Fusion-Boundary Macrosegregation in Welds Made with Dissimilar Filler Metals

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Introduction

Dissimilar filler metals, that is, filler metals different in composition from the workpiece, are more often used than not in arc welding. It has been long recognized that at the fusion boundary the melted base metal tends not to mix well with the weld pool and forms the so-called "unmixed" zone, which can be susceptible to cracking. Two mechanisms have been proposed to explain fusion-boundary macrosegregation based on basic solidification concepts, instead of just attributing it to weak convection near the pool boundary as in the past, and verified with aluminum welds made with dissimilar filler metals.

Technical Approach

Aluminum GMA welds were made with dissimilar filler metals. Pure Al and eutectic Al-Cu were selected for welding because of their easily recognizable microstructures (featureless and lamellar, respectively). Commercially pure Al (alloy 1100) was welded with Al-Cu filler metals. Eutectic Al-33Cu alloy was cast and welded with commercially pure Al filler metal (alloy 1100). The eutectic was welded either in the as-cast condition or after heat treating to coarsen the lamellar structure. The resultant microstructure at the fusion boundary was examined. The composition profiles across the fusion boundary were measured to determine macrosegregation at the fusion boundary.

Results/Discussion

The trailing portion of the weld pool boundary, that is the solidification front, is at the liquidus temperature of the weld metal (T_{LW}). However, if some melted base metal near the fusion boundary is unmixed, it solidifies at the liquidus temperature of the base metal (T_{LB}).

The mechanism for the formation of the filler-deficient zone (FDZ) is shown in Fig. 1 for the case where the filler metal makes $T_{LW} < T_{LB}$. The region of the liquid weld metal immediately ahead of the solidification front is below T_{LB}. The liquid base metal, if it is swept by convection nearly parallel to the pool boundary, can enter this cooler region and freeze quickly without much mixing. Depending on convection, "peninsulas" or "islands" roughly parallel to the fusion boundary can form as well as "beaches" along the fusion boundary.

$T_{LW} > T_{LB}$: *Non-isothermal pool boundary; quick freezing of liquid* ***weld*** *metal into* ***intrusions*** *in beach;* ***randomly oriented*** *peninsulas/islands*

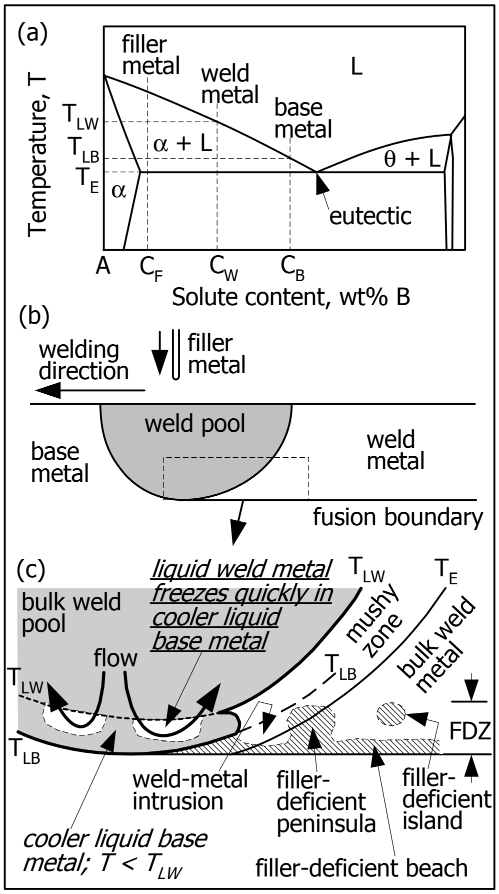


Fig. 1 Mechanism for formation of filler-deficient zone (FDZ) when filler metal makes $T_{LW} < T_{LB}$: (a) phase diagram; (b) longitudinal weld pool cross-section; (c) filler-deficient beach, peninsula and island.

$T_{LW} < T_{LB}$: *Non-isothermal pool boundary; quick freezing of liquid* ***base*** *metal into peninsulas/islands roughly* ***parallel*** *to fusion boundary*

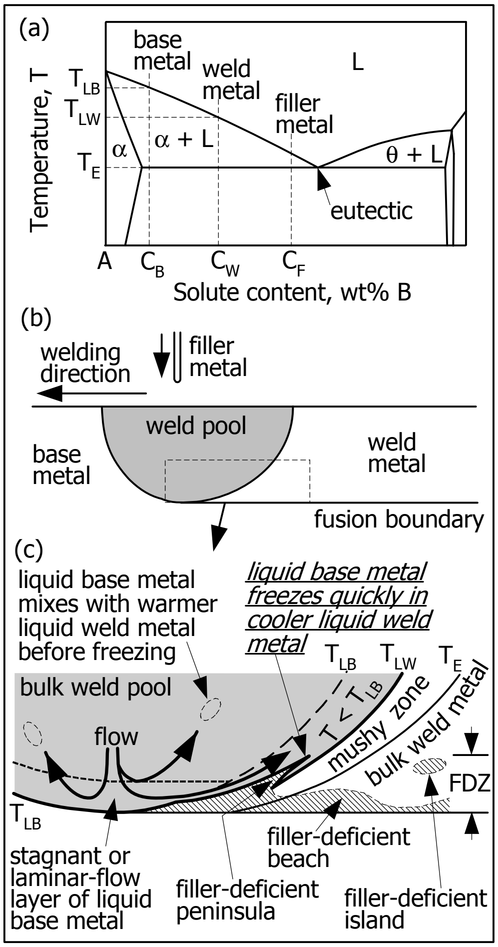
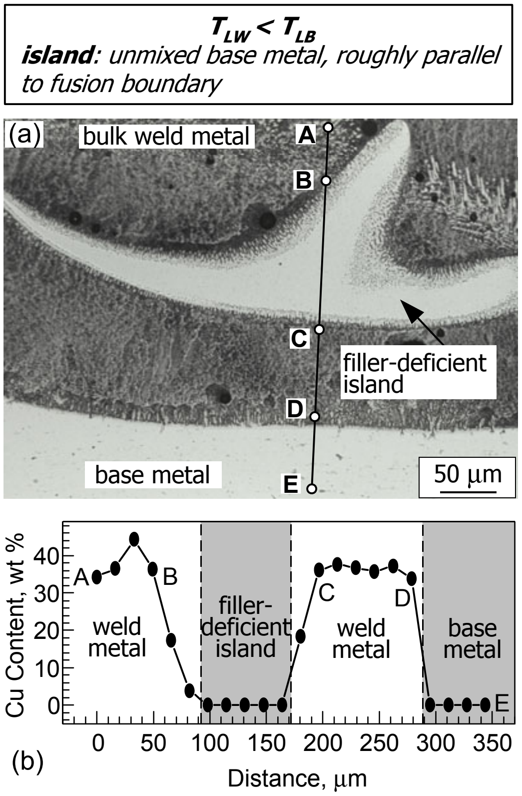


Fig. 2 Mechanism for formation of filler-deficient zone (FDZ) when filler metal makes $T_{LW} > T_{LB}$: (a) phase diagram; (b) longitudinal weld pool cross-section; (c) filler-deficient beach, peninsula and island.

The mechanism for the formation of the filler-deficient zone (FDZ) is shown in Fig. 2 for the case where the filler metal makes $T_{LW} > T_{LB}$. The liquid base metal near the fusion boundary is below T_{LW}. The liquid weld metal, if it is pushed by convection toward the pool boundary, can enter this cooler region and freeze quickly as intrusions without mixing. The unmixed liquid base metal remaining along the pool boundary can solidify as a “beach” while that between the intrusions as randomly oriented “peninsulas” or “islands.”

With similar convection, the chance of a wider macrosegregation zone is higher with a larger difference between T_{LW} and T_{LB}.

Figure 3 shows an "unmixed" island roughly parallel to the fusion boundary in an aluminum weld made with $T_{LW} < T_{LB}$. Figure 4 shows beaches, peninsulas and an island in an aluminum weld made with $T_{LW} > T_{LB}$. The latter two form in the space between weld-metal intrusions and are randomly oriented. These results confirm the proposed mechanisms.



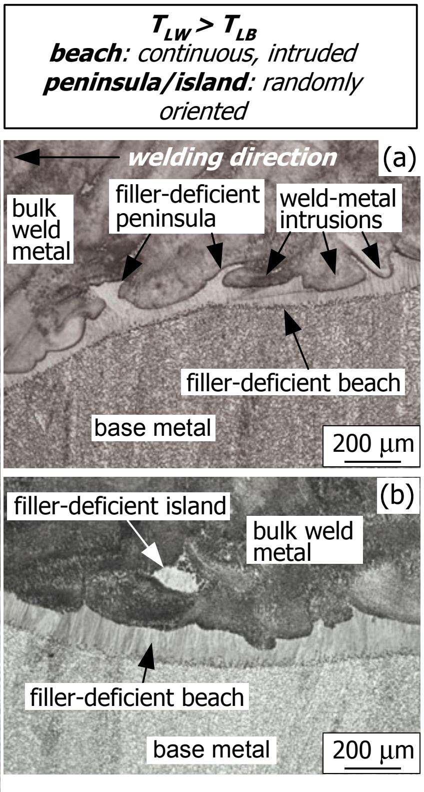


Fig. 3 Macrosegregation across fusion boundary when $T_{LW} < T_{LB}$: (a) transverse micrograph; (b) composition profile. Workpiece: 1100 Al; filler: Al-52.5Cu.

Fig. 4 Longitudinal micrographs along fusion boundary when $T_{LW} > T_{LB}$: (a) beach and peninsulas; (b) beach and island. Workpiece: heat-treated Al-33Cu eutectic; filler: 1100 Al.

CONCLUSIONS

Mechanisms have been proposed to explain macrosegregation near the fusion boundary, including "beaches", "peninsulas", or "islands" similar to the base metal in microstructure and composition. With $T_{LW} < T_{LB}$, the melted base metal near the fusion boundary swept into the cooler liquid weld metal immediately ahead the solidification front can quickly freeze without much mixing. With $T_{LW} > T_{LB}$, the liquid weld metal pushed into the cooler layer of liquid base metal near the fusion boundary can quickly freeze without much mixing. These mechanisms have been confirmed with aluminum welds made with dissimilar filler metals.