# Direct Laser Deposition of Copper Onto Steel

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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, difficulties such as solidification cracking can occur at the Steel-Cu interface, which compromises the structural integrity of the deposit. In this work, the solidification behavior and resultant cracking tendency of Steel-Cu deposits was evaluated under a wide range of dilution levels as a first step to developing a solution to this problem. Preliminary research on the use of a Ni interlayer to avoid interfacial cracking was also conducted.

## Experimental Procedure

Steel-Cu deposits were prepared over the entire dilution range by direct deposition of Cu onto steel using the GTAW process. Dilution was varied through variation in 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 dilution level. Preliminary experiments were conducted in which various Ni concentrations were first deposited onto steel, followed by direct deposition of Cu to produce a Steel-Ni-Cu deposit. Interpretation of the experimental results was aided by solidification modeling.

## Results and Discussion

The deposit microstructure and resultant cracking susceptibility were a strong function of the Cu concentration in the deposit. Deposits with Cu concentrations from approx. 10 –50 wt% Cu exhibited extensive solidification cracking, while deposits with Cu concentrations below 5 wt% Cu and above 55 wt% Cu could be produced crack-free. Deposits with Cu concentrations in between these ranges exhibited moderate cracking susceptibility. These composition-cracking relations can be explained based on the solidification behavior of the deposit. At low copper concentrations (< 5 wt%), the solidification temperature range and amount of terminal liquid are generally low, and cracking resistance is quite good. At higher Cu concentrations (> 55 wt%), there is a large amount of terminal liquid that back fills and "heals" solidification cracks as they form, again resulting in low cracking susceptibility. The back-filling phenomenon was observed directly through microscopy techniques. In between this range, the solidification temperature range is very high, and there is not sufficient terminal liquid to provide crack healing. As a result, the cracking susceptibility is high. A finite difference solidification model was developed based on the Scheil analysis that accounts for a varying distribution coefficient in order to predict the final microstructure as a function of copper concentration. Good agreement between the measured and calculated amount of terminal copper phase was observed. Preliminary results show that the addition of a Ni layer between the Steel and Cu may provide a solution to the cracking problem. This beneficial effect of Ni is attributed to its relatively high solubility for both Fe and Cu.

## Conclusion

Steel-Cu deposits with Cu concentrations from approx. 10 – 50wt% Cu exhibit high susceptibility to solidification cracking. Since the entire range of Cu concentration will exist in a Steel-Cu graded deposit, solidification cracking can be expected in deposits that start with steel and grade into pure Cu. Preliminary work shows that deposition of an intermediate layer of Ni may provide a solution to this problem.