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IMPACT OF COPPER VAPOUR CONTAMINATION ON ARGON ARCS

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A fast, accurate and comprehensive emission spectroscopic set-up has been employed to study the impact of copper vapour on an Ar-Cu mixture plasma. Temperature profiles in the arc have been determined in the absence of Cu vapour and then in its presence, using the absolute line intensity method for an Ar spectral line; these profiles have been compared with temperature profiles derived from relative intensities of Cu I lines. Temperature profiles derived from relative intensity of Cu I lines have been used to calculate the radial density distribution of copper atoms in the arc. The following observations have been made from the resulting atomic number densities: (i) the copper vapour concentrates in the fringes of the arc, with atomic number densities up to 8.6×10^{11} (cm^{-3}); and (ii) Cu atomic number densities in the core of the arc are small.

Key words: Copper vapour contamination, Argon arcs, Emission spectroscopy.

Introduction

An insight into the effects of metal vapour on the characteristics of welding arc can help improve the welding process itself. In order to enhance the existing understanding of the impact of metal vapour on argon welding arcs, an Ar-Cu mixture plasma was studied with the help of a fast, accurate and comprehensive optical emission spectroscopic set-up. Assumed to be in a LTE condition, the studied arc parameters were 1 atm, 200 Å, 13 mm electrode gap spacing, thoriated-tungston cathode tip and a solid Cu anode. In the described experimental set-up, copper vapour in the argon arc resulted from vapourization of the molten metal pool formed at the copper anode.

Experimental

Emission spectroscopic set-up. The fully-automated emission spectroscopic set-up, employed for the subject study, has been reported earlier [1]. The set-up is capable of simultaneously recording the side-on intensity of a spectral line, its neighbouring continuum and the intensity distribution of a spectral band (emanating from molecular spectra or atomic line shape) of approximately 110 Å. The entire data acquisition process, including XY electro-optical scanning of the discharge, scanning of the spectrograph spectral range, wavelength selection on the monochromator and the photo-diode array exposure time settings, is pre-programmable. A radial scan of the discharge, monitoring above data at 50 spatial points, is completed in 4 sec. and a raster scan of the arc (10 radial scans, each comprising 50 spatial points) simulataneously monitoring all the above mentioned data, is completed in 40 sec.

Procedure. The experimental study was performed in the following sequence. First, the 6965 Å Ar I line was recorded by executing a raster scan (16 radial scans, 200 data points each) of the Ar arc. A three dimensional plot of one of the recorded radial scans (4 mm above the anode). Second, the cooling water flow to the chilled Cu anode was reduced from 10 gal/min. to 1 gal/min. and within 5 min. the copper melted and its vapour was seen surrounding the arc. Third, another raster scan was performed with the same scan parameters as before. This time, the 6965 Å Ar I line was recorded with the monochromator and Cu I lines 5105Å (upper energy level of 3.817 eV) and 5153 Å (upper energy level of 6.191 eV) were simultaneously recorded with the spectrograph-OMA combination. The data acquisition process in the third step was completed in 4.25 min. In all, 6 similar raster scans were recorded consecutively. A three dimensional plot of the recorded radial scans (4 mm above the molten anode pool) of the subject copper lines is illustrated in Fig. 1.

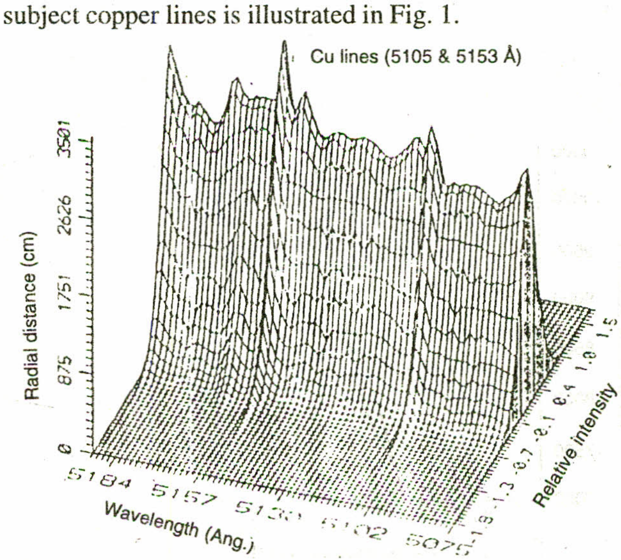

Fig. 1. Radial scan of Cu I lines 5105 Å and 5153 Å 4mm above the anode in an Ar-Cu mixture plasma at 1 atm., 200 A and 13mm electrode gap.

Results and Discussion

Using the above mentioned data and the Abel inversion procedure, radial temperature profiles were derived (at 6 axial locations 2, 4, 6, 8, 10 and 12 mm above the anode) from the following three measurements: (1) absolute intensity of 6965 Å Ar I line in the absence of Cu vapour, (2) absolute intensity of 6965 Å Ar I line in the presence of Cu vapour and (3) relative intensity of Cu I lines at 5105 and 5153 Å. The resulting temperature profiles at 3 axial locations 2, 6 and 10 mm above the anode are plotted in Figs. 2-5, respectively. Each of the curves 1 and 2 in these figures shows the temperature profiles as derived from absolute line intensity measurements of the 6965 Å line without and with Cu contamination, respectively. A comparison of these two measurements shows that the plasma cools down due to Cu vapour contamination. The decrease in temperature is more pronounced near the anode, e.g., Fig. 2 indicates a decrease of 800 K, 2 mm above the anode. Decrease in temperature is less pronounced at axial distances away from the anode.

The observation of decrease in temperature with metal vapour contamination is widely supported by other researchers. Essoltani *et al.* [2] pointed out that metal vapours have low excitation and ionization potential, and numerous spectral lines as compared to argon; consequently, the radiation, especially at low temperatures, from mixture plasmas is mostly due to metal vapour. Cram [3] also mentioned that the metal vapour is a much more effective radiator than argon at the same temperature and pressure because most bound energy levels of argon atoms and ions are located far above the ground state, so the atoms and ions are difficult to excite; by contrast, metal atoms and ions have many low-lying energy levels

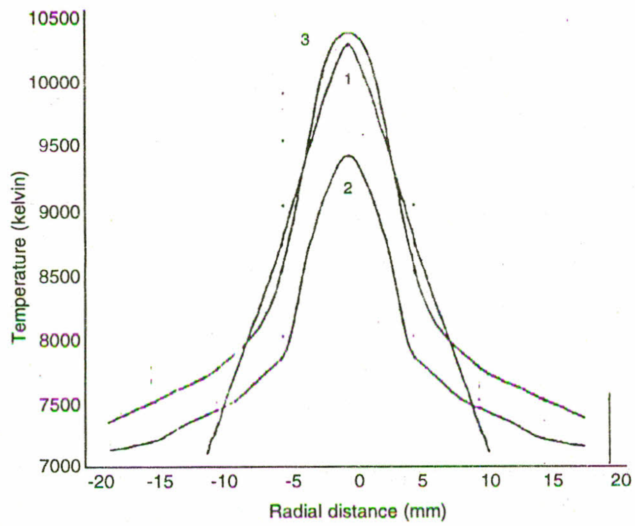

Fig. 2. Temperature profiles 2mm above the anode: (1) Ar I line 6965 Å, solid anode; (2) Ar I line 6965 Å, molten anode; (3) Cu I lines 5105 Å and 5153 Å, molten anode.

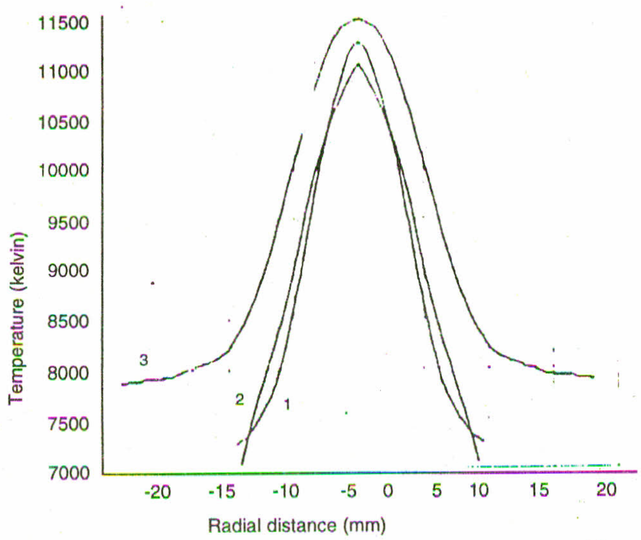

Fig. 3. Temperature profiles similar to those in Fig. 2, but measured 6mm above the anode.

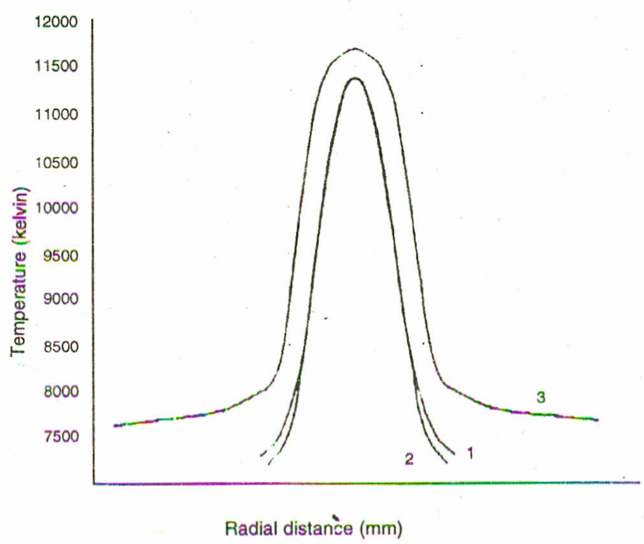

Fig. 4. Temperature profiles similar to those in Fig. 2, but measured 10mm above the anode.

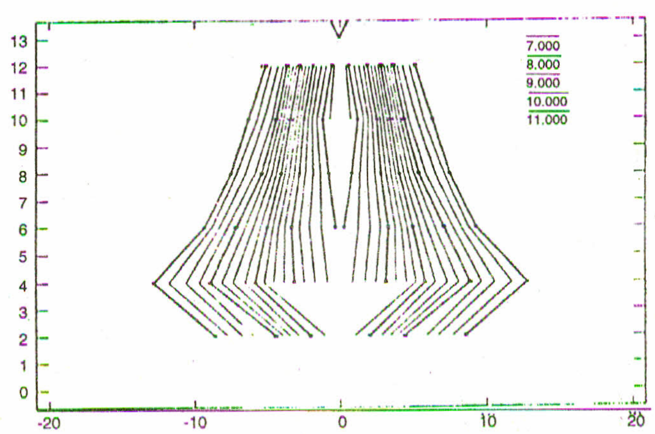

Fig. 5. Isotherms derived from absolute intensity of Ar I line 6965 Å, for an Ar-Cu mixture plasma at 1 atm., 200 A and 13mm electrode gap.

which are easily excited, giving rise to a rich line spectrum. The above references imply that the copper vapour contamination in argon arc leads to additional radiation, energy loss and cool down of the plasma; additionally copper vapour is also present in the arc fringes where temperatures are low. Proulx *et al.* [4] showed that the presence of even small concentrations of metal vapours can be responsible for a major increase of the radiative energy loss and consequently, its local cooling. Etemadi and Pfender [5] also reported a drop in temperature in the argon arc core due to presence of copper vapour. With the help of modeling studies, Mostaghimi and Pfender [6] found that even small traces of metal vapour may have a strong effect on the properties and behaviour of the plasma. They considered model system in which an argon plasma at atmospheric pressure is contaminated by small amounts of copper vapour. They found that the electrical conductivity increased by more than an order of magnitude in the presence of metal vapour; for an argon plasma contaminated with 1% copper vapour, the electrical conductivity at 5,000 K increased by a factor of 28. Increase in electrical conductivity reduces the resistive heating of the plasma, thereby leading to a decrease in temperature. By increasing the metal particle feed rate from 0 to 20 g/min., they found that peak temperature along the axis of the plasma can decrease from 9,500 to 3,500 K. Cheminat *et al.* [7] also found that the presence of copper vapour in a stabilized argon arc at one atmosphere leads to a large increase in electrical conductivity and a decrease in temperature. Farmer *et al.* [8], however, did not report any substantial change in the temperature distribution due to metal vapour contamination in a 200 ampere argon arc.

For comparison with the above radial temperature profiles derived from the 6965 Å Ar I line, each curve 3 in Figs. 2-4 show the temperature profile as derived from relative line intensity of Cu I lines 5105 and 5153 Å. Relative intensities of copper lines have not so far been employed for temperature determination in mixture plasmas. Hill [9], however, discussed the possibility of employing Cu I lines 5153 Å (6.2 eV) and 5700 Å (3.82 eV) for temperature measurements, he presented theoretical calculations of relative intensities as a function of temperature in the range 5,000-10,000 K. Upper energy levels of these two lines differ by 2.38 eV and, in this respect, are suitable for relative line intensity measurements: these lines, however, are located 547 Å apart and it will generally not be possible to practically record them simultaneously on an OMA system; such a limitation could be due to a large dispersion (desirable for good resolution) of the spectrograph and a limited width of the photodiode array. Perhaps, a more certain means of simultaneously recording the above two lines is the use of two spectrometers, as in the case of the current emission spectroscopic set-up. On the other hand, the 5105 and 5153 Å Cu I lines, recorded by the current set-up, not only have an upper energy level difference of 2.374 eV but are also spaced only 48 Å apart, and can easily be measured with the OMA.

The relative line intensity method is particularly useful for mixture plasma studies, in which the copper vapour concentrates in the arc fringes where the argon lines are very weak; this method, possibly in conjunction with absolute line-intensity method, enables temperature measurement every where in the arc including the fringes and beyond.

Next three temperature profiles, 4 mm above the anode and obtained from relative line intensities of three different Cu I line pairs, were compared. The following results were obtained in the radial centre of the arc: the line pair at 5153 and 5782 Å showed a temperature of 9,444 K; the line pair at 5105 and 5218 Å showed a tempearature of 18,442 K; and the line pair at 5105 and 5153 Å showed a temperature of 11,400 K. Such wide differences in three temperature profiles resulted because the first two line-pairs had not been simultaneously recorded. This experiment, thus, highlights the significance of simultaneous measurement [10] of all lines employed for temperature derivation by relative intensity method.

Figure 5 shows isothermal plots obtained from absolute line intensity of 6965 Å Ar I line in the Ar-Cu mixture plasma. Figure 6 shows a similar plot obtained from simultaneous relative line intensity measurements of Cu I lines 5105 and 5153 Å. From the above mentioned figures, it is evident that the copper vapour is present in the arc fringes and beyond. The maximum radius of the arc without copper contamination (Fig. 5) is at 4 mm above the anode and has a radial width of about 12 mm; however, with copper contamination (Fig. 6) this width increases to about 18 mm.

Cu vapour contents in Ar-Cu mixture plasmas, however, fluctuate at short intervals and therefore, data averaging of several radial scans can improve the accuracy of results.

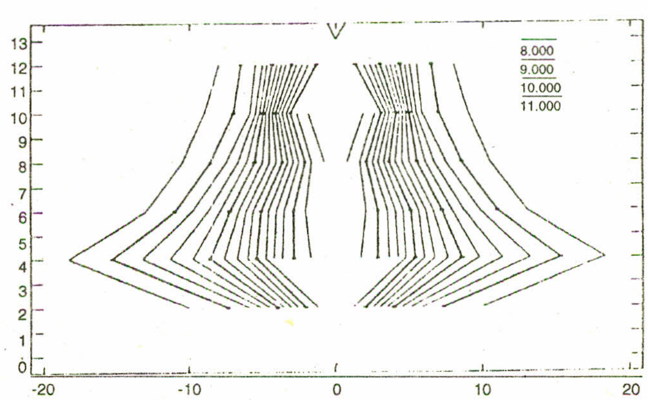

Fig. 6. Isotherms derived from relative intensity of Cu I lines 5105 and 5153 Å in an Ar-Cu mixture plasma at 1 atm., 200 A and 13mm electrode spacing.

Considering that 6 similar raster scans had been consecutively recorded and the XY scanners, employed in the set-up, have high repeatability, data averaging was performed for obtaining the side-on intensity profiles, the emission coefficient profiles and the atomic density profiles. The resulting side-on intensity profiles of 5105 Å Cu I line are shown in Fig. 7. The absolute emission coefficient profiles of Cu I line 5105 Å, at six above mentioned axial locations are shown in Fig. 8. These profiles, in combination with radial temperature profiles (including curve No. 3 in each of Figs. 2-4) derived from relative line intensity of 5105 and 5153 Å Cu I lines, were used to calculate the radial distribution of atom number densities of copper; for this purpose, the required partition functions for Cu I, were taken from Drawin [11]. The resulting atomic number density profiles for Cu are shown in Fig. 9.

The following observations are made from the resulting atomic number densities: (i) the copper vapour concentrates in the fringes of the arc, with atomic number densities up to 8.6 x 10^{11} (cm^{-3}) and (ii) Cu atomic number densities in the core of the arc are small. These results are in general agreement with Etemadi and Pfender [5].

Lastly, Fig. 10 shows a picture of an argon arc with Cu vapour contamination. As observed by Etemadi and Pfender [5], the copper contaminated plasma consists of two distinct

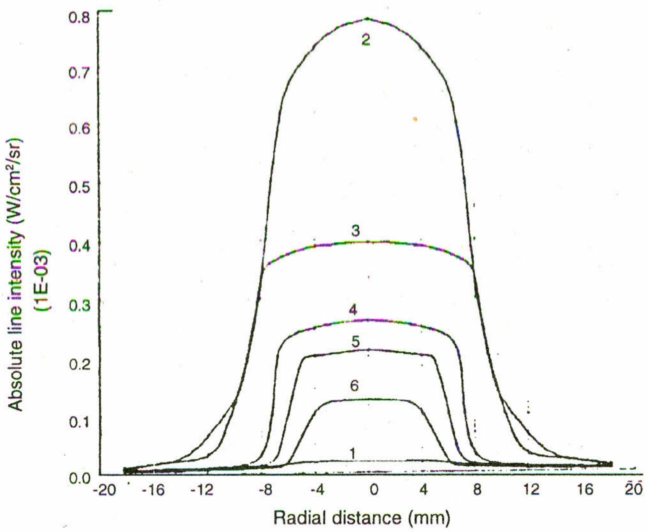

Fig. 7. Side-on intensity profiles of Cu I line 5105 Å, averaged over 6 radial scans at following distances above anode: (i) 2mm; (ii) 4mm; (iii) 6 mm; (iv) 8mm; (v) 10mm; (vi) 12mm.

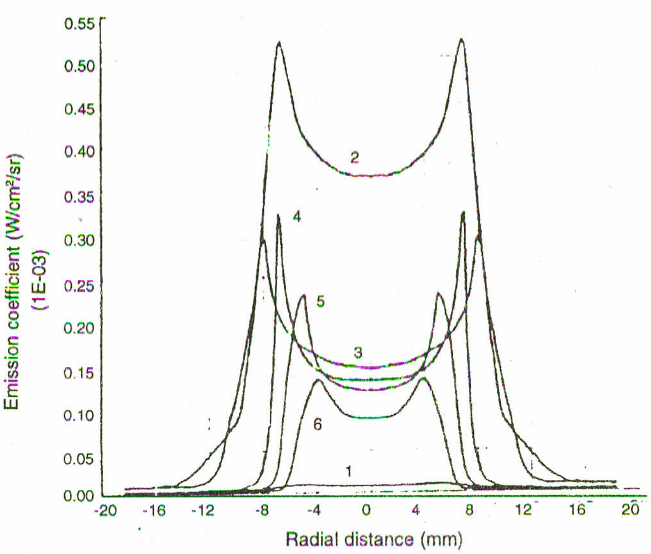

Fig. 8. Emission coefficient profiles of Cu I line 5105 Å, averaged over 6 radial scans, in a 1 atm., 200 A arc with 13mm electrode spacing, at following distances from the anode: (i) 2mm; (ii) 4mm; (iii) 6mm; (iv) 8mm; (v) 10 mm; (vi) 12 mm.

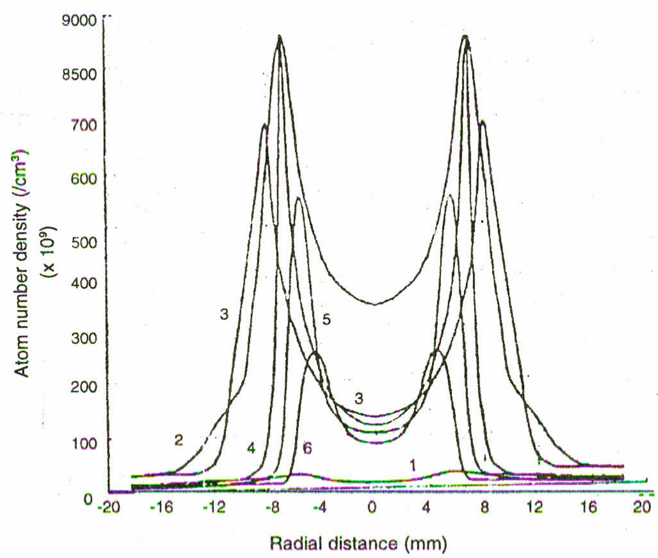

Fig. 9. Radial distribution of atomic number densities of copper, averaged over 6 radial scans, in a 1 atm., 200 A arc with 13mm electrode spacing, at following distances from the anode: (i) 2mm; (ii) 4mm; (iii) 6mm; (iv) 8mm; (v) 10 mm; (vi) 12 mm.

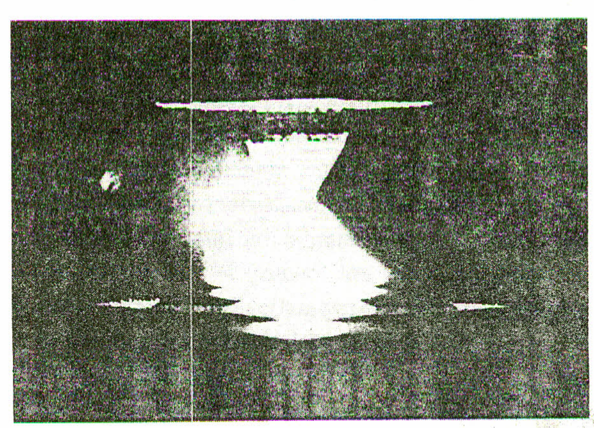

Fig. 10. Picture of an argon arc with Cu vapour contamination.

areas, (i) a highly luminous core area and a (ii) surrounding intense greenish region representing copper vapour outside the arc fringes.

Conclusion

Several useful conclusions can be drawn from the above mentioned results: (i) the plasma cools down due to Cu vapour contamination; (ii) the decrease in temperature is more pronounced near the anode and less pronounced at axial distances further from the anode; (iii) Cu vapour concentrates in the arc fringes where temperatures are low and Ar lines are very weak; (iv) the atomic number density of Cu vapour in the arc fringes is upto 8.6 x 10^{11} (cm^{-3}); (v) Cu atomic number densities in the core of the arc are small; (vi) the relative line intensity method, employing metal vapour lines, is particularly useful for mixture plasma studies; (vii) Cu I lines 5105 and 5153 Å form a suitable pair for relative line intensity measurements; (viii) simultaneous measurements of Ar and Cu lines enable calculation of temperature and atomic number density everywhere in the arc and its fringes and (ix) since mixture plasmas fluctuate at short intervals, data average using several consecutive scan can yield more accurate results.

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