SHIELDING GAS COMPOSITION AND ELECTRODE GEOMETRY
INFLUENCE ON ARC PROPERTIES

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INTRODUCTION

Prior physical measurements of the gas tungsten arc (GTA) generally have been confined to steady-state temperature and composition measurements of an arc shielded by pure argon. However, shielding gas mixtures of argon and helium, or argon and hydrogen are commonly used to optimize fusion zone dimensions. The roles that helium and hydrogen play, and their interrelationship to tungsten electrode tip geometry in controlling fusion zone profile are not well understood.

Tungsten electrode tip geometry effects on fusion zone profile have been thoroughly studied using a pure argon shield and, more recently, interrelationships between helium or hydrogen content of the shield and electrode tip geometry have been reviewed. A fundamental knowledge of the effects of these variables on arc properties and an understanding of which arc properties dominate fusion zone profile will undoubtedly facilitate welding science.

II. EXPERIMENTAL METHODS

Plasma diagnostic techniques were used to measure the arc properties presented. A computer-controlled emission spectroscopy system comprised of an Optical Multichannel Analyzer (OMA) interfaced to a 0.3-m monochromator was used to make temperature and composition measurements.

Temperature measurements were made by a two-line method which relates the spectral intensity ratio of two lines to temperature according to

$$\frac{S_1(T)}{S_2(T)} = \frac{A_1 g_1 \lambda_1}{A_2 g_2 \lambda_2} \exp \left[ \frac{E_1 - E_2}{kT} \right]$$

(1)

where $S_{1,2}(T)$ = relative intensity

$A_{1,2}$ = transition probability

$g_{1,2}$ = statistical weighting factor

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Temperature distribution in the arc requires spectral intensity maps of the arc for both lines. Intensity as a function of a linear dimension across the arc, \( S(x) \), is measured and converted to a radial distribution, \( S(r) \), by the well-known Abel integral inversion.

Temperature distributions were determined for arcs shielded with pure argon, four argon-helium mixtures (25, 50, 75, and 90 volume percent helium, balance argon), and one argon-hydrogen mixture (five volume percent hydrogen). Each of these shielding gases or mixtures was used with two tungsten electrode tip geometries. Both geometries were truncated cones with a 0.125-mm (0.005-in.) diameter truncation and either a 30- or a 90-degree vertex angle. All arcs were sustained with a current of 150 amperes.

## III. RESULTS AND DISCUSSION

Arc temperatures as a function of both shielding gas composition and electrode vertex angle were measured as a function of location in the arc. Essential features of these results indicate:

1. The average diameter of the electrically conducting (ionized) portion of the arc expands approximately 55 percent when the shield is changed from pure argon to a mixture of 10 percent argon and 90 percent helium when using a 30-degree electrode. An expansion of 78 percent was measured for a 90-degree electrode using these gases. The nonconducting region (neutral atomic) exhibits a similar expansion.

2. A five percent hydrogen, balance argon mixture did not exhibit this expansion.

3. Sharp tungsten electrode tip geometries typified by a 30-degree vertex angle exhibited high axial temperatures that decreased rapidly with radius when pure argon was used for a shield. However, as helium content increased in the shield, temperature decrease with radius became more gradual and axial temperatures decreased significantly.

4. Blunt electrode tip geometries, typified by a 90-degree vertex angle, exhibited less radical temperature gradients than obtained for sharp electrode tip geometries, regardless of the shielding gas composition.

These results contradict several common but undocumented assumptions. First, the high ionization potential of helium does not cause a monotonic increase in temperature as its content in the shielding gas is increased. Peak temperatures change little from those measured in pure argon. However, they are present over a much wider region of the arc, corroborating visual observations of arc
broadening when helium is added. Thermophysical properties of the shielding gas such as thermal conductivity and heat capacity appear to be much more important than ionization potential. Helium and hydrogen (at typical anode temperatures) have order of magnitude higher thermal conductivity and heat capacity than argon. These gases thus are much more efficient than argon for transporting heat to the weld.

Electrode tip geometry has a somewhat restricted influence on arc temperature distribution. In pure argon, an electrode with a 30-degree vertex angle produces more of a line heat source—high axial temperatures which decrease rapidly with radius, especially near the cathode tip. A 90-degree vertex angle produces a more evenly distributed heat source. When a significant amount of a high thermal conductivity gas is used in the shield, the arc behaves as a well distributed heat source regardless of the electrode vertex angle. These results agree with, and are predicted by, Shaw's model. However, differences due to electrode geometry seem to diminish near the anode surface. Accuracy of the data near the anode may be suspect since verification of the existence of local thermodynamic equilibrium is difficult in this region.

IV. CONCLUSIONS

Addition of significant amounts of helium to argon shielding gas causes a gas tungsten arc to be a broader, more isothermal, heat source than an arc shielded with pure argon. Blunt electrode tip geometries, compared to sharp ones, tend to cause flatter temperature distributions in pure argon but have temperature distributions similar to sharp electrode tips in moderate to high helium environments.

Thermophysical properties of the shielding gas constituents appear to have greater influence on fusion zone profile than does arc temperature. However, refined heat transfer models of the future will require arc temperature distributions as a function of essential welding variables since these models will use properties which are strongly temperature dependent.