Defining a Critical Weld Dilution to Avoid Solidification Cracking in Aluminium

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Extended Abstract

Numerous examples exist in welding practice wherein solidification cracking can be avoided by using an appropriate filler alloy. For example, when considering stainless steel welding, an appropriate filler alloy is selected that will provide for primary ferrite solidification. Boundaries between cracking and no-cracking have been fairly well defined, related directly to weld metal composition (e.g. Schaefler Diagram). This allows the welding engineer to vary either the filler metal alloy or weld dilution in order to generate a weld metal composition that is known to be crack safe. Likewise with aluminium welding, it is known that using Al-Si filler wire alloys (e.g. 4043 or 4047) allows highly crack sensitive alloys to be welded. In the case of aluminium alloy systems, however, the amount of filler dilution required to avoid cracking (i.e. critical composition of the weld metal) remains an ill-defined quantity.

Determining the critical dilution for a given aluminium alloy system and set of welding conditions would appear to be a simple enough task, but has rarely been performed or documented. In this study, however, this task was specifically undertaken using a 6060 base metal and 4043 filler metal. Welding was done using a gas-tungsten arc, cold wire feed (GTA-CWF) process. Welds were made bead-on-plate, i.e. without use of a weld joint, and with full penetration. Furthermore, welds were exposed to a controlled global strain rate during welding in order to aggravate crack initiation, and to permit variation in local straining conditions. Weld coupons were held in a horizontal tensile machine and pulled transverse to the welding direction at a fixed cross-head speed (see Figure 1).

Cross-head speeds were varied between 0 and 2 mm/min in different tests, with the critical dilution for crack avoidance determined in each case. An extensometer was used to measure the local strain rate across the weld in the vicinity where cracking initiates, for each respective cross-head speed. Local strain rates, measured across the weld root (see Figure 2), were observed to vary between $+0.0004 s^{-1}$ and $-0.0008\ s^{-1}$ depending upon the global straining

conditions and the filler dilution. Positive values represent movement of base metal away from the weld, whereas negative values represent movement toward the weld.

A continuous weld, 90 mm in length, was made across a 100 mm wide coupon. Tensile strain was applied at the mid-span and continued through weld completion. Cracks, when formed, initiated along the weld center-line (visible from top surface), between 10-30 mm beyond the point where strain was first applied. Critical dilution values for 4043, i.e. to avoid cracking, were found to increase with the applied cross-head speed (see Figure 3). When no filler was added, the strain adjacent the mushy zone was positive (away from the weld). However, when filler was added, the local strain became negative. Furthermore, the local strain rate became more negative with increasing filler dilution: $-0.0004 s^{-1}$ for 7% dilution, and $-0.0008 s^{-1}$ for 14% dilution (2mm/min cross-head speed).

The effect of filler metal reversing the local strain direction, and the positive effect this must have on crack avoidance, is obvious. The reasons behind this behaviour, however, are not as clear, be they effects from pool shape, heat input, or shrinkage. In addition, 4043 dilution shifts the weld pool composition to slightly higher silicon content, which results in a significant drop in solidus temperature and corresponding increase in solidification range ($\Delta T_{0\%4043}$ = 88°C, $\Delta T_{20\%4043}$ = 152°C). Details regarding the results of this study will be presented and viewed in perspective of existing theories regarding solidification cracking. It is believed that this new approach, examining critical dilution, will help to shed new light on this complex cracking problem.

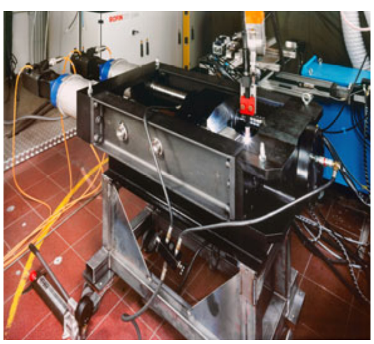

Figure 1: Controlled Tensile Weldability (CTW) test machine, where coupon is pulled in tension during welding.

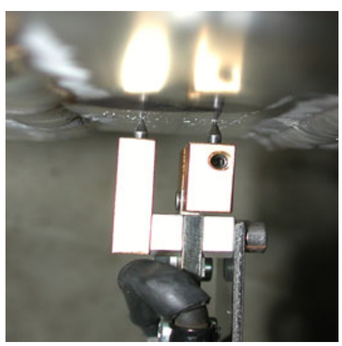

Figure 2: Extensometer applied to back side of plate with point contact on opposite sides of weld bead, fixed 10 mm apart.

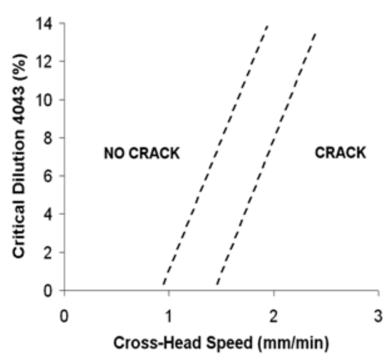

Figure 3: Boundary region for critical 4043 dilution in 6060, as affected by globally applied strain in CTW test.

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