Validating a Solid-State Resistance Weld Model Using the Gleeble 3500*

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Introduction

Developing qualified weld procedures requires substantial investment of engineering personnel, equipment, analysis/testing, and consumables, particularly if the parts being joined are complex, expensive and used in critical applications. While statistically-designed multivariate parameter spaces can substantially reduce experimentation, ideally, we would like to use a well-validated computational model to arrive at a weld schedule, which would then be qualified for production by minimal actual welding and testing. The work presented here is aimed at validating such a computational model for solid-state upset resistance welds in 304L. The model was developed with support of the U.S. Dept. of Energy's Advanced Super-Computing Initiative.

Procedure

Validation requires comparison of computed and measured temperature and deformation histories over the entire weld region, as well as comparison of resulting microstructures, residual stresses and properties in the weld-affected zone. Furthermore, since the model is only as good as the input properties, determination of constitutive material properties is an important aspect of the program. The Gleeble 3500 thermal-mechanical simulator was chosen to perform these experiments because of its close resemblance to the actual welding equipment (i.e. resistance heating power supply combined with servo-hydraulic force actuation), and its flexible temperature and deformation capabilities combined with comprehensive data acquisition.

Results and Discussion

Initial steps involved learning how to make the Gleeble accurately and reproducibily simulate the behavior of an upset resistance welding machine. For example, power programming is possible with the Gleeble in addition to its normal temperature program mode, but it did not reproducibly mimic the behavior of a typical AC resistance welding power supply, so an alternative procedure using temperature programming was used instead. Additionally, the force control mode was unable to maintain a constant force during the rapid weld heating event, falling by as much as 50% or more, even when the PID control parameters were optimized. This occurred because rapid softening of the specimen waist as it exceeded about 1000 C combined with an inappropriate model used to convert displacement to force in the ram displacement control loop to give an excessively long response time. Initial attempts at adjusting the proportional control parameters led to mechanical instability at low temperatures. A dynamic simulative model of the Gleeble's servo-hydraulic system was developed to fully understand the machine's force behavior, and tailor it to the desired behavior via modifications to the control system. This required a comprehensive evaluation of the machine's mechanical response as a function of actuation velocity and displacement in order to model the closed-loop (plant plus controller) system behavior. Supplemental data acquisition procedures to obtain full-field temperature and deformation results will also be described, as will procedures needed to obtain constitutive compression stress/strain data at elevated temperatures (>1000 C) after rapid heating cycles. Finally, the results of a matrix study of the heating and deformation behavior of a 1-piece hourglass-shaped sample will be compared with computations.

Conclusions

We describe activities aimed at validation of a comprehensive materials and process model for solid-state resistance welding of 304L stainless steel. These involved developing techniques on the Gleeble 3500 thermal-mechanical simulator to allow it to accurately simulate an actual resistance welder, and also techniques to obtain full field temperature and deformation histories. Finally, we compare the results of computation and experiment, and discuss discrepancies and future efforts at extending both the model and validation effort.)

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