Liquation Cracking in Full-Penetration Welds of 6061 Aluminum Alloy

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It is well known that liquation cracking can occur in the partially melted zone (PMZ) of alloy 6061 when it is welded with filler metal 5356 but not 4043. This paper attempts to explain this significant difference with the help of the weld-metal and PMZ curves of temperature (T) vs. solid fraction (f_S).

The crack susceptibility was evaluated by the circular-patch test. Alloy 6061 was gas-metal arc welded to itself with filler metal 5356 and 4043. The welds were then sectioned and etched with Keller's reagent. The dilution ratio was determined in order to determine the weld-metal composition. The weld microstructure was examined. The curves of temperature vs. solid fraction were calculated for both the PMZ (the base metal) and the weld metal based on the Scheil equation for multicomponent alloys.

Significant liquation was observed in the PMZ of all welds. The eutectic at the grain boundaries and the α phase next to the grain boundaries indicated that significant grain-boundary liquation occurred in the PMZ during welding.

Severe liquation cracking occurred in the weld made with filler metal 5356 at the dilution ratio of about 65%, but no liquation cracking was observed in the weld made with filler metal 4043 at the same dilution ratio.

The weld made with filler metal 5356 had a composition of about Al-2.38Mg-0.53Si. From the solidus map of Al-Mg-Si the solidus temperature of the weld metal was about 585 °C, which is lower than the solidus temperature 595 °C of the base metal (Al-0.91Mg-0.68Si) even though severe liquation cracking occurred in this weld.

The T-f_S curves showed that in the weld that cracked (filler 5356), the weld-metal f_S was greater than the PMZ f_S during PMZ terminal solidification. They also showed that, in the weld that did not crack (filler 4043), the weld-metal f_S was less than the PMZ f_S throughout PMZ solidification.

T-f_S curves were also calculated for alloy 6061 welded with fillers 5356 and 4043 from 10 to 90% dilution ratios to compare with Metzger's study

(Welding Journal, 1967). They showed that in the welds that cracked, the weld-metal f_S was greater than the PMZ f_S during PMZ terminal solidification. They also showed that, in the welds that did not crack, the weld-metal f_S was less than the PMZ f_S throughout PMZ solidification.

T-f_S curves were also calculated for alloy 6082 welded with fillers NG61 (close to 5356) and NG21 (close to 4043) from 10 to 90% dilution ratios to compare with the study by Gittos and Scott (Welding Journal, 1981). Again, the curves showed that in the welds that cracked, the weld-metal f_S was greater than the PMZ f_S during PMZ terminal solidification. They also showed that, in the weld that did not crack, the weld-metal f_S was less than the PMZ f_S throughout PMZ solidification.

The conclusions are as follows:

1. The circular-patch test in the present study shows that at the dilution ratio of about 65 %, filler metal 5356 has a greater tendency to cause liquation cracking in alloy 6061 than filler metal 4043.
2. T-f_S curves have been calculated, based on the Scheil equation for multi-component alloys for both the PMZ (same as base metal) and the weld metal at the fusion boundary. These curves cover both alloys 6061 and 6082 welded with filler metals 5356, 4043 and similar filler metals NG61 (close to 5356) and NG21 (close to 4043).
3. Regarding the 6061 welds made with filler metals 5356 and 4043 in the present study and Metzger's study, the T-f_S curves show that during PMZ terminal solidification the weld-metal f_S becomes greater than the PMZ f_S in those welds that cracked and less than PMZ f_S throughout PMZ solidification in those welds that did not crack.
4. Regarding the 6082 welds made with filler metals NG61 (close to 5356) and NG21 (close to 4043) in the study by Gittos and Scott, the T-f_S curves also show that during PMZ terminal solidification the weld-metal f_S becomes greater than the PMZ f_S in those welds that cracked and less than the PMZ f_S throughout PMZ solidification in those welds that did not crack.

5. Since the strength of a semisolid is most likely to increase primarily with increasing solid fraction, conclusions 3 and 4 further suggest the following explanation for liquation cracking in the PMZ of alloys 6061 and 6082 welded with 5356, 4043 and similar filler metals. When the weld-metal solid fraction exceeds the PMZ solid fraction during PMZ terminal solidification, the solidifying and contracting weld metal is likely to become stronger than the PMZ it pulls and cause liquation cracking.