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Ultraviolet Radiation Emitted by CO_2 Arc Welding

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The arcs associated with arc welding emit high levels of ultraviolet radiation (UVR), and this often causes acute injuries in the workplace, particularly photokeratoconjunctivitis. It is important to know the level of UVR emitted by arc welding under various conditions, as this information will help in evaluating potential UVR hazards in welding workplaces and taking protective measures against it. In this study, the ACGIH effective irradiance for UVR was measured experimentally for CO_2 arc welding in order to evaluate its UVR hazards. A welding robot was used in the experiment in order to realize reproducible and consistent welding operations.

The effective irradiance at 1 m from the arc was in the range 0.28–7.85 W/m^2 (28–785 μW/cm^2) under the study conditions. The corresponding permissible exposure time per day is only 4–100 s, suggesting that UVR from CO_2 arc welding is actually hazardous for the eye and skin. It was found that the effective irradiance is inversely proportional to the square of the distance from the arc, is strongly dependent on the direction of emission from the arc with a maximum at 50–60° from the plate surface, and tends to increase with welding current.

Keywords: ultraviolet radiation; CO_2 arc welding; effective irradiance

INTRODUCTION

The arcs associated with arc welding emit high levels of ultraviolet radiation (UVR), and there are a number of workers at risk from exposure. These include not only professional welders (an estimated 350 000 them in Japan) and workers who occasionally conduct welding operations, but also other workers in the welding workplace, performing tasks such as assembly, arc air gouging, can fabrication, crane operation, oxygen cutting, sheet metal work, slinging and chipping (JWES, 1980).

Exposure to UVR has several adverse health effects (e.g., Sliney and Wolbarsht, 1980); photokeratoconjunctivitis and skin erythema are typical acute effects, and cataracts, skin cancer and photoaging of the skin are delayed effects. However, there is little reliable data on the occurrence of these injuries in the welding workplace.

UVR from arc welding frequently causes acute injuries in the workplace, particularly photokeratoconjunctivitis accompanied by symptoms such as ocular pain, tearing, a sensation of sand in the eye and photophobia. The Japan Welding Engineering Society (JWES, 1980) surveyed photokeratoconjunctivitis in workers in welding workplaces and found that 86% of the workers had experienced it at some point in the past, and 45% currently experienced it more than once a month. Thus, considering the large population of workers at risk, many cases of photokeratoconjunctivitis are expected to occur in the welding workplace.

It is important to know the level of UVR emitted by arc welding, as this information will help in evaluating potential UVR hazards in welding workplaces and taking protective measures against it. Although a number of field and experimental measurements of UVR have been conducted for arc welding (Emmett and Horstman, 1976; Horstman *et al.*, 1976; Lyon *et*

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al., 1976; Sliney and Wolbarsht, 1980; Bennett and Harlen, 1980; Okuno, 1987; Mariutti and Matzeu, 1988; Hietanen and von Nandelstadh, 1998), only a few such measurements were based on a clearly defined effective irradiance suitable for UVR hazard evaluation. Moreover, detailed information on the conditions of welding and measurement is not, in most cases, provided in the literature. Thus, there is insufficient reliable data on the level of UVR emitted by arc welding. In particular, the effects of specific conditions have not been examined systematically.

The purpose of this study is to evaluate UVR hazards for CO_2 arc welding, which is a type of metal active gas (MAG) welding using CO_2 gas to shield the weld and which, at present, is the most commonly employed welding method in Japan. The effective irradiance that the American Conference of Governmental Industrial Hygienists (ACGIH, 2000) defines to evaluate UVR hazards was measured experimentally under various conditions. In particular, the effects of welding current and the angle and distance from the arc were examined systematically.

A major difficulty in measuring UVR from arc welding is that the intensity of UVR tends to fluctuate considerably due to the instability of the welding operation. To conduct reproducible and consistent welding operations, a welding robot was used in this study.

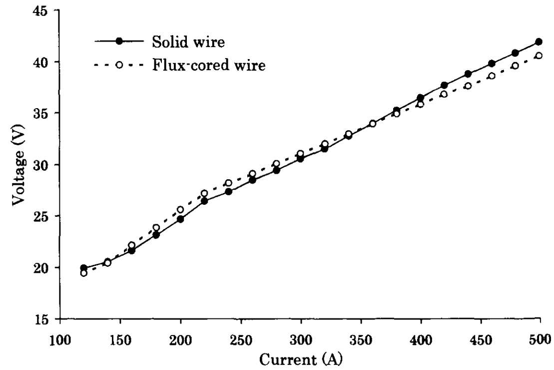

Fig. 2. Measured arc voltage against welding current.

Table 1. Welding conditions

Base plate	Mild steel, 100×75×12 mm
Wire	Solid wire (Kobe Steel Ltd, MG-50T), flux-cored wire (Kobe Steel Ltd, DW-Z100), 1.2 mm in diameter
Shield gas	CO_2, 20 l./min
Stick-out of wire	15 mm
Feed rate of wire	Set internally by the robot
Welding speed	30 cm/min
Welding current	120, 140, 160, ..., 500 A
Arc voltage	Set internally by the robot, Fig. 2

METHODS

The UVR level was measured while the welding arc was struck and maintained on a flat plate of mild steel for 10 s as it moved 5 cm horizontally (Fig. 1). Although metal surfaces were not joined, all other conditions were the same as in actual welding. A welding robot (Kobe Steel Ltd, Arcman-Ron) automatically moved the torch (the arc), struck and extinguished the arc, fed the wire and supplied the shield gas, as programmed beforehand. The welding current was set in the program, while the arc voltage was set internally by the robot for each value of welding current (Fig. 2). The welding wires used were a solid wire (Kobe Steel Ltd, MG-50T) and a flux-cored wire (Kobe Steel Ltd, DW-Z100). Table 1 summarizes the welding conditions.

A hazardous ultraviolet radiation meter (Sibata Scientific Technology Ltd. UV-3) was used to measure UVR. This meter measures UVR in the wavelength range 200–315 nm and has a relative spectral responsivity similar to the ACGIH relative spectral effectiveness for UVR hazards (ACGIH, 2000) in this range, as shown in Fig. 3 (Sibata Scientific Technology Ltd, 1997). The UVR meter ignores UVR in the range 315–400 nm where the relative spectral effectiveness has very small values, but this is acceptable for the measurements of most white-light sources and all open arcs (ACGIH, 2000), because the relative contribution of this range to the effective irradiance is negligible. Thus, the UVR meter measures the approximate effective irradiance.

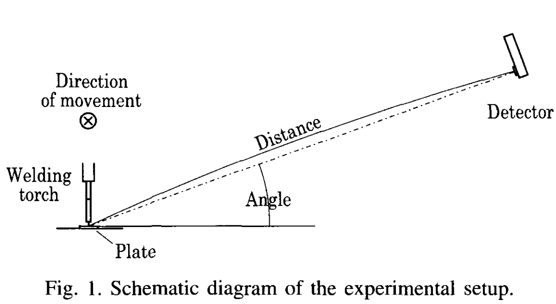

Fig. 1. Schematic diagram of the experimental setup.

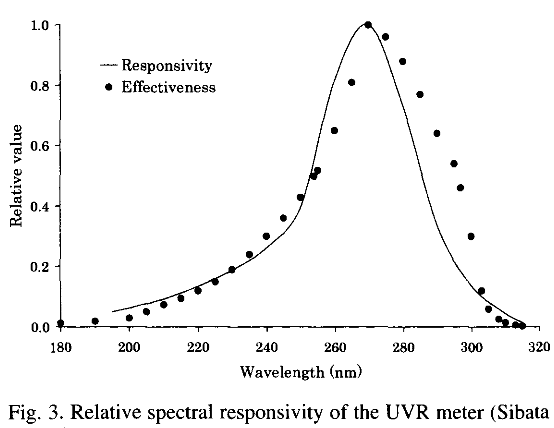

Fig. 3. Relative spectral responsivity of the UVR meter (Sibata Scientific Technology Ltd, 1997) and the ACGIH relative spectral effectiveness.

The UVR meter reports the effective radiant exposure during a certain exposure time, and thus the mean effective irradiance for the period can be obtained by dividing the reported value by the exposure time. The dynamic range of the UVR meter is from 1 mW/m^2 to 30 W/m^2 (0.1 μW/cm^2 to 3 mW/cm^2). The UVR meter was used in this study within a year of calibration by the manufacturer as recommended (Sibata Scientific Technology Ltd, 1997).

The exposure time was set at 0.1 min in the measurement. The detector head of the UVR meter was attached to a mechanical system that allowed the adjustment of position and angle. The aperture of the detector head was fixed at a given angle and a given distance from the center of the trajectory of the arc, and was turned to face it.

The experiment was performed in a large ventilated room, but there was virtually no airflow in the vicinity of the arc or the UVR meter.

The effective irradiance was measured under various conditions of welding current (120–500 A), distance (25–165 cm) from the arc, and angle (0–70°) from the plate surface at the arc. The measurement was repeated more than five times for each condition. The permissible exposure time per day was calculated by dividing 30 J/m^2 (3 mJ/cm^2) by the effective irradiance, in accordance with the ACGIH (ACGIH, 2000) standard.

RESULTS

Examples of the results are shown in Figs 4–6. The coefficient of variation (standard deviation/mean) for repeated measurements was 15% on average for the solid wire and 10% on average for the flux-cored wire.

The effective irradiance at 1 m from the arc was in the range 0.28–7.85 W/m^2 (28–785 μW/cm^2) under the study conditions. The corresponding permissible exposure time per day is 4–100 s.

The effect of distance from the arc on the effective irradiance is shown in Fig. 4. There are fewer data for shorter distances, because many of the measurements had to be skipped for these distances to avoid damage to the measuring instrument by spatter from the weld. The effective irradiance was found to be inversely proportional to the square of the distance from the arc, as predicted by the inverse square law.

The UVR intensity was found to be strongly dependent on the direction of emission (Fig. 5). The effective irradiance increased with the angle, reaching a maximum at 50–60°, and decreased rapidly for angles greater than 60° as the torch nozzle obstructed the arc.

It was found that the effective irradiance tends to increase with welding current for both wire types (Fig. 6).

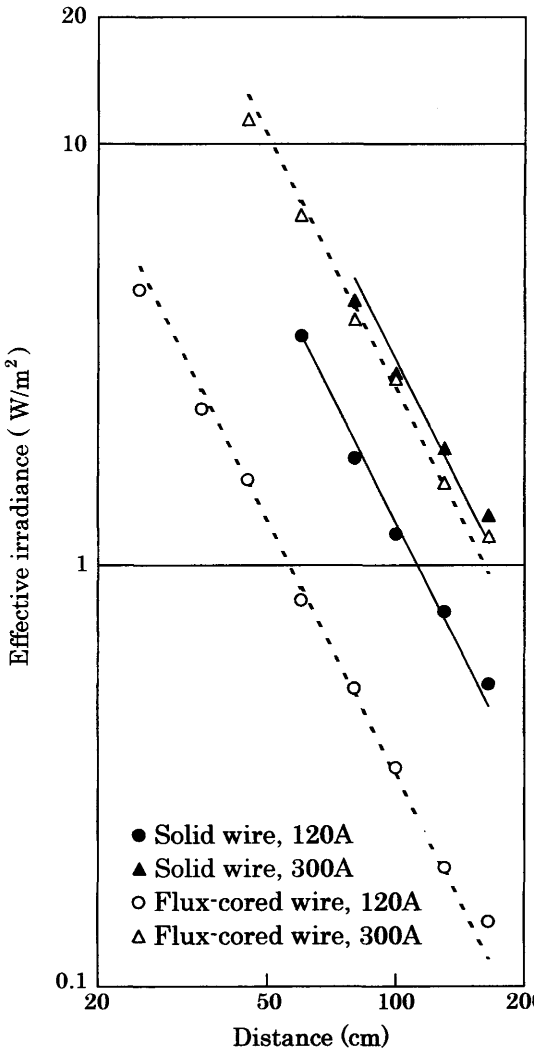

Fig. 4. Effective irradiance at various distances from the arc (circles and triangles). Measurements were made at 30° from the plate surface at the arc. Lines represent effective irradiance in inverse proportion to the square of distance (inverse square law).

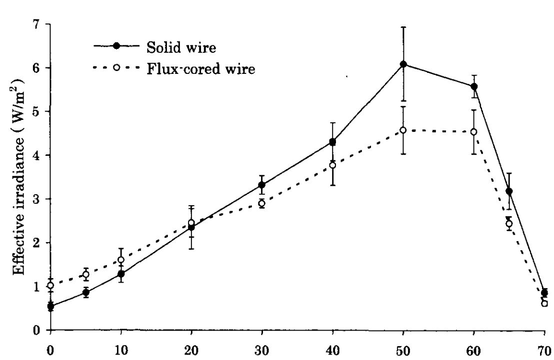

Fig. 5. Effective irradiance (mean ± standard deviation) at 1 m against angle from the plate surface at the arc. Values were calculated from measurements at 0.9 m using the inverse square law. The welding current was 300 A.

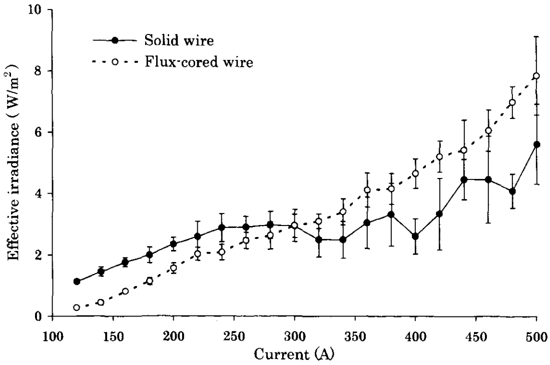

Fig. 6. Effective irradiance (mean±standard deviation) at 1 m from the arc against welding current. Values were calculated from measurements at 30° and 1.3 m from the arc using the inverse square law.

DISCUSSION

Although the UVR meter used in this study is designed to measure the ACGIH effective irradiance, it only approximates the ACGIH standard because there are slight differences between its relative spectral responsivity and the ACGIH relative spectral effectiveness for UVR hazards (Fig. 3). However, the degree of error should be small when measuring white-light sources such as welding arcs because the positive and negative errors at different wavelengths tend to cancel out. In fact, a trial calculation showed that the measured value would be only 6% lower than the effective irradiance for the spectral irradiance that was measured for CO_2 arc welding of mild steel in a previous study (Okuno, 1985).

The obtained effective irradiance of 0.28–7.85 W/m^2 (28–785 μW/cm^2) at 1 m from the arc, with a corresponding permissible exposure time per day of only 4–100 s, suggests that UVR from CO_2 arc welding is actually hazardous for the eye and skin.

The UVR level at the position of welders will be several times higher, because the welder is usually less than 1 m away and the effective irradiance is inversely proportional to the square of the distance, as shown in this study. Thus, welders should always wear an appropriate face protector (welding helmet or shield) and appropriate clothing to protect eyes and skin against UVR when conducting CO_2 arc welding.

UVR may also be hazardous at greater distances from the arc. For example, at 10 m, although the UVR level decreases to 1% of the level at 1 m, the permissible exposure time per day is still only 6 min to 3 h.

There are only a few studies whose results can be compared directly with the present results. In these studies, the effective irradiance was measured for CO_2 arc welding of mild steel with a solid or flux-cored wire at several welding currents (Lyon *et al.*, 1976; Sliney and Wolbarsht, 1980; Okuno, 1987), giving values slightly or considerably lower than those obtained for the same welding currents in this study. This suggests that there are other conditions that affect UVR emission from the arc.

The effective irradiance is inversely proportional to the square of the distance from the arc (Fig. 4), as predicted by the inverse square law. This suggests that the absorption or scattering of UVR by dusts or fumes generated in the welding operation is minimal, because if such effects had been significant, the UVR level would have decreased more rapidly with distance.

This relationship between the effective irradiance and distance can be useful in evaluating UVR hazards in workplaces, because if we know the irradiance at one distance from the arc, we can calculate the irradiance at any distance using the inverse square law.

The obtained dependence of the UVR intensity on the direction of emission (Fig. 5) is similar to the findings of a previous study (Sliney and Wolbarsht, 1980), although it reported that the maximum occurred at about 40° from the plate surface, as compared with 50–60° in this study. Thus, if a worker is conducting arc welding in the normal position, the most intense UVR emission is in the direction of the face.

The effective irradiance tends to increase with welding current for both wire types (Fig. 6). This shows that as the current increases, more energy is put into the arc, and part of this energy is emitted as UVR. However, the effective irradiance was not simply proportional to welding current, arc voltage or the product of both. In particular, in the case of the solid wire, the effective radiance was approximately constant in the middle of the current range (240–400 A). Dennis *et al.* (1997) observed a similar pattern for UVR emission from metal inert gas (MIG) welding, and suggested that this is due to the change in the mode of metal transfer in the arc from dip mode through globular mode to spray mode.

It is expected that the UVR levels in the welding workplace will become higher in the future, as there is a tendency to use larger welding currents for increased efficiency.

Welders should always wear a protector (welding helmet or shield) to protect the face, particularly the eye, against UVR when conducting arc welding. However, this is not entirely sufficient to prevent photokeratoconjunctivitis in the welding workplace. The survey by the JWES (1980) not only revealed an extremely high incidence of this injury in workers in the welding workplace, as mentioned earlier, but also found paradoxically that most workers (88%) wear a protector while conducting arc welding. The JWES has made the following speculations on these survey results, and the results of this study support them.

Firstly, welders may be exposed to UVR when striking the arc. In welding operations, a welder is not wearing a protector before striking the arc because the filters of protectors are so dark that nothing can be seen when the arc is not present, and when striking the arc, the welder tries to put on a protector at the same time. Thus, if putting on the protector is delayed, the welder is exposed directly to UVR from the arc. Although the exposure is brief for each strike of arc, if this occurs many times in a day, the total exposure time may become sufficient to cause photokeratoconjunctivitis. In fact, the total exposure time might easily exceed the permissible exposure time per day obtained in this study, i.e. 4–100 s at a distance of 1 m from the arc and much less at the normal position of the welder.

Secondly, workers in the welding workplace, both welders and non-welders, may be exposed to intense UVR from nearby arc welding conducted by other workers. In fact, this study showed that UVR might still be hazardous, even at 10 m from the arc.

To avoid such exposures, workers should always wear spectacles or goggles with transparent or almost transparent filters (lenses) in the welding workplace. These filters should block out almost all UVR. When striking the arc, the welder should put on an ordinary welding helmet or shield over the spectacles or goggles.

The coefficients of variation for repeated measurements in this study, i.e. 15% for the solid wire and 10% for the flux-cored wire, are satisfactory considering the difficulty of conducting reproducible and consistent welding operations, and are indicative of the usefulness of welding robots in such experiments.

The CO_2 arc welding conducted in this study differs in some respects from that conducted commonly in the workplace. In this study, for example, a welding robot was used, and metal surfaces were not joined. However, as these differences are not expected to directly affect the conditions of the arc or UVR, the UVR emission in this study would not differ significantly from that in the workplace. In fact, in a survey of 23 CO_2 arc welding operations in six workplaces, the range of effective irradiance was found to be 2.25–9.59 W/m^2 (225–959 μW/cm^2) at 1 m from the arc (unpublished data), which is comparable to the range obtained in this study. There is no other data on UVR in the workplace that can be compared directly with the results of this study.

CONCLUSIONS

The effective irradiance at 1 m from the arc of CO_2 arc welding is in the range 0.28–7.85 W/m^2 (28–785 μW/cm^2) under the study conditions. The corresponding permissible exposure time per day is only 4–100 s, suggesting that UVR from CO_2 arc welding is actually hazardous for the eye and skin.

The effective irradiance is inversely proportional to the square of the distance from the arc, is strongly dependent on the direction of emission from the arc with a maximum at 50–60° from the plate surface, and tends to increase with welding current.

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