F. Analysis of Crack Formation in the Longitudinal Varestraint Test

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Introduction

Matsuda and coworkers and the authors have demonstrated the utility of high-speed imaging of the Varestraint test. In this approach, the dynamics of cracking and the evolution of surface strains are directly measured. The work has shown that in longitudinal testing of Alloy 718, cracking initiates in the semisolid region behind the weld pool, and propagates in both the travel direction as well as away from it. Forward crack growth proceeds incrementally at an average velocity similar to the travel speed. Thus, the growth of the leading edge of the crack occurs at an approximately constant temperature and liquid fraction.

Procedure

In the present study, the dynamic crack growth observations are correlated with model estimates of the thermal fields, strain development, and solid fraction present during longitudinal Varestraint testing. Previously characterized niobium-bearing nickel-based alloys were evaluated. The strain model was calibrated with fiducial marks located adjacent to the weld, and the solidification models were based on both empirical measurements and Thermo-Calc estimates. Through the model comparisons, the temperature, solid fraction, local strain, and local strain rate associated with crack initiation and propagation were characterized. Additional experiments were designed to attempt to capture crack backfilling.

Results and Discussion

The experimental observations indicate that cracking in niobium-bearing nickel-based alloy Varestraint test welds initiates during primary austenite solidification (prior to the formation of terminal solidification constituents) at a local strain of approximately 1%. Local strain rates in the vicinity of the hot cracks were on the order of 0.5/sec at initiation and 1/sec during crack propagation. The forward crack tip propagation occurs at a rate similar to the travel speed, and thus remains approximately equidistant from the trailing edge of the weld pool. In this respect, the leading edge of the crack propagates in a manner similar to that expected for the propagation of hot cracks in real service weldments. The trailing crack tip propagates away from the trailing edge of the weld and terminates in the region of the weld which is near the solidus temperature. Analysis of opened crack surfaces indicates that the subsurface cracking behavior is similar to that observed on the surface

Model calculations of the solid fraction, temperature, and strain present at crack initiation provide a means for comparison of the effects of alloy composition on the hot cracking response. Moreover, these estimates provide for refinement of current hot cracking models, which are usually based on the total solidification temperature range. Thus, the important feature of crack initiation, as well as propagation, can be analyzed with improved fidelity. The model estimates of local temperature and strain fields, coupled with the cracking observations, provide for determination of the dynamic response at crack initiation and propagation, thereby improving the link between Varestraint testing and the analysis of real service weldments. Moreover, these models provide the only method, beyond post-weld sectioning, by which the subsurface cracking behavior can be assessed and quantified.

Conclusions

The combination of new experimental and modeling techniques to analyze cracking dynamics in the Varestraint test provides a powerful means of characterizing the salient features of solidification hot cracking and interpretation of Varestraint test data. Validation of the cracking models and the ability to assign a criteria for the initiation of cracking provides a link between actual weld cracking and the Varestraint test.