

Hot Ductility of Laser Deposited Alloy 690

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Introduction

Alloy 690 is a high-chromium nickel alloy used in corrosive media and high temperature applications. Direct laser fabrication is a method in which powder of the desired alloy is placed in the focal point of a laser and melting/solidification occurs. The resulting build-up can obtain net or near-net shape dimensions of components. If optimized, the processing parameters can produce fully dense parts with properties similar to wrought products. If the process is sub-optimized, interlayer microporosity may result, which is detrimental to ductility. Further fabrication such as repair welding requires good high-temperature ductility to avoid heat-affected zone (HAZ) and ductility dip cracking (DDC). The purpose of this follow-on study is to evaluate the effects post-processing on the hot ductility behavior of laser deposited Alloy 690.

Experimental Procedure

Alloy 690 powder was obtained and several direct laser deposits made. The wrought counterpart to the direct laser fabricated material was Alloy 690 plate and used as a control alloy during this investigation. In a previous study, the hot ductility behavior of as-deposited Alloy 690 powder was characterized. Hot isostatic pressing (HIPing) was performed on the laser deposited material to allow for a denser laser deposited material. Density measurements were taken on the as laser deposited material as well as the laser deposited and HIPed material. Specimens were machined for hot ductility testing, and tested on a Gleeble[®] 1500/20 thermomechanical simulator. Both light microscopy (LM) and scanning electron microscopy (SEM) were used to evaluate material response to simulated thermal cycles.

Results

The microstructure of wrought Alloy 690 is a typical equiaxed microstructure for a rolled material. This material exhibited a bimodal grain distribution, and several second-phase particles. The as-laser deposited Alloy 690 was shown to have a microstructure typical of a laser welded austenitic material whose primary solidification mode is austenite. The as-deposited Alloy 690 exhibited a number of open pores, apparently at the interlayer regions, which resulted from the layer-by-layer fabrication technique used.

The material was fabricated with what now appears to be sub-optimized parameters such that a few percent of interlayer porosity resulted. The density measurements showed that the as-deposited material contained about two percent porosity, assuming the HIP produced a fully-dense material.

The on-heating Gleeble hot ductility results for wrought Alloy 690 showed that the nil-strength temperature is about 1320°C, while the on-cooling data showed the ductility recovery temperature is about 1220°C. A ductility dip was seen about 1000°C. This type of behavior has been observed in face-centered cubic materials, which typically have low levels of impurities and tramp elements such as sulfur and phosphorus. The on-heating data for as-laser deposited Alloy 690 specimens showed that the ductility is quite low when compared to the wrought material at all temperatures examined (with the exception of the nil-strength temperature). When the fracture surfaces were examined in the SEM, it was readily apparent that the laser-deposited material contained continuous pores. Upon closer review, it was observed that the pores could extend over 100 microns in length and approximately 50 microns in width. However, after HIPing, the laser-deposited Alloy 690 exhibited improved hot ductility.

Conclusions

If a material which normally exhibits a ductility dip at intermediate temperatures on cooling from welding is laser-deposited, and contains continuous open pores, post fabrication techniques such as repair and attachment welding may result in an increased susceptibility to ductility-dip cracking. However, HIPing such a material appears to improve its elevated temperature properties, and aids in mitigating its inherent susceptibility to the ductility-dip cracking.