

Development of a Cr-free Welding Consumable for Reduction of Cr Fume Emissions

by Jeffrey W. Sowards, Boian T. Alexandrov, Gerald S. Frankel and John C. Lippold, The Ohio State University

Introduction

Existing filler metals used to weld stainless steels such as E308-16, contain substantial levels of chromium and the fume generated by these electrodes during welding contains hexavalent chromium (Cr(VI)) compounds. Recent legislation has been imposed that drastically reduces the permissible exposure levels of hexavalent chromium to personnel working in the vicinity of welding operations. The following work is intended as a possible solution to reduce hexavalent chromium emissions in fume generated from shielded metal arc welding by replacing existing consumables with a Ni-Cu-based electrode. Several aspects of weldability are important to examine regarding the development of these electrodes since acceptable performance levels of welds must be maintained. Mechanical properties, resistance to weld cracking, and corrosion resistance are evaluated with respect to electrode development. The emission of fume and hexavalent chromium is also examined.

Procedure

GMAW and SMAW electrodes were tested. The GMAW electrode was a Ni-Cu-Pd alloy while the SMAW electrodes consisted of Ni209 core-electrode with Cu- and Pd-additions made to the flux coating. Single and double V-groove welds were made on AISI 304L plate with the electrodes. Mechanical testing was performed, including bend tests, tensile tests, and micro-hardness measurements. Hot-ductility testing was performed with a Gleeble® 3800 thermo-mechanical simulator to evaluate weld metal ductility signature. Polarization measurements were performed on weld metal samples to evaluate breakdown and repassivation potentials. Long term immersion tests were performed. Optical and scanning electron microscopy was used to evaluate weld metal microstructure and failure locations during weldability testing. Fume was collected and fume generation rates were measured with a bulk fume collection hood; XRD was performed on the bulk fume hood filters. An electrical low pressure aerosol impactor (ELPI) was used to collect fume and separate particles by size range. Chemical analysis measurements were performed on the fume and weld metal using XEDS. Solidification simulations were performed with Thermo-Calc software to examine the effect of varying dilution on the solidification temperature interval.

Results

Mechanical testing showed weld metal tensile strength of the Ni-Cu-based electrodes exceeded minimum values of E308-16 though ductility, measured by area reduction and sample elongation, was consistently lower. Bend tests passed AWS D1.6:1999/4.6.5 standards. Hot ductility testing revealed an average nil-strength temperature of approximately 1334°C for the deposited weld metal. Sulfur and Phosphorus segregated along fracture surfaces during hot-ductility tests. Microsegregation of Ti, Si, Mn, and Cu into interdendritic regions occurred upon solidification. Chemical analysis of microsegregation was in good correlation to predictions made with Thermo-Calc Scheil-Gulliver simulations. Simulations also showed that higher dilution levels of the weld metal by the 304L base material increased the solidification temperature range.

Conclusions

- Mechanical properties of welds made with Ni-Cu and Ni-Cu-Pd electrodes are comparable to electrodes currently used to join stainless steels, such as E308-16.
- Impurity-rich compounds were found along grain boundaries and may be detrimental to weldability if not properly controlled.
- Microsegregation of Ti, Si, Mn and Cu occurred along interdendritic regions during solidification.
- Simulations showed that the solidification temperature range increased as dilution of the base material was increased.
- Breakdown potentials were lower for Ni-Cu-Pd weld metal than AISI 304 though repassivation potentials much higher than the AISI 304.
- Fume generation rates were higher for the Ni-Cu-based electrodes when compared with measurements performed on E308-16 electrodes though Cr- and Mn-concentrations were reduced dramatically.