D. Direct Metal Deposition of Copper onto Steel using a Nickel Interlayer

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Introduction

Laser Engineered Net Shaping™ (LENS™) is an emerging Solid Freeform Fabrication (SFF) process capable of producing fully dense metallic parts with complex shapes directly from a computer-aided drawing (CAD) without the need for molding or tooling. The LENS™ process also shows promise in producing components with graded compositions. One potential application is the production of steel – copper die casting materials. Copper is currently being considered for deposition on dies made out of steel to enhance thermal management. However, solidification cracking occurs when graded Steel-Cu deposits are fabricated. Research on the use of a Ni interlayer between Steel and Cu to avoid solidification cracking is presented. The effects of solidification temperature range and the amount of terminal liquid on solidification cracking susceptibility of a wide range of Fe-Ni-Cu alloys will be discussed. It has been found that the interlayer composition must be nearly 100% Ni to avoid solidification cracking when depositing Cu onto Steel.

Experimental Procedure

Steel-Ni-Cu deposits were prepared with a broad range of compositions by depositing Ni onto Steel and subsequently Cu onto the Steel-Ni alloy using the GTAW process. Composition of each deposit was varied by changing the filler metal feed speed and welding current. The deposits were characterized by light optical and electron microscopy techniques. The cracking susceptibility was also determined for each composition. Solidification modeling was utilized to determine the solidification temperature range and predicted amount of terminal liquid. Modeling results were compared to experimentally observed amounts of terminal liquid measured via quantitative image analysis (QIA). QIA was also used to quantify the effect of Ni in reducing the amount of terminal Cu in Fe-Ni-Cu alloys with a constant nominal composition of Cu.

Results and Discussion

The deposit microstructure and resultant cracking susceptibility were a strong function of the Ni and Cu concentration in the deposit. Deposits with low levels of Ni and moderate levels of Cu were most susceptible to cracking. Deposits with approximately the same nominal composition of Cu, but increasing levels of Ni (at the expense of Fe) exhibited a concomitant decrease in terminal Cu rich liquid and cracking susceptibility. An interlayer composed of nearly 100% Ni was necessary to eliminate cracking in Steel-Ni-Cu continuously graded deposits. These composition-cracking relations can be explained based on the solidification behavior of the deposit. At low nickel and copper concentrations, the solidification temperature range is high and amount of terminal liquid is sufficient to wet dendritic boundaries resulting in poor cracking resistance. As the nominal Ni concentration increases, while Cu concentration remains constant, the amount of terminal Cu rich liquid decreases. It was found that Fe-Ni-Cu deposits with only trace amounts of Fe exhibited no terminal Cu rich liquid and no cracking susceptibility. Modeling using a Scheil simulation coupled with the Thermocalc database was performed to identify the expected solidification temperature range and amount of terminal Cu rich liquid for a wide range of Fe-Ni-Cu alloys. Predicted amounts of terminal Cu using the above approach had good agreement with experimentally observed levels of terminal Cu.

Conclusions

Steel-Ni-Cu deposits exhibit high susceptibility to solidification cracking over a broad range of compositions. An interlayer consisting of nearly 100% Ni must be present before Cu can be subsequently deposited on a Steel substrate.