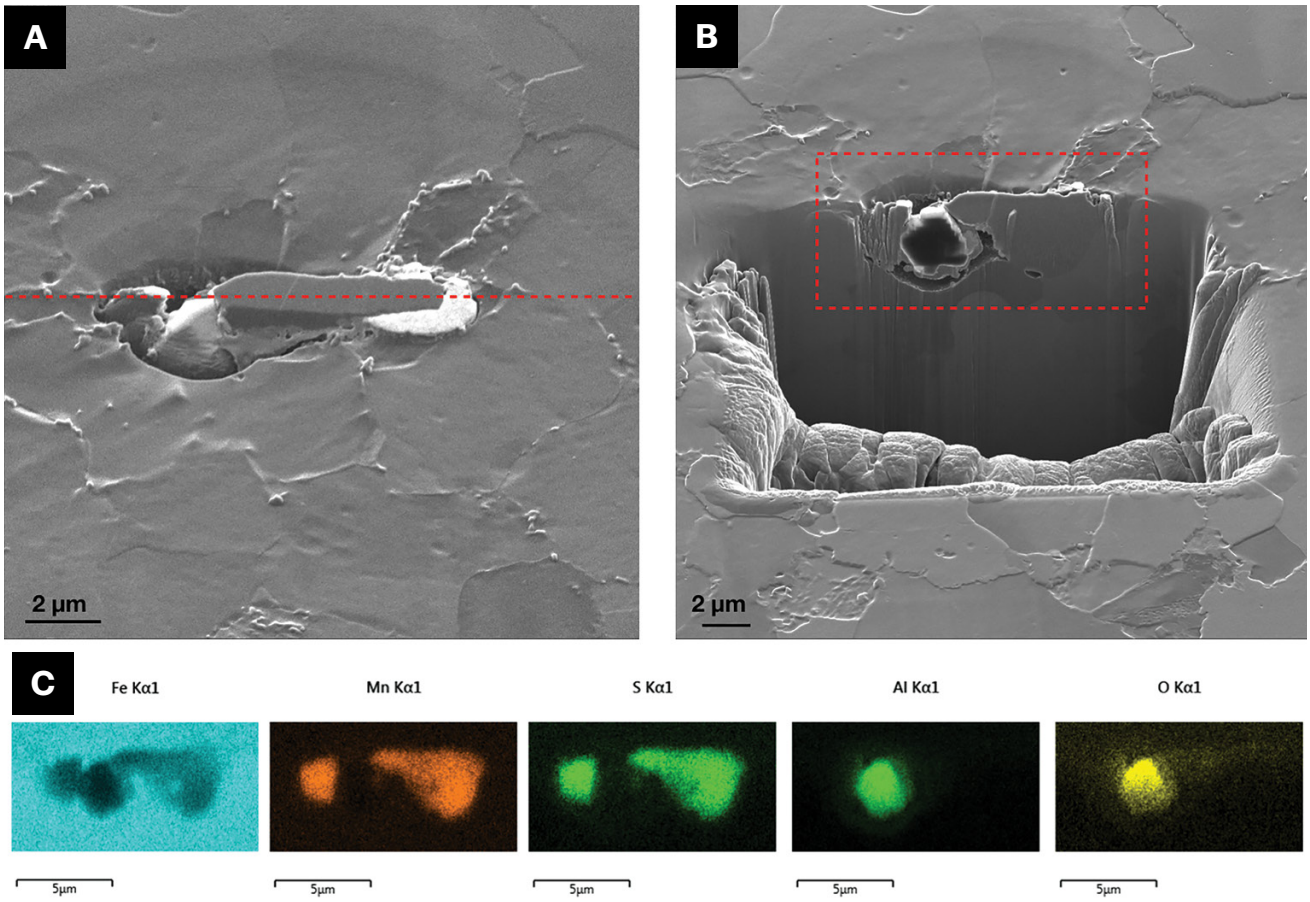

Fig. 8 — A — Top-down view; B — a cross-sectional view of the as-welded inclusion/matrix interfacial debonding in the HAZ region pointed to by the arrow in Fig. 7C; C — EDS mapping results of the selected rectangular region.

$$\frac{\partial C_{MnS}(x,t)}{\partial t} = D_{MnS}\frac{\partial^2 C_{MnS}(x,t)}{\partial x^2} \quad (1)$$

At Mn/S γ interface, $x = S(t)$

$$D_{MnS}\frac{\partial C_{MnS}^{S^-}}{\partial x} - D_{\gamma}\frac{\partial C_{\gamma}^{S^+}}{\partial x} = \left(C_{MnS}^{S^+} - C_{\gamma}^{S^-}\right)\frac{dS(t)}{dt} \quad (2)$$

In γ region, $S(t) < x \leq L$

$$\frac{\partial C_{\gamma}(x,t)}{\partial t} = D_{\gamma}\frac{\partial^2 C_{\gamma}(x,t)}{\partial x^2} \quad (3)$$

where C is concentration, D is diffusion coefficient, S is interface location, x is distance, and t is time. As illustrated in Fig. 11, after 2 s, the size of MnS, represented by the position of the MnS/γ interface, increased from the initial 0.5 µm to 2.0 µm (4.0 µm in diameter). The SEM images in Fig. 3 also show that in the base metal, the size of MnS was 0.22 µm, but after the CGHAZ heat cycle, the MnS grew to a stringer morphology 0.42 µm wide and 5.9 µm in length. This is a direct observation of MnS growth in the CGHAZ region. This substantiates that MnS undergoes growth during the typical thermal cycles of the CGHAZ. The predicted size of MnS was smaller than the observed stringer-type MnS, which can be several hundred microns in length. This difference may be attributed to the observed MnS stringers growing along the rolling direction and following the path of the grain boundaries, where diffusion is much faster than in the bulk, resulting in larger-sized MnS. Additionally, when the growth of multiple MnS inclusions converges at the grain boundary, they may merge and eventually form the stringers. Besides the phase diagram predicting the dissolution of MnS on heating and regrowth on cooling, experimental evidence has been reported in the literature supporting the reprecipitation during cooling. For example, Glue et al. (Ref. 29) observed the original α – MnS particles dissolving during high-temperature (1100–1400°C) heat treatment. Upon cooling, sulfides were found to reprecipitate. Wang et al. (Ref. 42) observed MnS inclusions to grow in low-carbon steel with a low sulfur content of ≤ 0.035%. It must be noted