Temperature Measurements in Gas Tungsten Arcs

Results of temperature tests disagree with some previous studies

BY G. N. HADDAD AND A. J. D. FARMER

ABSTRACT. Properties of gas tungsten arc columns in air are compared with those of free-burning arcs enclosed in a chamber. Temperature profiles are presented and the effects of arc current, torch to work distance, gas flow rate, nozzle diameter and electrode extension are discussed.

The results are consistent with previous measurements on free-burning arcs in a static gas environment and in disagreement with some previous measurements of welding arcs.

Introduction

In a previous paper (Ref. 1) we presented spectroscopic temperature measurements for electric arcs burning in a static atmosphere confined in a chamber (free-burning arcs). The present paper utilizes the methods detailed previously to derive temperatures in the column of arcs burning between a GTAW torch and a flat-plate, water-cooled anode in the open air.

We have varied the arc current, the gas flow rate, the electrode-work distance, the electrode extension and the size of the gas shielding nozzles. The consequences of these changes are assessed in terms of their effect on the measured arc temperature distributions.

Experimental Details

The spectroscopic apparatus and method are described in detail in Ref. 1. The experiments were performed using the apparatus shown in Fig. 1. Light from the arc is imaged onto the entrance slit of a monochromator at a magnification of 5:1. The acceptance cone of the monochromator is limited to f/100 to provide adequate spatial resolution at the arc. The arc is translated so that its image traverses the entrance slit of the monochromator in a line perpendicular to the arc axis. The dimensions of the entrance slit are 100μm by 250μm, corresponding to an observation area at the arc of 20μm by 50μm, with the long dimension parallel to the arc axis. The arc can also be moved in the vertical direction to a selected position for the lateral scan. The signal from the photomultiplier at the exit

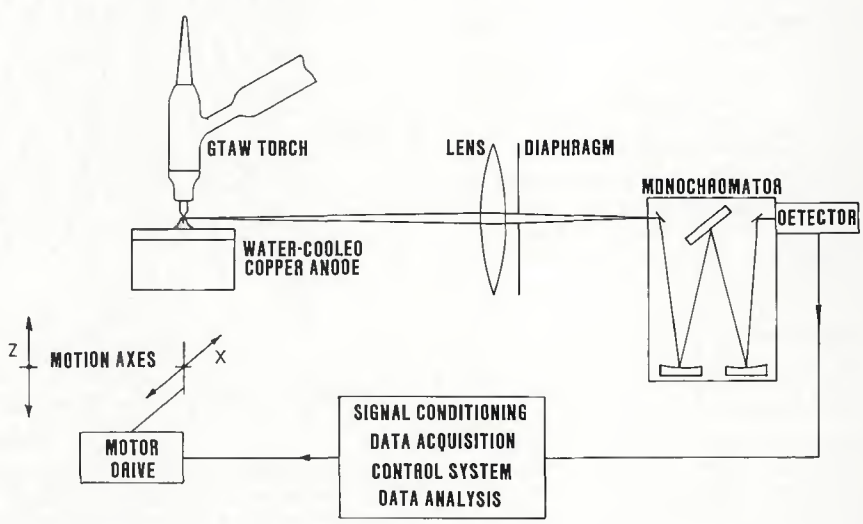

Fig. 1—Schematic diagram of experimental apparatus

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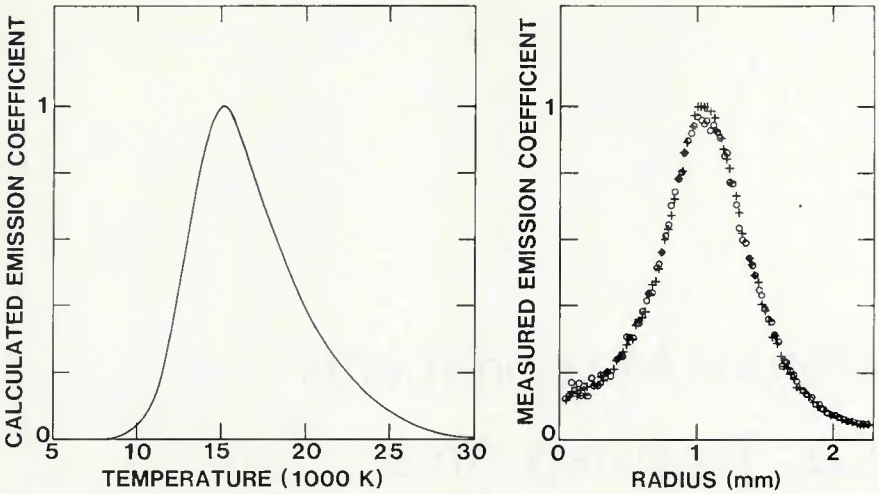

Fig. 2 – Calculated emission coefficients as a function of temperature and measured radial variation of the relative emission coefficient. Both curves are for the ArI 696.5 nm line and have been normalized to their peak values. The measured data are for a 200 A arc at an axial position 0.5 mm from the cathode. The two different symbols represent each half of the distribution

slit of the monochromator is recorded every 25 μm of travel and stored in a data acquisition computer.

In the work reported here, we have removed the water-cooled chamber described in Ref. 1 and used a GTAW torch (CNI Model 18) mounted above a flat water-cooled copper plate. Argon specified as 99.999% pure is supplied to the torch. The electrode is a 3.2 mm (⅛ in.) diameter, 2% thoriated tungsten rod ground to a conical tip of 60 deg included angle. We have used arc currents of 100 A and 200 A, nozzle diameters of 6 and 10 mm (0.24 and 0.39 in.), gas flow rates of 10 and 30 L/min (4.7 and 14.2 ft^3/h), electrode extension distances (measured from the face of the ceramic nozzle) of 0, 2 and 5 mm (0.00, 0.08 and 0.20 in.) and arc lengths of 2 and 5 mm (0.08 and 0.20 in.).

Chordal intensity distributions are recorded at a number of axial positions for the ArI 696.5 nm line with the monochromator slits adjusted so that the total width of the line is accepted. In addition, corresponding distributions are measured for the continuum radiation in an adjacent region which is free of spectral lines. The continuum measurement is subtracted from the line measurement to yield the chordal distribution of the total (frequency-integrated) line intensity. This distribution is then converted by means of an Abel inversion to the radial variation of the relative emission coefficient. The uncertainty in the relative emission coefficient derived in this way is ~2%.

The assumption of local thermodynamic equilibrium (LTE) is used to derive radial temperature distributions from the measured relative emission coefficients. According to this assumption, the absolute emission coefficient in any spectral line depends only on atomic constants and the temperature. For the ArI 696.5 nm line, the atomic constants are well known and it is, therefore, a straightforward procedure to evaluate the variation of the absolute emission coefficient as a function of temperature. The calculated curve passes through a maximum value at a temperature T = 15,200 K and, provided the arc temperature exceeds this value, the measured radial variation of the relative emission coefficient will exhibit a corresponding off-axis maximum. Figure 2 shows the calculated emission coefficient as a function of temperature and the measured radial variation of the relative emission coefficient for a 200 A arc at an axial position 0.5 mm (0.02 in.) from the cathode. The curves have been normalized at their peak values and the correspondence of the maxima implies a temperature of 15,200 K at a radius of approximately 1 mm (0.04 in.). Using this as a calibration point and assigning the higher temperatures to regions near the arc core, the calculated curve can then be used to derive a radial temperature distribution from the measured radial variation of the relative emission coefficient.

Results

In Fig. 3 we compare the temperature profiles measured in a GTAW torch burning to a water-cooled anode with the profiles of a free-burning arc in a chamber. In both cases we used a current of 200 A and an electrode-to-work distance of 5 mm (0.20 in.). For the GTAW torch the gas flow rate was 10 L/min (4.7 ft^3/h) through a 10 mm (0.39 in.) internal diameter nozzle, and the electrode extension was 2 mm (0.08 in.).

The differences between the two profiles are generally small (<500 K). The largest differences occur in the cooler, outer regions of the arc. The chamber arc shows slightly higher temperatures than the GTAW torch. It should be observed that these differences are of the order of the day to day repeatability in the measurements of temperature. During the course of this series of experiments we have found that the effect of the elec-

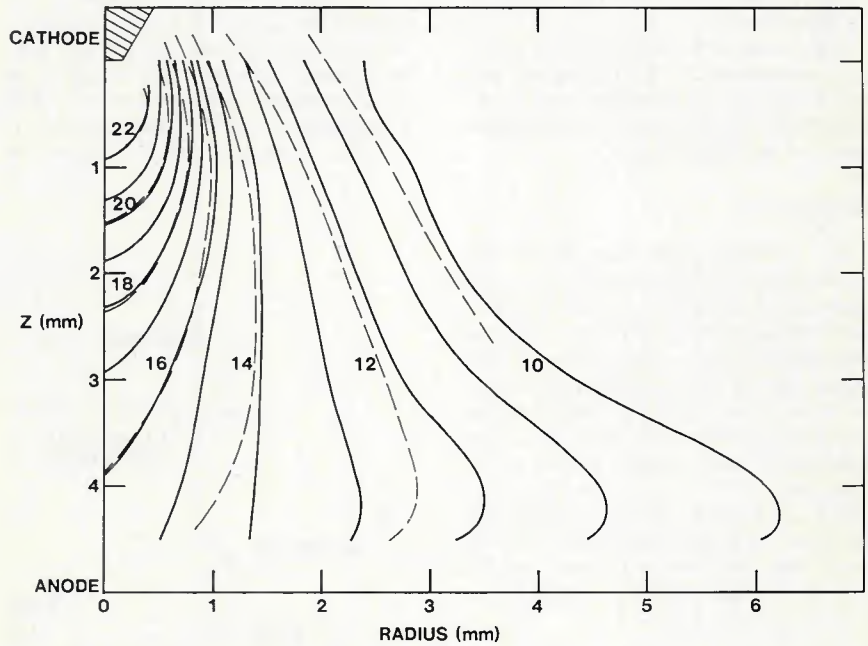

Fig. 3 – Temperature profiles for a GTAW arc. Arc current 200 A, arc length 5 mm, gas flow 10 L/min, electrode extension 2 mm, nozzle diameter 10 mm. Dashed lines show results of measurements in an enclosed chamber (see text). The temperature contours are labelled in units of 1000 K

trode tip shape is quite important in determining the temperature profile—particularly where we are looking for small differences between similar arcs. We have therefore taken care to maintain the sharpness of the tip of the 60 deg conical electrode in the torch to ensure that the results are directly comparable with the measurements in the chamber. (In the series of previous measurements (Ref. 1) in the chamber, the purity of the argon was such that a sharp tip could be maintained throughout a long series of experiments.)

Figure 4 shows the measured temperature profile for a 100 A arc with all other conditions maintained as above. The temperatures in the core of the arc are lower and the diameter of the arc is substantially smaller when compared to the 200 A results. This is in agreement with the results presented in Ref. 1. Once again, we have compared the results with those measured in the chamber, and the differences are less than 500° K at all points in the arc. Figure 5 shows a measured profile for a 200 A, 2 mm (0.08 in.) long arc with a flow rate of 10 L/min (4.7 ft^3/h) and an extension distance of 2 mm (0.08 in.). Comparison of Fig. 5 with Fig. 3 shows that the axial temperatures are somewhat higher and the arc diameter is somewhat smaller for the shorter arc. We have recently made measurements of a 2 mm (0.08 in.) arc burning in a chamber, and these results are also presented in Fig. 5. Once again, the differences between the torch and chamber measurements are small.

Variations of flow rate from 10 to 30 L/min (4.7–14.2 ft^3/h) have a minimal effect on the measured temperature profiles. The profile obtained with the lower flow rate shows a slightly hotter arc core (≃300° K), and minor differences are also evident in the outer layers.

Variations of the electrode extension distance over the range from 0 to 5 mm (0.00–0.20 in.) also have little effect. The largest extension (5 mm) (0.20 in.) produced arcs with core temperatures as much as 1000° K lower than those of arcs produced using extension distances of 0 and 2 mm (0.00 and 0.08 in.).

The smaller diameter nozzle (6 mm) (0.24 in.) consistently produced on-axis temperatures of the order of 500° K higher than those from the larger diameter nozzle (10 mm) (0.39 in.).

Recent measurements by Key, *et al.* (Ref. 2), made under similar conditions to those underlying our results in Fig. 4 indicate peak temperatures of only about 12,000° K. The results of Key, *et al.*, are in agreement with some earlier work (Refs. 3, 4, 5). In contrast, the results of Kobayashi and Suga (Ref. 6) and other groups (Refs. 7, 8) indicate peak temperatures in close agreement with our results.

Reports of GTAW arc temperatures therefore fall into two groups, one quoting substantially lower temperatures than the other. The techniques used by the lower temperature group include probes, ArII line ratios and Thomson scattering. The higher temperature group uses the "off-axis maximum" technique used here, and ArII/ArI line ratios. The difference between the two groups may be associated with the difficulty of defining a unique temperature in this type of plasma. There is evidence that the criteria for the validity of LTE are not satisfied in free-burning arcs (Ref. 9), and this may lead to ambiguous interpretations of measured spectroscopic data.

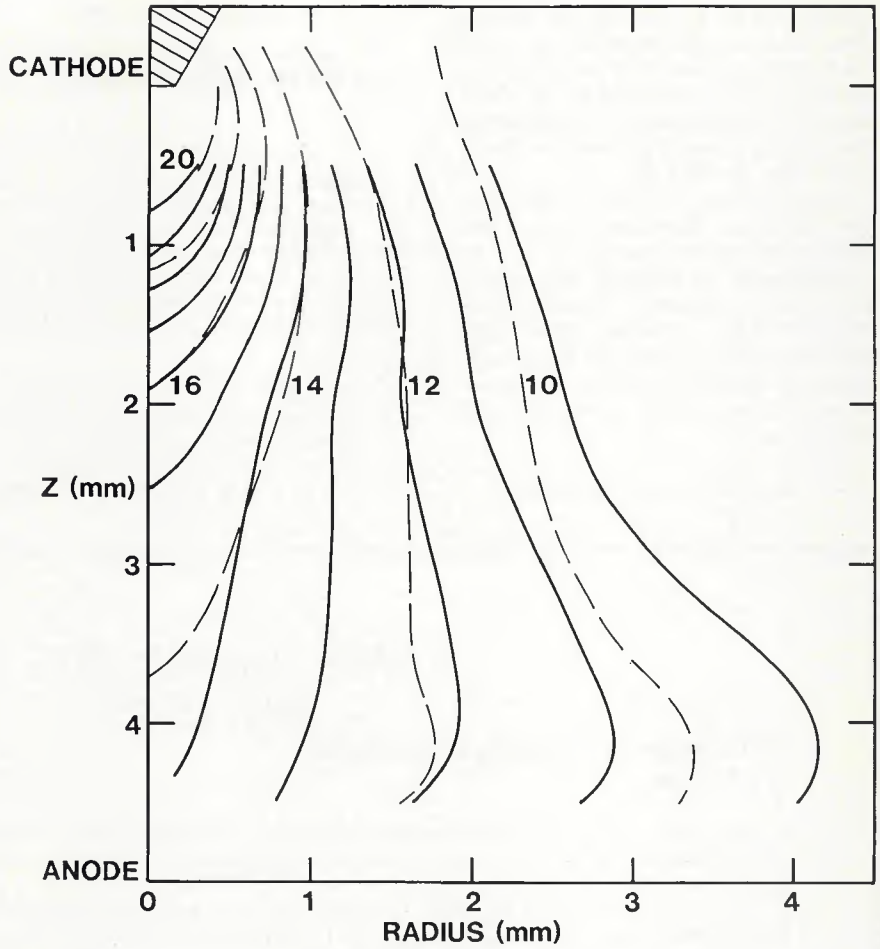

Fig. 4 — Temperature profile for a 100 A arc. Other conditions as in Fig. 3

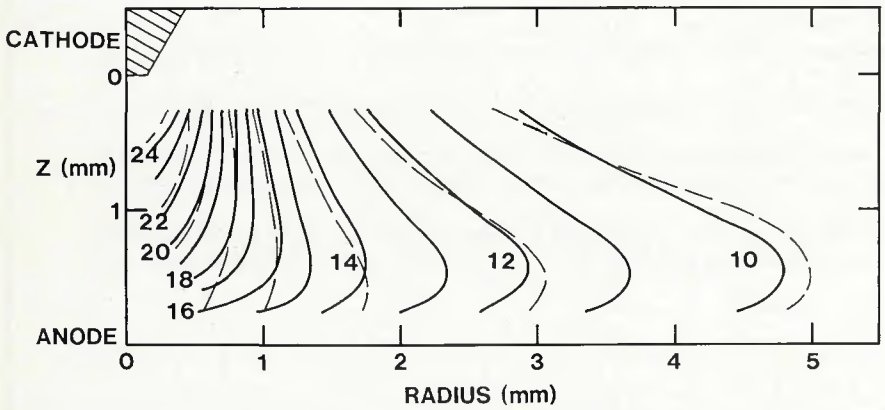

Fig. 5 — Temperature profile for a 200 A, 2 mm long GTAW arc. Other conditions as in Fig. 3

Conclusions

Our experiment shows that the temperature distribution of an arc burning in an enclosed atmosphere of pure argon differs by only a few hundred degrees

from that of an arc burning in a flowing shield of argon surrounded by air, under the conditions used in normal GTAW. Clearly the structure of the GTA column burning in air is essentially unaffected by the presence of the reactive environment outside the shielding gas.

The effects of variations in gas flow rate, electrode extension distance and nozzle diameter are minimal.

The present results agree satisfactorily with some previous measurements. However, there is another class of measurements which yield much lower temperatures, and the origin of the differences with these measurements remains unexplained.

Acknowledgment

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By J. R. Payne

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