C. Liquation Cracking in Full-Penetration Al-Si Welds

by G. Cao and S. Kou, University of Wisconsin

Introduction

For aluminum alloys the partially melted zone (PMZ) is a region immediately outside the weld metal where liquation occurs during welding because of heating above the eutectic temperature of the workpiece. Al-Si alloys with high Si contents are the most widely aluminum casting alloys. Solidification cracks, cold shuts and gas holes in aluminum castings are often closed by repair welding with filler metals. Sometimes, aluminum castings need to be welded to wrought aluminum alloys. It is essential to ensure that welding does not induce liquation cracking in the castings. The purpose of the present study is to investigate liquation cracking in welds made on cast high-Si, Al-Si alloys.

Procedure

The circular-patch test was used to evaluate the crack susceptibility in alloy A357 (Al-7Si). The workpiece was 102 mm by 102 mm by 3.2 mm, with an opening at the center to host a 57 mm-diameter, 3.2 mm-thick circular patch. Full-penetration, gas-metal arc welds were made with filler metals 1100 (Al), 4043 (Al-5Si), 4047 (Al-12Si) and 5356 (Al-5Mg). The weld-metal compositions were determined from measured dilution ratios of the resultants welds. The macrostructure and microstructure of each weld were examined.

Results and Discussion

The base metal and the PMZ both consisted of Al-rich dendrites and lamellar interdendritic Al-Si eutectic. However, in the heat-affected zone the lamellar interdendritic eutectic became divorced, that is, it coarsened and became the Al-rich phase and Si particles. When welding the A357 workpiece to an A357 patch, liquation cracking was significant with filler metals 1100 and 5356 but slight with 4043 and 4047.

Based on the multicomponent Scheil model and including as many as 10 different elements, curves of temperature (T) vs. fraction solid (f_S) were calculated for the weld metal and the PMZ, which are competing with each other in increasing f_S and hence crack resistance.

The T-f_S curve of alloy A357 shows that, by the time the PMZ cools to about 590^{o}C, its fraction solid exceeds 0.3. Flemings indicated that the strength of a semisolid is very low until f_S increases to 0.2 - 0.4 (~ 0.3). PMZ solidification is essentially over (f_S = 0.99) when the temperature drops to about 550^{o}C. With f_S > 0.99, there is too little liquid to form continuous grain-boundary films to cause liquation cracking. It is proposed that liquation cracking can occur if the weld-metal f_S exceeds the PMZ f_S during the last 40^{o}C of PMZ solidification before f_S reaches 0.99, which is 590 - 550^{o}C in the case of A357.

It was found that, with filler metals 1100 and 5356, the weld metal that is solidifying, contracting and straining the solidifying PMZ is significantly higher in f_S (and hence crack resistance) than the PMZ within 590 - 550^{o}C. This explains the significant liquation cracking observed in high-Si, Al-Si casting alloys welded with filler metals 1100 and 5356.

With filler metals 4043 and 4047, the weld metal is only slightly higher in f_S (and hence crack resistance) than the PMZ within 590 - 550^{o}C, which explains the slight

liquation cracking in high-Si, Al-Si casting alloys welded with filler metals 4043 and 4047.

In all welds, liquation cracks were completely backfilled and healed, instead of open as in full-penetration welds of wrought aluminum alloys, such as alloys 2219 and 6061. The T-f_S curves showed that, as compared to alloys 2219 and 6061, alloy A357 has a much higher fraction liquid (1 – f_S) for backfilling before PMZ solidification was essentially over (f_S = 0.99).

The T-f_S curves were also calculated for two other high-Si, Al-Si casting alloys, A356 and 359, and the fraction liquid is high before PMZ solidification was essentially over, thus suggesting a strong tendency for backfilling and healing.

Conclusions

The results in the present study suggest, from the viewpoint of minimizing liquation cracking, fillers 4043 and 4047 for welding high-Si, Al-Si casting alloys such as A357, A356 and 359. Fillers 1100 and 5356 are not recommended for these casting alloys, especially when considering welding them to alloy 1100. Liquation cracks in these casting alloys tend to be completely backfilled and healed – unlike open liquation cracks in similar welds of wrought alloys 2219 and 6061.

It is proposed that liquation cracking is likely to occur in the PMZ if, within the last 40^{o}C of solidification before f_S reaches 0.99, the PMZ becomes lower in f_S, and hence resistance to cracking, than the solidifying weld metal, which contracts and strains the PMZ. For alloy A357, the temperature range is 590 - 550^{o}C.

T-f_S curves show that in welds with significant liquation cracking (fillers 1100 and 5356), the weld-metal f_S is significantly higher within 590 - 550^{o}C, while in welds with slight liquation cracking (fillers 4043 and 4047), it is only slightly higher. This is consistent with the proposed model.

The T-f_S curves show that, as compared to alloys 2219 and 6061, high-Si, Al-Si alloys such as A357, A356 and 359, have a much higher fraction liquid (1 – f_S) for backfilling before PMZ solidification is essentially over (f_S = 0.99).