

A. Repair Weldability of Heat-Resistant Alloys

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Introduction

Degradation of cast austenitic materials can occur when the material is exposed at elevated temperature for long periods of time, typically many years. When this degradation occurs, normally in the form of embrittlement, repair welding is often used to either repair cracks or replace components. The heat-affected zone is usually the location of weld cracking in these service-exposed materials during repairing. Since it is difficult to run a laboratory simulation of the long-term aging up to several years in the actual operating environment, the main purpose of this work was to fundamentally study the cracking mechanism in service-aged alloys with the aid of Gleeble simulation. The study focuses on the failure analysis, microstructural characterization and the repair weldability of two cast, heat-resistant alloys, HP45-Nb modified and HP50, which had been service exposed for approximately 10 years at elevated temperature.

Procedure

Optical microscopy and SEM were used for the microstructural analysis. Semi-quantitative, composition analysis was conducted with EDS. TEM was used for phase identification. Weldability tests, including the bead-on-pipe test and modified Y-groove test, were run at levels of increasing restraint to investigate the susceptibility to weld cracking. Gas tungsten arc welding was used to produce all the welds. Hot ductility tests were run on a Gleeble thermal mechanical simulator over a wide range of temperature from 500°C up to the nil strength temperature (NST), to study both the liquation and ductility dip cracking susceptibility of these alloys.

Results and Discussion

Microstructural Characterization.

Compared with the original as-cast material, the morphology of grain boundary phases changed from lamellar to blocky. Further heat treatment of the service-exposed material was carried out at 1000°C and 1200°C for up to 60 hours followed by water quenching. After these treatments no new precipitates were found, but cooling rate seemed have significant effect on the amount of precipitates. A large amount of precipitates were observed in the slower cooled sample. Three distinct regions were identified in the aged alloys.

Chromium- and molybdenum-rich phases were observed coexisting at the grain boundaries. After heat treatment at 1000°C and 1200°C for 60 hours, Nb-rich phases were noticed at both grain boundaries and within the cells. These Nb-rich phases are very small and tend to be spherical.

Weldability Testing

The weldability tests were conducted in a succession of increasing of restraint levels. The bead-on-pipe tests were run on both longitudinal and circumferential directions with weld lengths of 20mm, 40mm, and 60mm. No cracking occurred in these tests. The modified Y-groove tests were developed to create more restraint with varied length of Y-grooves machined out from the pipe along the longitudinal direction. These tests also did not result in cracking. The hot ductility tests are followed to fundamentally

study the cracking mechanism of these aged materials. A narrow range of NST-NDT indicated a good resistance to liquation cracking which corroborated the results obtained from bead on pipe and modified Y-groove tests. There is some evidence that elevated temperature, ductility dip cracking may occur in these alloys.

Conclusions

Although some degree of elevated temperature embrittlement is observed in both the study alloys, the weldability tests that were used were not severe enough to cause cracking in the HAZ of the cast alloys. Coupled with Gleeble hot ductility studies, these results suggest that cracking during repair welding is probably not due to HAZ liquation, as was previously proposed. Rather it appears that failure results from elevated temperature, solid-state embrittlement that gives rise to a "ductility dip". When the elevated temperature restraint exceeds the ductility minimum, failure occurs. The microstructural and fractographic features leading to this embrittlement will be reviewed and a mechanism for repair weld failures proposed.