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Blue-Light Hazard from CO_2 Arc Welding of Mild Steel

T. OKUNO*, J. OJIMA and H. SAITO

Hazard Evaluation and Epidemiology Research Group, National Institute of Occupational Safety and Health, Japan, Nagao 6-21-1, Tama-Ku, Kawasaki 214-8585, Japan

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Objectives: The objective was to quantify the blue-light hazard from CO_2 arc welding of mild steel.

Methods: The spectral radiance of arcs in CO_2 arc welding of mild steel was measured for solid and flux-cored wires at welding currents of 120–480 A. Effective blue-light radiance and the maximum acceptable exposure duration were calculated from the spectral radiance using their definitions in American Conference of Governmental Industrial Hygienists guidelines.

Results: The effective blue-light radiance ranged from 22.9 to 213.1 $Wcm^{-2}sr^{-1}$. The corresponding maximum acceptable exposure duration was only 0.47–4.36 s, meaning that the total daily exposure to the welding arc without eye protection should not exceed this duration.

Conclusions: It is very hazardous to view the arcs in CO_2 arc welding of mild steel. Welders and their helpers should use appropriate eye protectors in these arc-welding operations. Also, they should avoid direct light exposure when starting an arc-welding operation.

Keywords: blue light; CO_2 arc welding; photoretinopathy

INTRODUCTION

The ultraviolet radiation produced by arc welding often causes workers to suffer from erythema and keratoconjunctivitis, as is well known, but the light (visible light) produced is also hazardous. Light-induced retinal injury has been reported in people who have stared at a welding arc without adequate protection (Würdemann, 1936; Minton, 1949; Naidoff and Sliney, 1974; Romanchuk *et al.*, 1978; Uniat *et al.*, 1986; Cellini *et al.*, 1987; Brittain, 1988; Power *et al.*, 1991; Fich *et al.*, 1993; Arend *et al.*, 1996). This injury appears as retinal changes such as edema or a hole and is accompanied by symptoms such as decreased visual acuity, blurred vision, or scotoma. These symptoms appear immediately or within a few hours after exposure and then gradually improve over a period of weeks. In some cases, patients completely recover within a few weeks or months, whereas in other cases, patients still have symptoms after several months.

The mechanism of the light-induced retinal injury associated with arc welding is not thermal because the temperature rise in the retina is estimated to be insufficient to cause a burn; therefore, the injury mechanism is considered to be photochemical (Naidoff and Sliney, 1974).

Photochemical retinal injury, known as photoretinopathy, is caused by light primarily in the wavelength region of 400–500 nm. Because the light in this region appears blue to the eye, it is called blue light. The hazard of blue light is generally measured by effective blue-light radiance, which is obtained by weighting the spectral radiance of a light source against the blue-light hazard function (Fig. 1) and integrating this in the wavelength range of 305–700 nm (ICNIRP, 1997; ACGIH, 2009). The maximum acceptable exposure duration is calculated by dividing 100 $Jcm^{-2}sr^{-1}$ by the effective blue-light radiance. Thus, measuring the effective blue-light radiance of welding arcs is the first step toward preventing photoretinopathy due to arc welding.

*Author to whom correspondence should be addressed.
Tel: +81-44-865-6111; fax: +81-44-865-6124;
e-mail: okuno@h.jniosh.go.jp

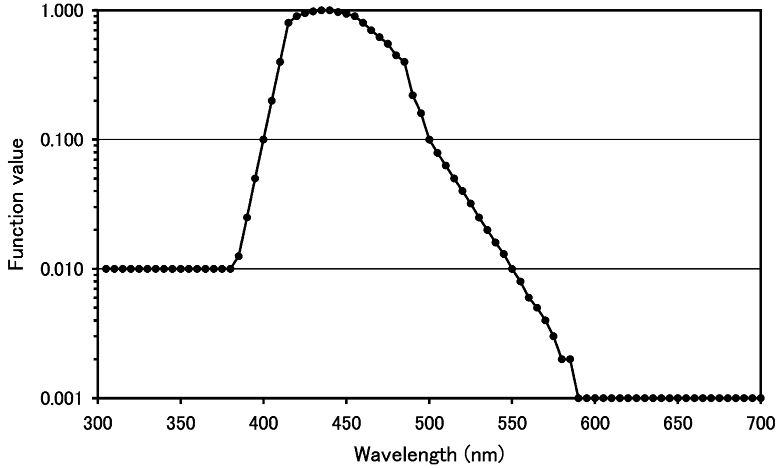

Fig. 1. Blue-light hazard function (ICNIRP, 1997; ACGIH, 2009). The blue-light hazard function shows the capability of light to produce photochemical retinal damage as a function of wavelength.

Few studies have measured the blue light of welding arcs (Marshall *et al.*, 1977; Okuno, 1986; Hietanen, 1998; Peng *et al.*, 2007), and only two of them have determined effective blue-light radiance, partly because of technical difficulties. Marshall *et al.* (1977) experimentally determined the effective blue-light radiance of arcs for different arc-welding processes under a total of 20 conditions. They showed that the effective blue-light radiance of arcs is at potentially hazardous levels for all the processes evaluated, although the hazard varies greatly depending on the process and the condition. Okuno (1986) also determined the effective blue-light radiance of welding arcs under 14 conditions but found generally much lower levels of effective blue-light radiance. In these two studies, effective blue-light irradiance (spectral irradiance weighted against the blue-light hazard function) was measured at a distance from the welding arc and then the effective blue-light radiance was calculated by dividing the effective blue-light irradiance by the estimated size (area) of the arc and multiplying this by the square of the measurement distance. However, because welding arcs have no definite boundaries and consequently no definite size, this method is an approximation and may not provide accurate results.

In a previous comprehensive survey of blue-light hazards, we examined CO_2 arc welding (a type of gas metal arc welding that uses CO_2 gas to shield the weld) of mild steel and shielded metal arc welding of mild steel as well as many other light sources (Okuno *et al.*, 2002). We experimentally measured the spectral radiance of the welding arcs and calculated the effective blue-light radiance from the spectral radiance. It was shown that these welding processes emit hazardous levels of blue light under the conditions employed, suggesting the need for further examination of welding processes. In particular, it is of practical importance to examine CO_2 arc welding in more detail because it is currently the most widely used welding process in Japan and therefore, many workers are potentially exposed to its blue light. In this study, we experimentally determined the effective blue-light radiance of arcs for CO_2 arc welding of mild steel with solid and flux-cored wires at welding currents of 120–480 A.

METHODS

We used a welding robot (Arcman-Ron, Kobe Steel, Ltd., Kobe, Japan) to produce an arc of CO_2 arc welding on a 12-mm-thick flat plate of mild steel placed on a motor-driven movable stage (Fig. 2). The robot, programmed beforehand, automatically strikes and extinguishes an arc, moves the torch (arc), feeds the wire, and supplies the shield gas. Metal surfaces were not joined. The arc was moved at the lowest settable speed of 12 cm min^{-1} to facilitate the measurement of light. To achieve a sufficient relative speed for welding, the mild-steel plate was moved at 60 cm min^{-1} in the opposite direction. Blue light was evaluated for a solid wire (MG-50T, Kobe Steel, Ltd.) and a flux-cored wire (DW-Z100, Kobe Steel Ltd.) at welding currents of 120–480 A and intervals of 40 A. Table 1 summarizes the welding conditions.

A spectroradiometer (PR-705, Photo Research Inc., Chatsworth, CA, USA) was used to measure the spectral radiance of welding arcs in the wavelength range of 380–780 nm at intervals of 2 nm. The measuring field of the spectroradiometer was set to a diameter

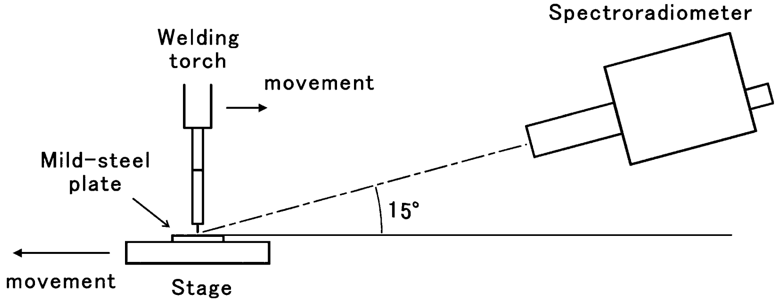

Fig. 2. Schematic of the experimental setup.

Table 1. Welding conditions

Base plate	Mild steel, 100 mm × 75 mm × 12 mm
Wire	Solid wire (Kobe Steel Ltd. MG-50T), Flux-cored wire (Kobe Steel Ltd. DW-Z100), 1.2 mm in diameter
Wire feed rate	Unknown[a]
Wire stick-out length	15 mm
Shield gas	CO_2 gas, 20 l min^{-1}
Welding speed	72 cm min^{-1}
Welding current	120 A to 480 A at intervals of 40 A
Arc voltage	Unknown[a]

[a]Set internally by the welding robot.

of 1/8°, and a conversion lens (KR2005, Kenko Co., Ltd., Tokyo, Japan) was attached to the aperture of the spectroradiometer to reduce the measuring field to a diameter of 1/16°. Two accessory neutral density (ND) filters of ~1% transmission (ND-100) and ~10% transmission (ND-10) and an ND filter for camera use of ~12.5% transmission (PRO ND8, Kenko Co., Ltd.) were attached to the aperture because the light from welding arcs is too intense for direct measurement. A clear protection filter for camera use (MC Protector, Kenko Co., Ltd.) was also attached to protect the aperture from welding dust and spatter. The spectroradiometer internally makes corrections for the spectral transmittance of the two accessory ND filters. Corrections for the spectral transmittance of the conversion lens, the camera ND filter, and the clear protection filter were made by dividing the measured spectral radiance by their spectral transmittance after measurement. The exposure time was set to 40 ms. The spectroradiometer was calibrated by the manufacturer prior to the measurements.

Spectral radiance was measured while the welding arc was maintained on the mild-steel plate for 10 s as it moved 2 cm horizontally. The spectroradiometer was positioned at an angle of 15° and a distance of ~0.8 m from the center of the trajectory of the arc and was aimed at the center (Fig. 2). In this setup, the measuring field at the arc position was a circle of 0.8-mm diameter, and the mean spectral radiance over this field was measured.

The experiment was performed in a large ventilated room, but there was virtually no ventilation airflow around the welding arc or the spectroradiometer.

The effective blue-light radiance of the welding arc was obtained by weighting the measured spectral radiance against the blue-light hazard function (Fig. 1) and integrating it with respect to wavelength. The integration, however, was started at 380 nm instead of 305 nm. This modification is acceptable because the blue-light hazard function is very small in the wavelength range of 305–380 nm and therefore, the radiant energy in this range is expected to contribute little to the effective blue-light radiance for white-light sources such as welding arcs. For example, a simple calculation shows that the contribution of this wavelength range is only 1% for light sources with a flat spectral distribution.

Effective blue-light radiance was measured 18 times for each condition, and the mean (M) and standard deviation (SD) were calculated. Some of the measurements showed extremely low values evidently because the measuring field failed to fall precisely within the arc. These abnormal measurements were excluded by eliminating values less than (M − SD), and the mean and standard deviation were recalculated. The maximum acceptable exposure duration was calculated from the effective blue-light radiance for each condition.

RESULTS

At least 13 valid measurements could be taken for each condition, and these were used to calculate the mean spectral radiance and mean effective blue-light radiance. One to five of 18 measurements were excluded as abnormal measurements for each condition, which resulted in a 3–20% increase in the mean effective blue-light radiance and a 5–33% decrease in the standard deviation.

The spectral radiance of welding arcs had a characteristic shape with many emission lines (Figs 3 and 4). The overall intensity of arc light generally increased with the increase of the welding current for each welding wire, but the spectral features remained unchanged.

Similarly, the effective blue-light radiance calculated from the spectral radiance of welding arcs generally increased with the increase of the welding current; at high welding currents, the effective blue-light radiance was higher for solid wire than for flux-cored wire. The effective blue-light radiance ranged from 33.7 to 213.1 $Wcm^{-2}sr^{-1}$ for solid wire and from 22.9 to 162.9 $Wcm^{-2}sr^{-1}$ for flux-cored wire (Fig. 5). The corresponding maximum acceptable exposure duration was 0.47–2.97 s for solid wire and 0.61–4.36 s for flux-cored wire, meaning that the total daily exposure to the welding arc without eye protection should not exceed this duration.

DISCUSSION

This study shows that arcs in CO_2 arc welding of mild steel should not be viewed for >0.47–4.36 s in total per day. Thus, in CO_2 arc-welding operations, every welder and helpers who view the arc and

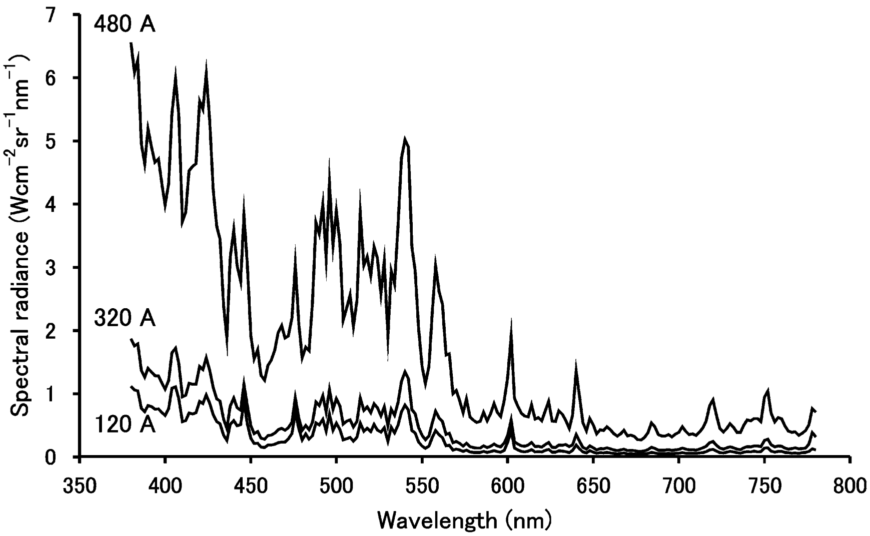

Fig. 3. Spectral radiance of arcs in CO_2 arc welding of mild steel with solid wire.

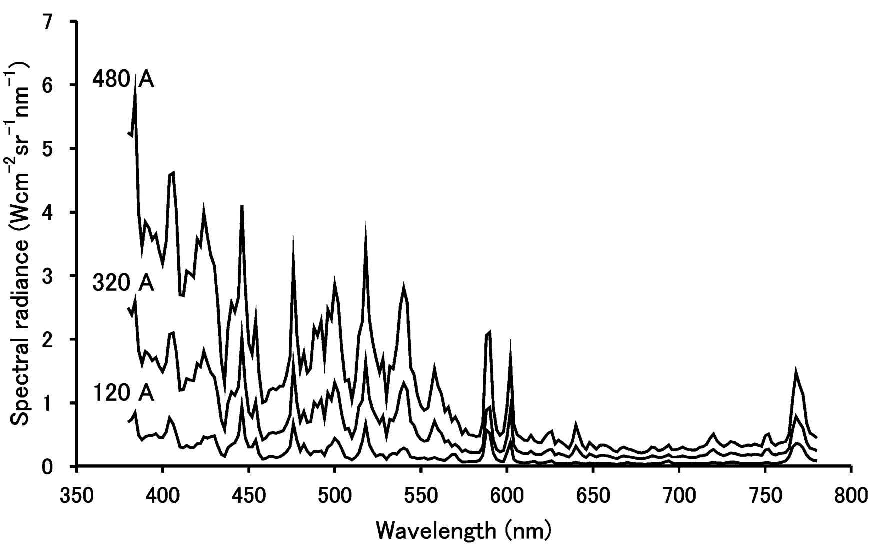

Fig. 4. Spectral radiance of arcs in CO_2 arc welding of mild steel with flux-cored wire.

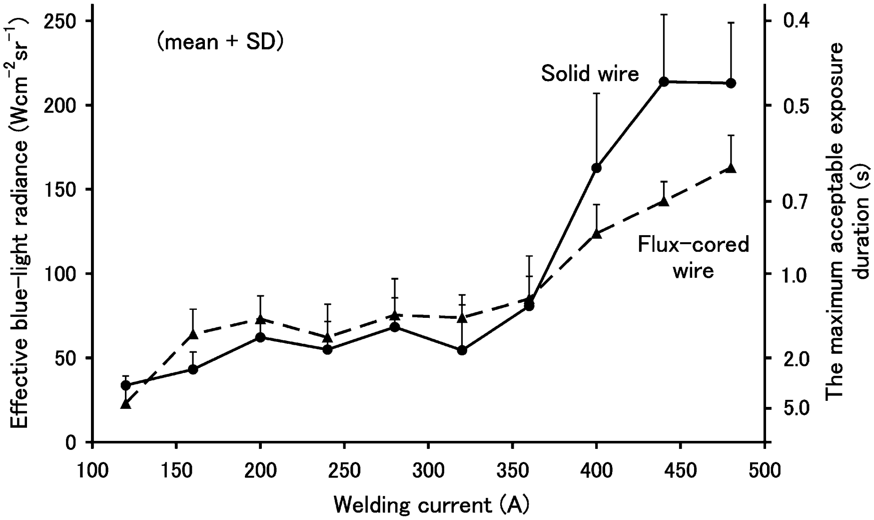

Fig. 5. Effective blue-light radiance of arcs in CO_2 arc welding of mild steel. The maximum acceptable exposure duration is shown on the right-hand scale.

objects in the vicinity of the arc should wear an eye protector with a filter of the appropriate shade number and look through the filter to protect themselves from blue light. In addition, as they are putting on their eye protector (filter), they should avoid direct light exposure when striking an arc. Although the exposure when striking the arc lasts only a split second, welders usually perform this task many times a day and therefore, the total exposure duration can exceed the limit. Thus, welders and their helpers should make sure that they put on their eye protectors before striking the arc when they start an arc-welding operation.

Our data (Fig. 5) are consistent with the effective blue-light radiance that Marshall *et al.* (1977) determined for CO_2 arc welding of mild steel, although they used a different measurement method (17.5 and 53.7 Wcm^{-2}sr^{-1} at welding currents of 90 and 150 A, respectively). This supports the reliability of our methods and results, despite the technical difficulties of determining the effective blue-light radiance of welding arcs.

When a welding arc is considered to be a small light source subtending an angle <0.011 rad, criteria for small light sources can be used to allow longer exposure (ICNIRP, 1997; ACGIH, 2009). For example, Marshall *et al.* (1977) took photographs of arcs for different arc-welding processes and measured the area inside the contour corresponding to the irradiance level of 1/e (~37%) times the peak irradiance on the photograph. They found that the arc size in CO_2 arc welding of mild steel is 1.2–9.2 mm^2, which corresponds to a diameter of 1.2–3.4 mm if the arc is assumed to be circular. When a welder views this arc at a distance of 50 cm, the arc subtends an angle of 0.0024–0.0068 rad, which is <0.011 rad, and the small-light-source criteria can be used. However, welding arcs have no definite boundaries and consequently no definite size and so it is generally difficult to apply the small-light-source criteria to welding arcs.

The criteria (ICNIRP, 1997; ACGIH, 2009) do not explicitly state but imply that effective blue-light radiance should be averaged over a circle of 0.011-rad angular diameter. Thus, the blue-light hazard quantified in this study is thought to be for a viewing distance of 7.3 cm because the effective blue-light radiance was determined with an averaging field of view of 0.8-mm diameter, which corresponds to 0.011-rad angular diameter at this viewing distance. However, welding arcs are normally viewed at greater distances. In this case, effective blue-light radiance may be lower depending on the arc size, because it is averaged over a larger area, and therefore, the blue-light hazard may be lower.

Because the effective blue-light radiance of arcs can vary greatly depending on the welding process and condition, further studies need to be conducted for other welding processes and conditions. For example, arc welding of aluminum alloys should be evaluated because its arcs appear whiter than those in the arc welding of steel, which indicates that they emit a large amount of blue light.

CONCLUSIONS

This study demonstrates that it is very hazardous to view arcs in CO_2 arc welding of mild steel.

Welders and their helpers should use appropriate eye protectors in these arc-welding operations. Also, they should avoid direct light exposure when starting an arc-welding operation.

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