Fume Generation Mechanism in Wire Arc Spraying

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ABSTRACT Fume generation has been investigated using a laser strobe high speed video system with a line filter centered at the wavelength of aluminum vapor emission line, and has been quantified with computerized image processing of the images. The images indicate that the fumes are generated mainly at the cathode wire tip because of the high current density at this location. The control of fume generation will be most effective if the heat input to the cathode wire can be controlled.

1. INTRODUCTION

Wire Arc spraying is one of the most economical thermal plasma coating processes. Wire arc spraying has been used widely to coat engineering structures to protect them against corrosion and wear. The material to be deposited is introduced into the arc in the form of wires serving as consumable arc electrodes. A cold gas jet across the arc atomizes and drives the molten droplets from the electrode tips. One disadvantage of wire arc spraying is the generation of substantial amounts of metal fumes which pose a evaporation hazard to human health. The effects of the operational parameters on the fume generation has been investigated [1-4]. The control of fume generation at the source by modification of the process would lead to a wider acceptance of wire arc spraying. The purpose of this study is to clarify the mechanisms of fume generation in wire arc spraying to identify means for its control.

2. EXPERIMENTAL PROCEDUERS

Fume generation has been investigated using a laser strobe high speed video system with a line filter centered at 313 nm where aluminum vapor has strong emission line. Only the aluminum vapor images can be recorded by use of the filter, because it has been assumed that the fumes originate from nucleation of evaporated metal. The experimental set-up is shown in Fig. 1. Aluminum has been used as the wire, and air or nitrogen has been used as the atomizing gas. Images of the luminous arc, the melting behavior of the wire electrodes and the the droplet formation have been recorded without the filter. Fume generation has been quantified with computerized image processing of the video images. Compared to conventional measurements of fume generation using sampling methods [1-4], our new method based on fume visualization will yield more accurate values of the total quantity of the generated fumes and will show the locations of the dominant generation.

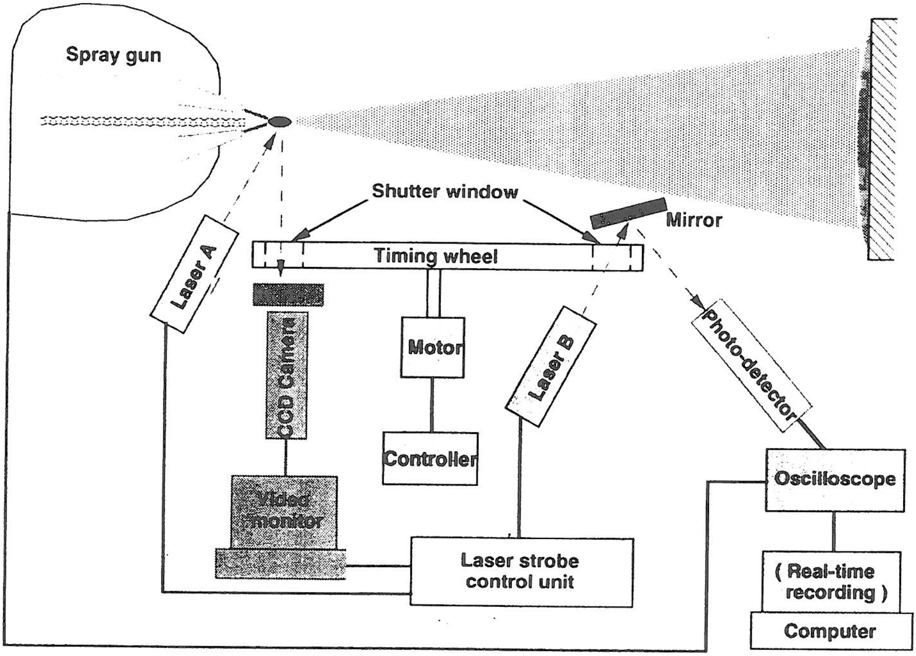


Fig. 1 Experimental set-up

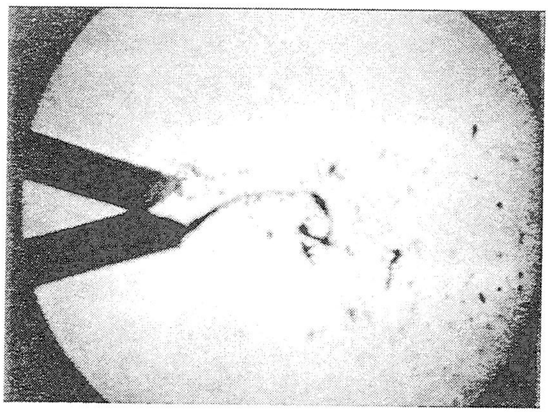


Fig. 2 High speed image of droplet formation

Wire arc spraying has been operated with atomizing gas pressures from 276 kPa to 414 kPa, with arc currents from 100 A to 200 A, and with the arc voltage at 34 V. A converging-diverging (c-d) nozzle was used as well as a conventional straight bore nozzle for producing a high velocity atomizing gas stream. The conventional straight bore nozzle produces expansion and strong diamond shocks at the exit of the nozzle resulting in a non-uniform, highly decelerated jet in the arc zone. The c-d nozzle produces a properly expanded supersonic flow, therefore more consistently atomized particles can be obtained. The nozzle throat-to-exit area ratio is matched for a Mach number of 1.4.

3. RESULTS AND DISCUSSION

An arc image of wire tips during spraying is shown in Fig. 2. The wire tips and the molten droplets are illuminated by a laser, and are photographed with a high speed CCD camera with 100 ns shutter speed. Asymmetric melting behavior of the cathode (top wire) and the anode (bottom wire) is shown. The cathode melts fast due to more constricted arc attachment compared to more diffuse arc attachment at the anode. The anode melts slowly, resulting in elongated relatively large droplets.

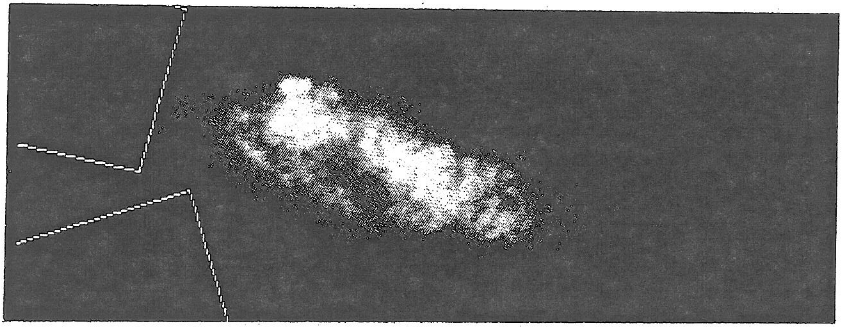
Images of aluminum fumes from wire tips are presented in Fig. 3. These images have been recorded with the line filter centered at 313 nm in front of the camera. Fumes are generated from the cathode as shown in Fig. 3(a), from both electrodes in Fig. 3(b), or from the the anode in Fig. 3(c). The approximate position of the electrodes are drawn in these figures because the electrodes are not recorded when the filter is used. These figures indicate that the fumes usually are generated directly at the wire tips.

Effects of the arc current on fume generation with a standard nozzle and with a c-d nozzle are shown in Figs. 4 and 5, respectively. High current results in the large fume generation due to two factors: high current leads to higher temperatures at the wire tips, and to higher feeding rates of the wire. The fume generation is expected to be mainly attributed to the metal evaporation due to the superheating at the wire tips. As also shown in this figure, the fume generation with air as the atomizing gas is larger than that with nitrogen. This result indicates that oxidation enhances the aluminum evaporation resulting in enhanced fume generation. The temperatures at the wire tips increase due to the exothermic reaction of aluminum oxidation.

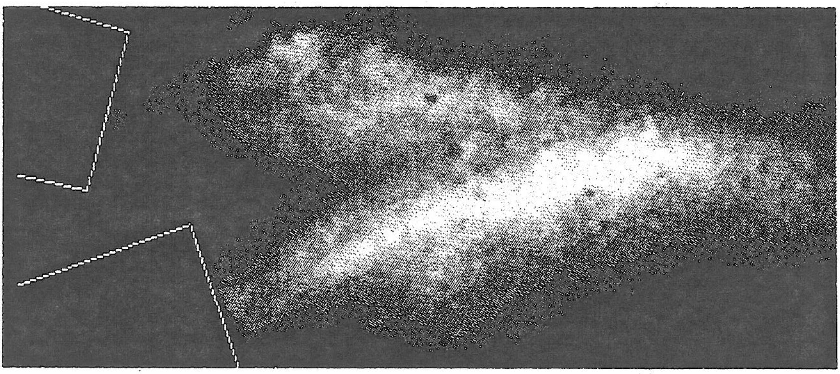
The fume generation can be reduced with the c-d nozzle compared to the standard nozzle. The c-d nozzle can produce a properly expanded supersonic flow with a longer potential core, however the standard nozzle forms a strong shock wave and non-uniformity of the atomizing gas stream. The reduced fume generation is due to a more uniform flow field and less turbulence of the atomizing gas. The dependence of the fume generation on the wire polarity has also been checked, because gravity is expected to affect the fume generation. However the fume generation with reverse polarity is almost the same as that with normal polarity.

Effects of atomizing gas pressure on fume generation with the standard nozzle and with the c-d nozzle are shown in Figs. 6 and 7, respectively. The atomizing gas pressure or the velocity have little effect on the fume generation. The fume generation with nitrogen is about 20 % lower than that with air as atomizing gas. Furthermore the fume generation with the c-d nozzle is about 20 % lower than that with the standard nozzle.

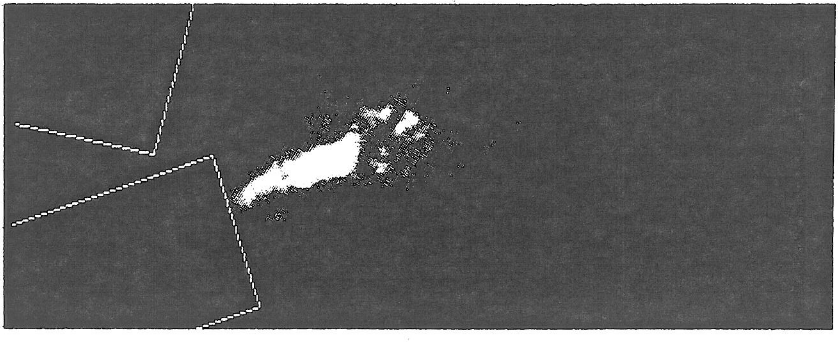
The origins of the fumes for different currents with the standard nozzle and with the c-d nozzle are shown in Fig. 8. The fumes are generated predominantly at the cathode wire tips. This is expected because the high current densities at this location leads to the high gas temperatures and metal evaporation rates. This result indicates that the control of fume generation will be the most effective if the heat input to the cathode wire can be controlled. The fume generated from the cathode decreases with the arc current, and



(a)



(b)



(c)

Fig. 3 High speed image of aluminum fumes

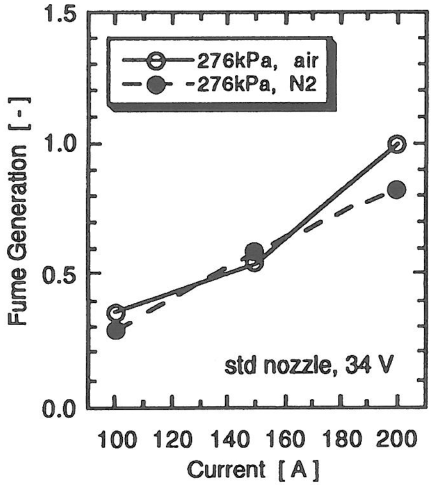


Fig. 4 Effect of arc current on fume generation with standard nozzle.

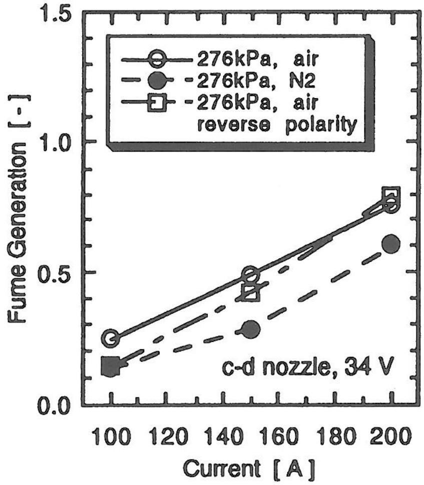


Fig. 5 Effect of arc current on fume generation with c-d nozzle.

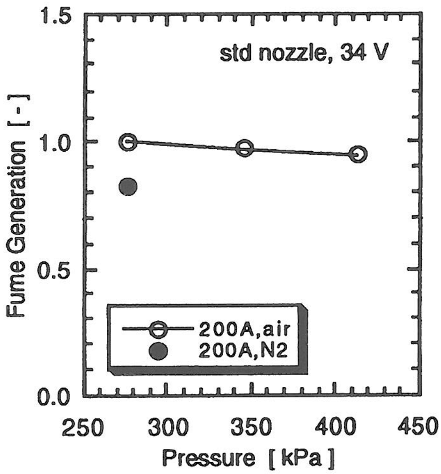


Fig. 6 Effect of atomizing gas pressure on fume generation with standard nozzle.

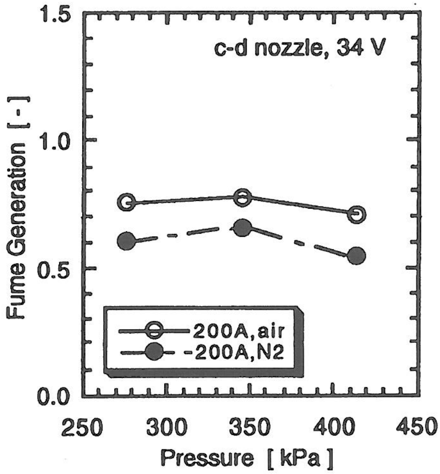


Fig. 7 Effect of atomizing gas pressure on fume generation with c-d nozzle.

more fumes are generated from the both wires at the high current, because the high current results in the high temperature even at the anode wire tips as well as the cathode.

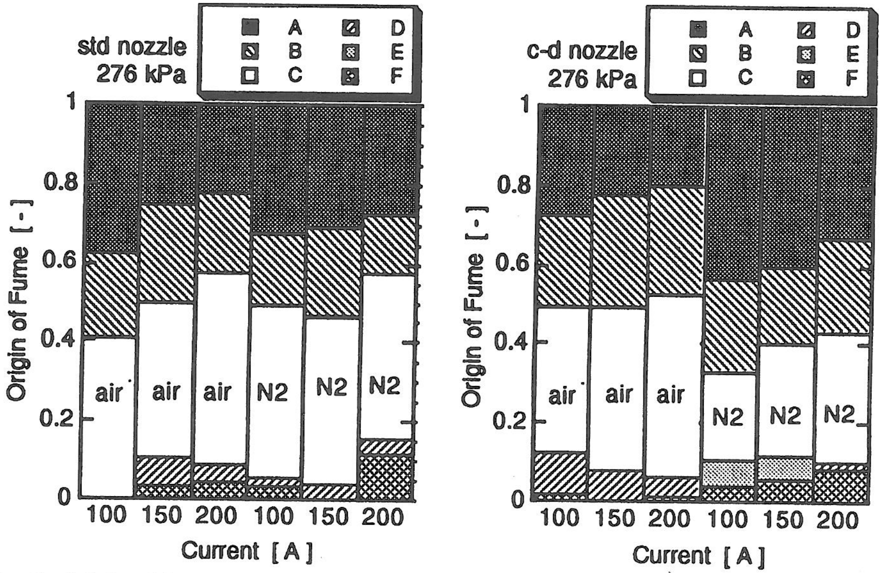


Fig. 8 Origin of fume with standard nozzle (a) and with c-d nozzle (b); A: cathode only; B: mainly cathode; C: both; D: mainly anode; E: anode only; F: no fume.

4. CONCULUSIONS

Fume generation has been quantified with computerized image processing of the images recorded by a laser strobe high speed video system with a line filter centered at the wavelength of aluminum vapor emission line. The fume generation is attributed to the metal evaporation owing to the superheating at the wire tips The oxidation enhances the metal evaporation and the fume generation. The fumes are generated mainly at the cathode wire tip because of the high current density at this location. The control of fume generation will be the most effective if the heat input to the cathode wire can be controlled.

5. ACKNOWLEDGMENTS

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