High-Speed High-Resolution Imaging of Crack Formation in the Varestraint Test

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Introduction

Weld metal solidification hot cracking is a complex phenomena in which the contraction strains developed during solidification cannot be accommodated by the semi-molten alloy. Substantial progress has been made in experimental quantification of the factors contributing to this phenomena, e.g. solidification temperature range, solidification path, fraction of terminal constituents, restraint, etc. There has also been significant progress in modeling of the process, and new methods are available for estimating the thermodynamic quantities needed for such computations, e.g. Thermo-Calc, surface energy estimation routines, etc.. However, there continues to be limited mechanistic understanding of crack initiation and the evolution of crack backfilling.

Procedure

To gain insight into the mechanisms of hot cracking, high-speed high-resolution optical digital cinematography was used to observe the formation and growth of solidification hot cracks in the Varestraint test. This technique uses a high quality zoom lens system (up to XXX magnification) and a high-speed CCD camera (up to 2000 frames/sec) to image the trailing edge of the weld pool during sample straining. For development of the technique, Alloy 718 was used as a model system since it is relatively susceptible to cracking, and there is substantial supporting information concerning the effects of composition and solidification temperature range.

Results and Discussion

The experimental set-up and imaging techniques will be described in detail. As might be expected, the highly dynamic thermal and mechanical environment of the Varestraint test complicates high resolution imaging of the cracking event, and required the development of specialized filtering, fixturing, and timing methods. The digital imaging system employed in this work allows for the simultaneous acquisition of up to 16 channels of data. Specific data recorded in these tests included torch and straining ram position, as well as the gas-tungsten arc welding power supply parameters. The optical filtering techniques and data reduction schemes will be described.

Since the individual frames are stored as digital images, it is possible to conduct image analyses on individual image frames or groups of sequential frames. As a result, the local microstructural features in the vicinity of the crack can be assessed quantitatively. Features such as dendrite spacing, solidification grain boundary orientation with respect to the straining axis, and the fraction of liquid present at the location and time of crack initiation can be determined. These measurements will be described and compared with those inferred from post test metallography.

Backfilling is a mechanism by which alloys with high terminal liquid fractions can, in effect, display comparatively low susceptibility to hot cracking in the Varestraint test. It is not entirely clear, however, what sequence of events is associated with this process. The high speed imaging technique discussed in this work provides a means for observing the backfilling process in real time, and provides a basis for improvement of solidification hot cracking models.

Conclusions

A technique for observing hot crack formation in the Varestraint test at high resolution has been developed. Quantitative microstructural and temporal information can be extracted from the recorded images, and provides a new means for characterizing the salient features of solidification hot cracking. It is hoped that these observations will improve our understanding of the mechanisms associated with the process, and will provide a basis for refining numerical models of the phenomena.

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