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The Weld Nugget™

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Residual Stresses in Welds

Welds undergo rapid heating and cooling not only in the weld zone but also in the surrounding parent metal. The rapid expansion and contraction leads to residual stresses in the weld that are due to CTE (coefficient of thermal expansion), distortion of the components due to stress relieving, and changes in alignment between parts during welding. The net result is formation of residual stress in the weld that can be tensile or compressive. Residual tensile stress can lead to crack growth while residual compressive stresses produce conditions which resist crack growth. Since fatigue life is a major issue for welds, it is beneficial to have some level of compressive stress in the weld especially when the microstructure is susceptible to cracking. In this newsletter, we will review conditions related to weld configuration and geometry that lead to residual stresses in the weld.

In fusion welding processes, metal in the fusion zone rises in temperature till it reaches and exceeds the melting point. Heat is conducted away from the fusion zone and the adjacent HAZ (heat affected zone) and into the parent metal whose temperature also increases. At the conclusion of the weld, heat continues to be conducted away by the base metal, and leads to solidification and contraction of the heated areas with maximum contraction in the fusion zone. As the fusion zone solidifies and contracts, it pulls neighboring material towards itself. However, if the base metal is already welded to other components or somehow anchored with minimal mobility, then the fusion zone contraction will result in residual stress in the weld depending on weld configuration. Figure 1 shows schematics of butt weld, fillet weld, and edge weld sections. In a butt weld with minimal mobility, weld contraction can lead to tensile stresses in the weld as the weld is getting pulled in opposite directions. In an edge weld, where the contracting weld is getting pulled in the same direction, the residual stress will be compressive; the fillet weld will be intermediate.

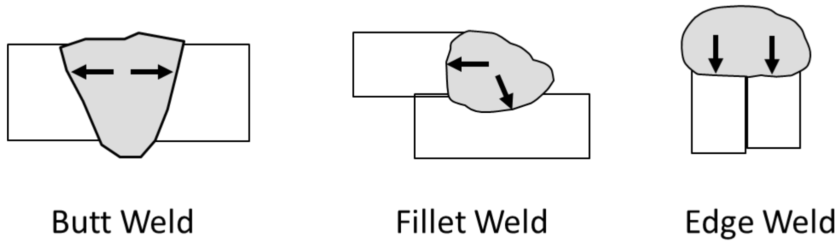

Figure 1: Schematics shows contraction direction of the fusion zone when the parts are anchored and unable to move. Butt weld produces maximum residual tensile stress and edge produce no residual tensile stress; fillet weld is in between.

Residual stress can be further managed by producing a desired surface profile on the weld. A concave surface profile will result in tensile stresses in the weld, whereas a convex surface profile will result in a compressive stress in the weld. Figure 2 shows examples of concave and convex profiles in fillet welds. Welding processes where a filler wire is added can be controlled to produce the desired profile such that the weld is under some level of compression, as seen in Figure 2(b). Filler wire is added by default in MIG welding, but can also be added in TIG welding and laser welding. While the main purpose of wire addition is to produce sufficient weld size and, in some cases, to change weld metallurgy, a secondary benefit of wire addition is to generate a convex profile. However, there are many fusion processes that are run autogenously (no filler wire) such as TIG, Laser, and E-beam and the likelihood of forming a concave profile becomes greater as the molten metal settles to fill any gap between the parts, as can be seen in Figure 2(a).

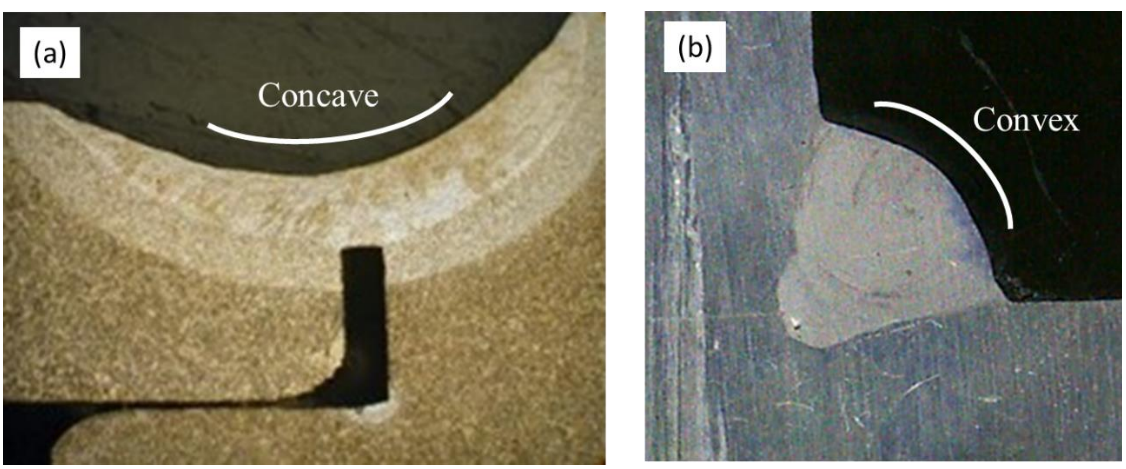

Figure 2: Weld sections (a) showing laser butt weld with a concave profile, and (b) showing MIG weld with a convex profile

One way to produce the desired convex profile without adding a filler wire is to incorporate designs and process features that will contribute volume to the fusion zone and result in a convex profile. Figure 3(a) shows laser butt weld where incorporation of a part corner into the weld has led to formation of convex profile; Figure 3(b) shows similar effect on a corner weld. By incorporating the free corners of the parts into the fusion zone, the weld increases in volume and the consumed corner becomes a defacto filler wire. If a free corner is not available, design features such as raised ledge can be machined in the vicinity of the weld which will melt during the welding process and produce the required convex profile.

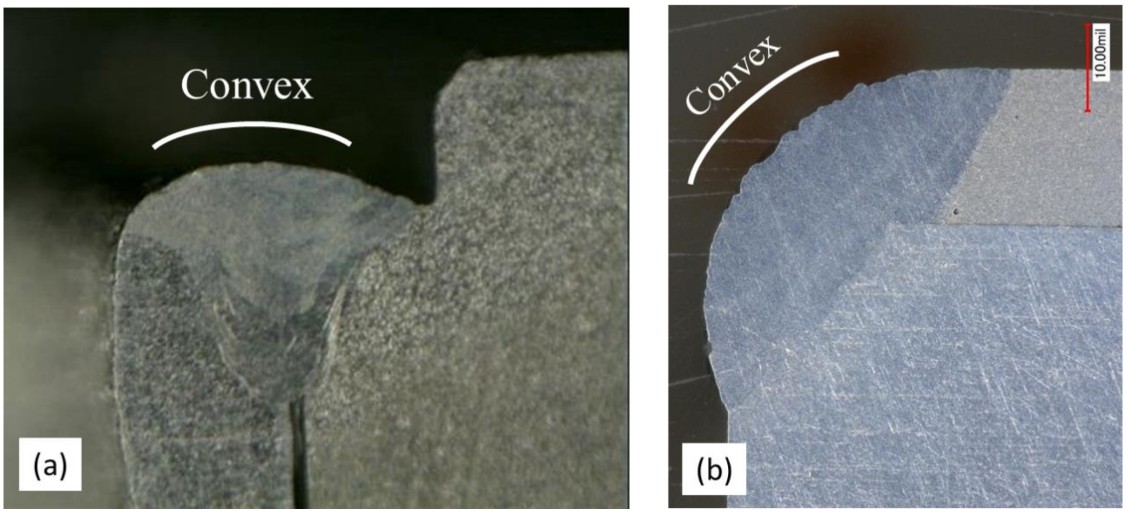

Figure 3: Laser weld sections showing convex profiles produced by including a free corner into the fusion zone; the free corner becomes a defacto filler wire.

Often times, the primary focus in designing and specifying a weld is to make the weld as strong as possible, and for the weld to meet all the important specifications such as requirements for cracks, porosity, gaps, root fusion, and depth of fusion. While issues such as surface profile and residual stresses may not be paramount in the early stages of a welding project, a design engineer would be wise to dig deeper and correctly specify the weld profile in order to improve fatigue life of the welded joint.