To be presented at the 7th International Conference on Trends in Welding Research, May 16-20, Pine Mountain, Georgia, USA

Welding of Nickel-Based Superalloys: How to Avoid Stray Grains and Why

J. M. Vitek, S. S. Babu, and S. A. David

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6096, U.S.A.

When welded, single crystals are prone to stray grain formation. Such stray grains destroy the single-crystal microstructure. In the case of nickel-based superalloys, the elimination of the single crystal structure is likely to lead to a deterioration in mechanical properties. Thus, it is critical to maintain the single crystal microstructure when welding commercial nickel-based superalloys. Furthermore, it has been shown in previous work that cracks tend to propagate along the stray grain boundaries, which are high-angle boundaries and are weak points in the microstructure. Therefore, elimination of stray grains may also go a long way toward the elimination of cracking in welded nickel-based single crystal superalloys.

Work was carried out to investigate the mechanism of stray grain formation in nickel-based single crystal superalloys. A comparison of experimental work with theoretical model predictions indicated that constitutional supercooling is the stray grain formation mechanism. Once the mechanism for stray grain formation was identified, extensive modeling was undertaken to identify the optimum welding conditions in order to avoid their formation and retain the preferred single crystal microstructure. The modeling study integrated three different models. A thermal model was used to determine the weld pool shape and the thermal properties along the solidification front (solidification front velocity and thermal gradient). These results were combined with a geometric model to account for the crystallographic orientation of the weld and the specific dendrite growth directions that are active during solidification. This provided information on the thermal gradient and growth velocity as a function of position and orientation. The final model was one that predicted the extent of constitutional supercooling ahead of an advancing front and used the location and orientation dependent results to identify the extent of stray grain formation during welding.

Calculations were carried out for several different weld conditions and weld orientations. The results led to the identification of the optimal processing conditions that are needed to avoid the formation of stray grains. It was found that high weld velocity and low weld power are desirable. Examples will be provided to show how the stray grain formation tendencies vary with weld conditions, and how they vary with location in the weld pool. The results were compared with experimental findings and all of the experimental trends were reproduced in the model predictions.

This research was sponsored by the Office of Fossil Energy, U.S. Department of Energy, National Energy Technology Laboratory, and the Division of Materials Sciences and Engineering, U. S. Department of Energy, under Contract DE-AC05-00OR22725 with UT-Battelle, LLC.