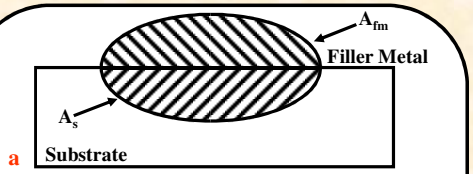
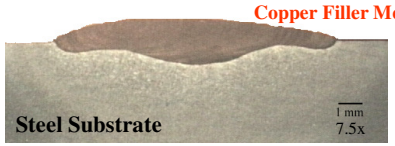
Cracking Susceptibility of AISI 1013 Steel – Copper Alloys

Class 6



a

$$D = \frac{A_s}{A_s + A_{fm}} \qquad C_{fz} = C_{fm}(1-D) + C_s(D)$$



b

Figure 1: a) Dilution schematic and equations for dilution (D) given area of substrate (A_s) and filler metal (A_{fm}). Composition of a given element in the fusion zone (C_{fz}) given composition of same element in filler metal (C_{fm}) and D. b) Dilution sample cross section - DEOX Copper bead on AISI 1013 steel plate

The tool and die industry would like to exploit copper's high thermal conductivity in order to improve thermal management in dies constructed of tool steel. Copper is typically considered a contaminant in steel and is a known promoter of solidification cracking in ferrous alloys. A solution to the solidification cracking dilemma will potentially allow copper to be functionally graded into steel using newly developed direct metal deposition manufacturing technology. The first step in a research effort to produce such dies was to identify the compositional cracking range of copper in steel. AISI 1013 steel was selected as a simple system that can be used to model tool steel, yet be applicable to a broader range of steel-copper applications.

The compositional cracking range of copper in AISI 1013 steel was found by fabricating a series of copper bead on steel plate welds of varying copper compositions by use of a Gas Tungsten Arc Welder with cold wire feed. The samples were sectioned, ground and polished using standard metallographic techniques, then etched in 2% Nital. Quantitative Image Analysis (QIA) and light optical microscopy were used to determine the compositional cracking range of copper in steel. Additionally, QIA was used to identify the appropriate solidification model; a modified "Scheil" condition. This combined information will be used in the future fabrication of functionally graded steel-Cu dies using direct metal deposition technology.

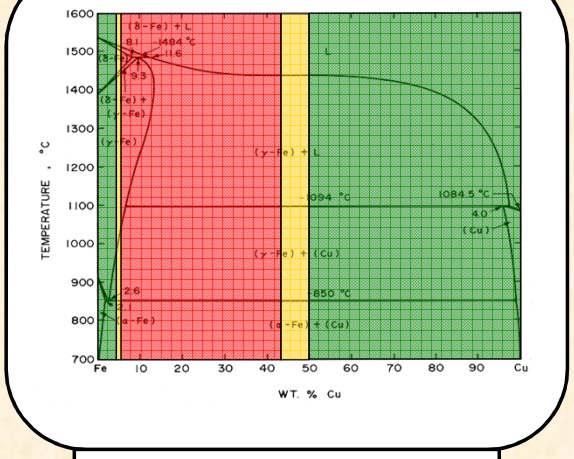
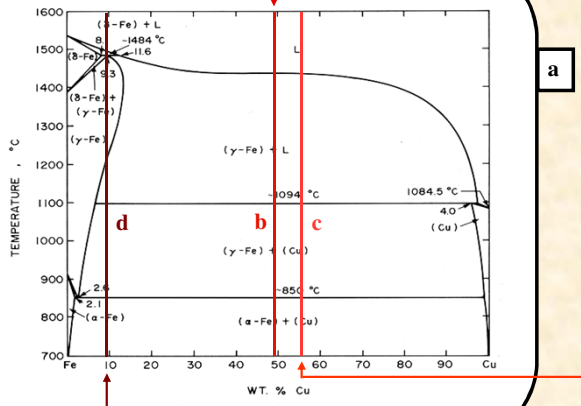


Figure 3: Crack susceptibility (CS) as a function of composition. Green – low CS, Yellow – moderate CS, Red – high CS

Figure 2: a) Fe-Cu: representative phase diagram for dilution control experiments. Large solidification temperature range and low solubility of Fe and Cu contribute to solidification cracking. Compositions of representative microstructures are indicated.



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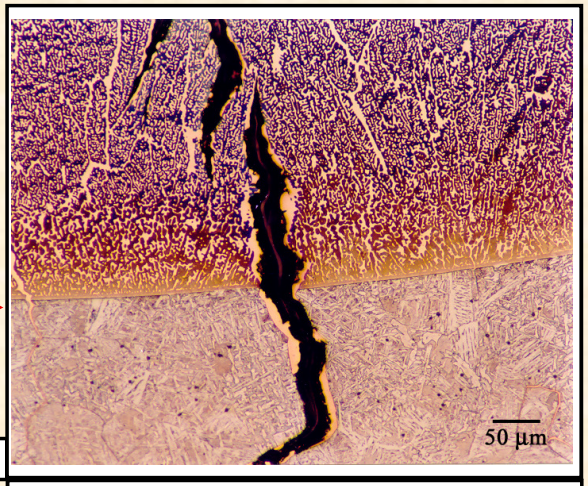

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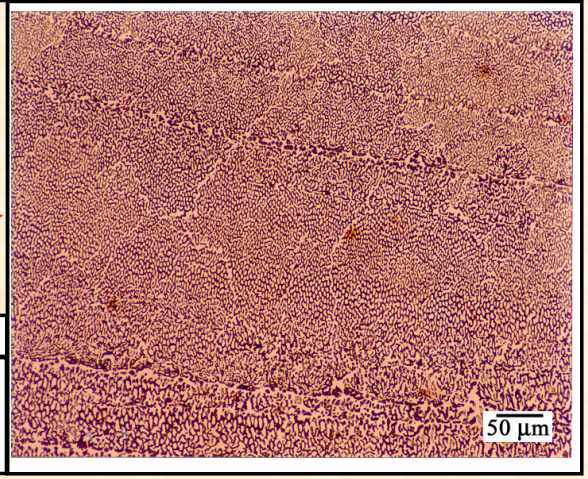
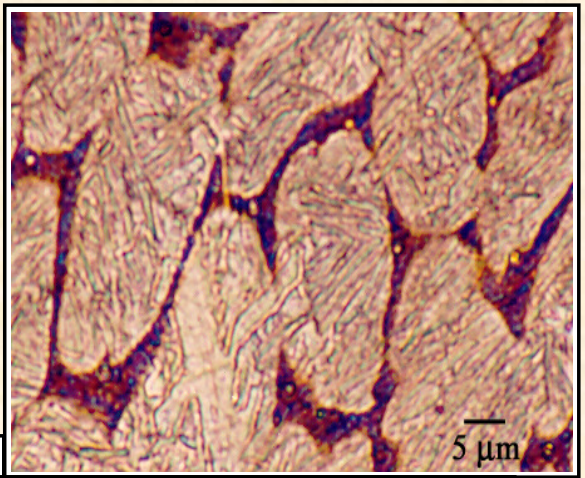


c

Figure 2: b) Steel – 49 wt% Cu; copper and cracking in fusion zone extended into heat affected zone along former austenite grain boundary c) Steel – 56 wt% Cu; no cracking. 200x magnification



d

Figure 2: d) Steel – 9.2 wt% Cu; reddish hue due to etching effect as Cu concentration increases in inter columnar space. Small cuprous colored spheres in inter columnar space confirmed as Cu by Electron Microprobe using Energy Dispersive Spectroscopy. 1100x magnification