-Base Alloys, John Wiley & Sons, Inc., 2009.

Figure 3: Weld Distortion for Different Joint Designs



Transverse shrinkage of weld
Angular distortion of butt weld
Longitudinal shrinkage of weld
Angular distortion of filler weld
Neutral axis
Pulling effects of weld
Center of gravity of weld
Pulling effect of weld above neutral axis
Neutral axis
Center of gravity of weld
Pulling effects of weld
Longitudinal neutral axis of member
Pulling effect of weld below neutral axis