PREDICTION OF RECRYSTALLIZATION IN FRICTION STIR PROCESSED 304L STAINLESS STEEL

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ABSTRACT

Friction stir processing (FSP) and friction stir welding (FSW) are very similar processes, but they have different purposes. The purpose of FSW is to join parts together. The purpose of FSP is to locally modify microstructure and properties, and in the case of weld repair this would involve passing a tool through an existing arc weld, and surrounding heat-affected zone (HAZ), to repair stress corrosion cracks. While FSP could be a solution for weld repair of irradiated stainless steel, it may promote the formation of sigma phase and chromium carbide in the stir zone, lowering corrosion resistance and rendering it unacceptable for nuclear service conditions. One hypothesis is that sigma phase and chromium carbide formation can be minimized or eliminated if FSP is done under conditions that avoid dynamic recrystallization in the stir zone. Because strains, strain rates, and temperatures are difficult to measure in the stir zone, an Eulerian finite element approach will be used to predict material flow and temperatures during FSP. The simulation data will be used to calculate fraction recrystallization in the stir zone, allowing for the establishment of relationships between FSP process conditions and the achievement of successful weld repair microstructures. The fraction of material recrystallized can then be calculated from the strains, strain rates, and temperatures that emerge from the steady-state FSP simulation. We follow the approach of Venugopal [1], who calculated volume fraction recrystallized and the average recrystallized grain size, using the following equations adapted to 304L stainless steel:

$$\chi = 1 - exp\left[\ln(2)\left(\frac{\varepsilon-\varepsilon_c}{\varepsilon_{0.5}}\right)^2\right] \tag{1}$$

$$\varepsilon_c = 5.32\ \times 10^{-4}\ e^{8700/T} \tag{2}$$

$$\varepsilon_{0.5} = 1.264\ \times 10^{-5} {d_o}^{0.31} \varepsilon^{0.05} e^{6000/T} \tag{3}$$

$$d = 20{,}560 \dot{\varepsilon}^{-0.3} e^{-0.25}\left(\frac{Q}{RT}\right) \tag{4}$$

where χ is the fraction recrystallized, d is the recrystallized grain diameter (μm), ε_c is the critical strain, $\varepsilon_{0.5}$ is the plastic strain for 50% volume recrystallization, d_o is the initial grain diameter (μm), ε is strain, $\dot{\varepsilon}$ is strain rate, Q=310 kJ/mol, and R=8.314×10^{-3} kJ/mol-K. For the calculation of residual stresses, the mesh used in the Eulerian simulation was imported into ANSYS, along with the steady-state temperatures [2]. Displacement boundary conditions were applied and then cooling of the part was simulated using a thermo-elasto-plastic model, providing the residual stress field in the friction stir processed part.

REFERENCES

[1] Venugopal, S. and P.V. Sivaprasad, *A journey with Prasad's processing maps.* Journal of Materials Engineering and Performance, 2003. **12**(6): p. 674-686.

[2] Buffa, G., A. Ducato, and L. Fratini, *Numerical procedure for residual stresses prediction in friction stir welding.* Finite Elements in Analysis and Design, 2011. **47**(4): p. 470-476.