Atom Indonesia

Journal homepage: http://aij.batan.go.id

Assessment of Levels of Occupational Exposure to UV-A and UV-C Radiation among Shielded Metal Arc Welders in Accra, Ghana

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ARTICLE INFO

Article history:
Received 17 June 2019
Received in revised form 10 January 2020
Accepted 27 May 2020

Keywords:
ultraviolet radiation
radiant exposure
non-ionizing radiation
safety standards

ABSTRACT

This study attempted to quantify the irradiance levels of ultraviolet A (UV-A) and ultraviolet C (UV-C) from the shielded metal arc welding (SMAW) process to welders in Accra, Ghana. Exposures were assessed via measurements, observations, and interviews. The assessments were done based on safe exposure levels prescribed by recognized international organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the American Conference of Governmental Industrial Hygienists (ACGIH). Results from the measured UV-C irradiance levels $E_{UV\text{-}C}$ ranged between 0.16 ± 0.08 W/m^2 and 10.46 ± 1.96 W/m^2 with its corresponding permissible exposure duration $t_{max\text{-}UV\text{-}C}$ per day ranging from 5.74 s to 367.35 s. The measured UV-A irradiance levels $E_{UV\text{-}A}$ ranged from 0.88 ± 0.03 W/m^2 to 23.72 ± 6.66 W/m^2 with its corresponding permissible exposure duration $t_{max\text{-}UV\text{-}A}$ per day ranging from 421.59 s to 11 363.64 s. The obtained effective irradiance E_{eff} has a range of 2.08 W/m^2 to 28.79 W/m^2 with the range of permissible exposure duration t_{max} per day of 1.04 s to 14.40 s. It was found that the total exposure time of the welders exceeded the permissible exposure durations and that the safety practices among the welders were unsatisfactory.

INTRODUCTION

The ultraviolet (UV) radiation is an electromagnetic radiation with a wavelength shorter than that of visible light. The UV region covers the wavelength range of 100-400 nm and is divided into three regions [1-3]:

- UV-A (315-400 nm)
- UV-B (280-315 nm)
- UV-C (100-280 nm)

Workers may be exposed to ultraviolet radiation (UVR) from the Sun and artificial sources such as specialized lamps and welding arcs. UV-A activates melanin pigment already present in the upper skin cells. It creates a tan that appears quickly but is also lost quickly. Furthermore, UV-A penetrates into the deeper skin layers, where connective tissue and blood vessels are affected [4]. As a result, the skin gradually loses its elasticity and starts to wrinkle. Therefore, large doses of UV-A cause premature aging. Furthermore, recent studies strongly suggest that it may enhance the development of skin cancers. The mechanisms of this UV-A damage are not fully understood, but a popular hypothesis assumes that UV-A increases oxidative stress in the cell. As with the effects on the skin, UV radiations can penetrate the eye to different depths. While UV-B and UV-C are fully absorbed by the cornea, UV-A passes through these surface layers to the lens and can cause photokeratitis (inflammation of the cornea), photoconjunctivitis (inflammation of the conjunctiva), and pterygium [5].

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The UV-C is a lower-penetrating form of UV compared to UV-A or UV-B and is invisible to the human eye. The UV-C (short wave) ranging from 200 to 280 nm is the most effective wavelength range for inactivation of microorganisms with peak effectiveness near 265 nm [6]. UV-C exposure can also lead to ocular damage, which generally begins with photokeratitis, but can also result in photokeratoconjunctivitis. Symptoms, which depend on UV-C radiant exposure, can begin within minutes after exposure and are considered similar to a welder's burn. Symptoms can include a sensation of sand in the eyes, excessive tearing, and general discomfort around the eye ranging from moderate to severe depending on the individual [7]

The arcs associated with arc welding emits hazardous levels of UVR, and the UVR exposure could potentially injure the welders involved [8,9]. Arc welding produces the full spectrum of UVR. The short distance between the arc and the welder's skin may not be sufficient to absorb most of the UV-C. Arc welders may therefore be at significantly increased risk of developing the health effects associated with the UV-A and UV-C emissions [8].

The purpose of this study was to quantify the irradiance levels of UV-A and UV-C from the shielded metal arc welding (SMAW), which is the most commonly employed welding method in maintenance, construction, and repair applications in factories and worksites in Ghana, received by the welders [10] and determine whether safety practices among the welders were satisfactory.

THEORY/CALCULATION

Calculation of permissible exposure duration

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines or Exposure Limits (EL) and the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) represents conditions under which it is expected that nearly all individuals may be repeatedly exposed without acute adverse effects and, based upon best available evidence, without noticeable risk of delayed effects [11,12]. The ICNIRP guidelines or ACGIH TLV for human exposure of the eye and skin to UVR is 30 J/m^2 is based on 270 nm wavelength which is the wavelength to which the biological systems are most sensitive; it is provided for a recommended 8-hour period. When the irradiance level is known, the permissible exposure duration, t_{max}, in seconds, to the spectrally weighted UVR is calculated by dividing the TLV by the irradiance level [12].

When the effective irradiance is known, the permissible exposure duration, t_{max}, in seconds, to the spectrally weighted UVR is calculated by Eq. (1) [11,12].

$$t_{max}(s) = \frac{30\ \frac{J}{m^2}}{E_{eff}\ \frac{W}{m^2}} \quad (1)$$

For UV-C radiation, the TLV for human exposure of the eye and skin is 60 J/m^2 at 253.7 nm for a daily eight-hour work shift and Eq. (2) shows its use in calculation of permissible exposure duration [13].

$$t_{max-UV-C}(s) = \frac{60\ \frac{J}{m^2}}{E_{UV-C}\ \frac{W}{m^2}} \quad (2)$$

In Eq. (2), $t_{max\text{-}UV\text{-}C}$ = permissible exposure duration related to the UV-C limit in seconds; and $E_{UV\text{-}C}$ = irradiance level of UV-C.

For UV-A irradiance levels, the TLV is 10 000 J/m^2 [12]. The permissible exposure duration can then be found using Eq. (3) [12].

$$t_{max-UV-A}(s) = \frac{10000\ \frac{J}{m^2}}{E_{UV-A}\ \frac{W}{m^2}} \quad (3)$$

In Eq. (3), $t_{max\text{-}UV\text{-}A}$ = permissible exposure duration related to the UV-A limit in seconds; and $E_{UV\text{-}C}$ = irradiance level of UV-A radiation.

Uncertainty Estimation

To calculate the uncertainty of the irradiance level measurements, the various sources of uncertainty in the measurements were identified. The uncertainty from each source was estimated and finally the individual uncertainties were combined to give the overall uncertainty at any point. The standard uncertainty for the irradiance level *u(E)* was first found by calculating the estimated standard deviation *S*, which is given by Eq. (4):

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad (4)$$

In the equation, x_i is the result of the *i*th measurement and $\bar{x}$ is the arithmetic mean of the *n* results considered and $\bar{x} = \sum_i^n \frac{x_i}{n}$

Because the distribution was a normal one, *u(E)* was calculated using Eq. (5)

$$u_1 = \frac{S}{\sqrt{n}} \quad (5)$$

where *n* = number of measurements, which is equal to 3.

The instrument used in measuring the irradiance levels, UV254SD UV-A and UV-C light meter with datalogging SD card, had a measurement accuracy of ± 4 % of full-scale reading, and read to the smallest division or unit of 0.001 [14]. Therefore, to estimate the instrument uncertainty, the smallest division is multiplied by interpolation factor of 0.5 as in (6)

$$\text{Instrument uncertainty, } a = 0.5 \times 0.001 \quad (6)$$

Therefore, the instrument uncertainty for the UV254SD was ± 0.0005. This was taken as a uniformly distributed uncertainty.

To find the standard uncertainty, Eq. (7) is used [15],

$$u_2 = \frac{a}{\sqrt{3}} \quad (7)$$

Therefore, the standard uncertainty of the UV254SD is

$$u_2 = \frac{0.0005}{\sqrt{3}}$$

$$= 2.8868 \times 10^{-4}$$

The combined standard uncertainty, u_c, was then found using Eq. (8)

$$u_c = \sqrt{{u_1}^2 + {u_2}^2} \quad (8)$$

Therefore, the combined standard uncertainty of the UV-A and UV-C irradiance level is as given by Eq. (9).

$$u_c = \sqrt{{u_1}^2 + (2.8868 \times 10^{-4})^2} \quad (9)$$

The expanded uncertainty, U, at a 95 % confidence level was found by multiplying the combined standard uncertainty by a coverage factor, $k = 2$ [14]. Symbolically, $U = k \times u_c$

$$= 2 \times u_c$$

The irradiance levels were written as $\bar{x} \pm U$ in the units of W/m^2. This reported uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$, providing a level of confidence of approximately 95 % [15].

EXPERIMENTAL METHODS

Study population

Subjects consisted of welders in the various welding industries. First, worksites or factories that used the SMAW process were identified in a preliminary survey. A total of 70 welders were identified in the various worksites and factories. The researchers sought consent from the relevant bodies, including the welders themselves, in order to carry out the assessment. Welders that gave their consent were the only ones assessed.

Administration of questionnaire

Questionnaires were administered to the welders at their workplaces. They were required to provide information regarding their ages, the years in which they started their careers as welders, the estimated number of hours of welding in a day, the number of days they performed welding tasks in a week, and how often they welded without personal protective equipment (PPE).

Measurement of the UV-A and UV-C irradiance levels

The fact that the potential for harmful effects is strongly dependent on the wavelength of the UV radiation leads to ranking the various wavelengths relative to 270 nm, which is the wavelength to which the biological systems are most sensitive. The recommended TLV for eight-hour radiant exposure, which is applicable to both the eye and the skin, is 30 J/m^2 for 270-nm radiation. For other wavelengths, whose spectral effectiveness is less than that of 270-nm UV, the TLV is proportionately greater. For heterochromatic UV radiation, the 30 J/m^2 TLV applies to the effective spectral irradiance, which is defined in Eq. (9) [9,16].

$$E_{eff} = \sum E_\lambda \times S(\lambda) \times \Delta\lambda, \quad (10)$$

In Eq. (10), E_{eff} = effective irradiance in W/m^2, E_λ = spectral irradiance in W/(m^2 nm); $S(\lambda)$ = relative spectral effectiveness (unitless), and $\Delta\lambda$ = bandwidth in nanometers of the calculation or measurement intervals.

The UV-A and UV-C irradiance levels are practically measured with a radiometer (survey meter) whose response to the different wavelengths is weighted by $S(\lambda)$. The UV-A and UV-C irradiance level received by each welder was obtained using a General Tools & Instruments UV254SD UV-A and UV-C light meter with datalogging SD Card with a measurement accuracy of ± 4 % of full-scale reading + 2 digits [14]. The radiometer has a serial number of Q612737. It was designed to measure the irradiance levels of UV-A and/or UV-C light from many industrial and commercial applications including welding, UV sterilization of food, photochemical matching, erasure of electrically

programmable read-only memory (EPROM) chips, and curing of inks. The UV254SD has the performance and features needed to satisfy the most demanding aspects of these applications. It combines the capabilities of UV-A (long waves in the 365 nm band) and UV-C (short waves in the 254 nm band) measurement in one instrument. The UV254SD comes with UV-A and UV-C probes and measures UV light intensity within two automatically-switched full-scale ranges: 2 mW/cm^2 and 20 mW/cm^2. Measurement of the intensity of the UV light is done by holding either the UV-A or UV-C probe by its handle, pointing the sensor with its end directed at the light source. The display reads out the intensity of the source's UV-A or UV-C light component in units of mW/cm^2. The UV spectrum charts from the UV254SD are shown in Figs. 1 and Fig. 2.

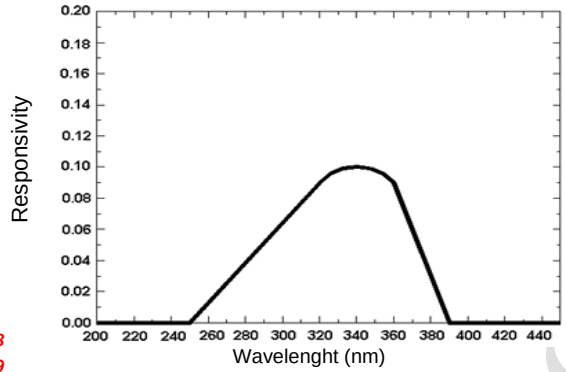

Fig. 1. UV-A sensor spectrum of UV254SD.

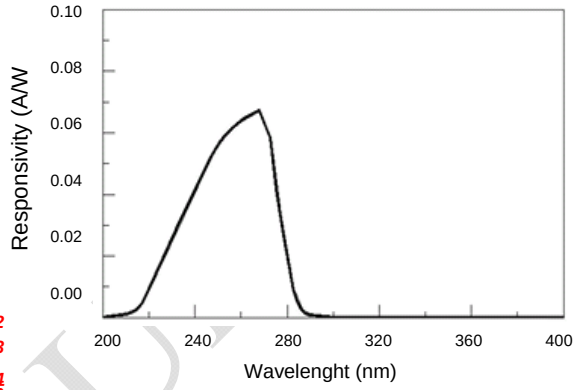

Fig. 2. UV-C sensor spectrum of UV254SD.

The probes where tested against UV lamps with known UV-A and UV-C irradiance levels at the Ghana Standards Authority (GSA) and the spectral response was confirmed to be accurate. When a filter is placed on the probe to prevent UV detection the meter recorded no readings. Information on each welding machine such as manufacturer, model, year of purchase, number of years of usage, and current used, was recorded. Measurements were made in close proximity to the head and trunk level of the welders. At least three measurements were taken for each welder and an average was taken. It was quite difficult taking measurements as these welders usually performed welding for a short time before stopping and subsequently resuming the welding task for several minutes before stopping again. The researcher needed to be vigilant to ensure the accurate reading of the irradiance levels.

Measurement of the UV-A and UV-C irradiance levels was taken with the UV-A and UV-C probe respectively. The seat of the probe was placed in the socket at the top of the UV254SD and the UV-A measurement mode was selected. The radiometer was calibrated to give the irradiance level directly and respond with a spectral weighting $S(\lambda)$ in accordance with Table 1.

Table 1. UV exposure limits and spectral weighting function [5,18]

λ^a (nm)	EL^d (J m^{-2})	EL^d (mJ cm^{-2})	S(λ)^b	λ^a (nm)	EL^d (J m^{-2})	EL^d (mJ cm^{-2})	S(λ)^b
180	2,500	250	0.012	310	2,000	200	0.015
190	1,600	160	0.019	313^c	5,000	500	0.006
200	1,000	100	0.030	315	1.0×10^4	1.0×10^3	0.003
205	590	59	0.051	316	1.3×10^4	1.3×10^3	0.0024
210	400	40	0.075	317	1.5×10^4	1.5×10^3	0.0020
215	320	32	0.095	318	1.9×10^4	1.9×10^3	0.0016
220	250	25	0.120	319	2.5×10^4	2.5×10^3	0.0012
225	200	20	0.150	320	2.9×10^4	2.9×10^3	0.0010
230	160	16	0.190	322	4.5×10^4	4.5×10^3	0.00067
235	130	13	0.240	323	5.6×10^4	5.6×10^3	0.00054
240	100	10	0.300	325	6.0×10^4	6.0×10^3	0.00050
245	83	8.3	0.360	328	6.8×10^4	6.8×10^3	0.00044
250	70	7	0.430	330	7.3×10^4	7.3×10^3	0.00041
254^c	60	6	0.500	333	8.1×10^4	8.1×10^3	0.00037
255	58	5.8	0.520	335	8.8×10^4	8.8×10^3	0.00034
260	46	4.6	0.650	340	1.1×10^5	1.1×10^4	0.00028
265	37	3.7	0.810	345	1.3×10^5	1.3×10^4	0.00024
270	30	3.0	1.000	350	1.5×10^5	1.5×10^4	0.00020
275	31	3.1	0.960	355	1.9×10^5	1.9×10^4	0.00016
280^c	34	3.4	0.880	360	2.3×10^5	2.3×10^4	0.00013
285	39	3.9	0.770	365^c	2.7×10^5	2.7×10^4	0.00011
290	47	4.7	0.640	370	3.2×10^5	3.2×10^4	0.000093
295	56	5.6	0.540	375	3.9×10^5	3.9×10^4	0.000077
297^c	65	6.5	0.460	380	4.7×10^5	4.7×10^4	0.000064
300	100	10	0.300	385	5.7×10^5	5.7×10^4	0.000053
303^c	250	25	0.120	390	6.8×10^5	6.8×10^4	0.000044
305	500	50	0.060	395	8.3×10^5	8.3×10^4	0.000036
308	1,200	120	0.026	400	1.0×10^6	1.0×10^5	0.000030

^{a}Wavelengths chosen are representative; other values should be interpolated.
^{b}Relative spectral effectiveness.
^{c}Emission lines of a mercury discharge spectrum.
^{d}EL for a monochromatic source, but also limited by a dose-rate of 10 kW/m^2 (1 W/cm^2) for durations greater than 1 s as well in order to preclude thermal effects.

It was also designed to mimic the directional sensitivity of the human skin, which was assumed to be a plane surface and follow a cosine dependence (cosine response). To determine a realistic level of exposure, the probe was held by its handle in close proximity to the welders' head or chest, which are the parts of the body of interest and where significant exposure was expected to occur. The sensor of the probe was pointed at the direction of the light source. The display then showed the irradiance level of the source's UV-A and UV-C light component in the unit of mW/cm^2, which was

converted to W/m^2 for the purposes of this study. For every measurement, multiple sampling times of at least 30 seconds were used. Not less than three sampling times were used for each measurement. Multiple readings were logged in the memory of the radiometer and also recorded on a data sheet for each sampling time. The maximum value measured in three selected sampling times, was then chosen and averaged.

RESULTS AND DISCUSSION

Types of welding machines surveyed

There were basically two categories of welding machines, the locally manufactured ones and the imported ones, and all of them were alternating current (AC) welding machines. Out of the 70 welders studied, 51 (72.86 %) of them used the locally manufactured welding machines which are either using transformer oil or motor-driven and 19 (27.14 %) of them used imported arc welding machines.

Welding machine operators

Specific codes were used by the researchers to identify each welder in place of their names to protect their anonymity. These codes corresponded to the part of the Greater Accra Region their workshops or factories were located. The welders were between 16 and 65 years old and hailed from a variety of work fields including, among others. car maintenance/repair, advertisement, and construction sites. The average distance of welders from the welding arc was measured to be 52.71 cm, although measurements were recorded at various distances ranging from 30 cm to 70 cm.

Assessment of UV-C irradiance levels from SMAW

Figure 3 shows the UV-C irradiance $E_{UV\text{-}C}$ measured from the SMAW machine at the head/trunk level of the welders. The $E_{UV\text{-}C}$ ranged from 0.16 ± 0.08 W/m^2 to 10.46 ± 1.96 W/m^2. The average $E_{UV\text{-}C}$ was calculated to be 1.89 W/m^2. The $E_{UV\text{-}C}$ may actually be higher since the welders have the tendency for going closer to the workpiece during the strike of the arc, and irradiance is inversely proportional to the square of distance.

The corresponding permissible exposure duration ($t_{max\text{-}UV\text{-}C}$) per day for the $E_{UV\text{-}C}$ were calculated. The $t_{max\text{-}UV\text{-}C}$ is intended to provide protection to workers from acute and delayed effects of UV-C exposure. Conforming to the irradiance level, the $t_{max\text{-}UV\text{-}C}$ ranged from 5.74 s to 367.35 s. The 5.74 s corresponded to the worst-case UV-C exposure of 10.46 ± 1.96 W/m^2, and hence the $t_{max\text{-}UV\text{-}C}$ increases as the irradiance level decreases. Figure 3 shows the $t_{max\text{-}UV\text{-}C}$ correlating to the $E_{UV\text{-}C}$ of the welders. The range of $t_{max\text{-}UV\text{-}C}$ suggests that UV-C from SMAW may actually be hazardous to the eye and skin. The average $t_{max\text{-}UV\text{-}C}$ was found to be 66.52 s and the welders are likely to exceed this in a day.

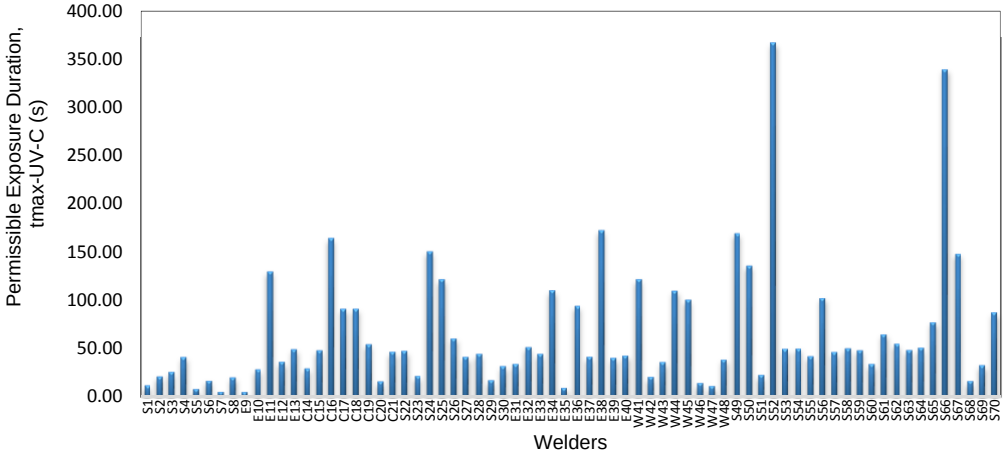

Fig. 3. Irradiance level of UV-C radiation $E_{UV\text{-}C}$ of various welders using SMAW.

Permissible exposure duration of UV-C

The corresponding permissible exposure duration ($t_{max\text{-}UV\text{-}C}$) per day for the $E_{UV\text{-}C}$ were calculated. The $t_{max\text{-}UV\text{-}C}$ is intended to provide protection to workers from acute and delayed effects of UV-C exposure. Conforming to the irradiance level, the $t_{max\text{-}UV\text{-}C}$ ranged from 5.74 s to 367.35 s. The 5.74 s corresponded to the worst-case UV-C exposure of 10.46 ± 1.96 W/m^2; hence, the $t_{max\text{-}UV\text{-}C}$ increases as the irradiance level decreases. Figure 4 shows the $t_{max\text{-}UV\text{-}C}$ correlating to the $E_{UV\text{-}C}$ of the welders. The range of $t_{max\text{-}UV\text{-}C}$ suggests that UV-C from SMAW may actually be hazardous to the eye and skin. The average $t_{max\text{-}UV\text{-}C}$ was found to be 66.52 s and the welders are likely to exceed this in a day.

Therefore, the total exposure time may become sufficient to cause ocular damage such as photokeratitis (inflammation of the cornea) and photokeratoconjunctivitis (inflammation of the conjunctiva, the ocular lining) or skin defects such as erythema, if the permissible exposure duration is drastically exceeded in a day, especially if the welder does not wear the appropriate welding gear or personal protective equipment (PPE). Appropriate PPE such as masks, gloves, and welding goggles have been found to diminish UV radiation levels by large amounts [17].

Assessment of UV-A irradiance levels from SMAW

The irradiance of UV-A (315-400 nm) radiation $E_{UV\text{-}A}$ was measured at various distances between the welders and the welding arc. The $E_{UV\text{-}A}$ ranged from 0.88 ± 0.03 W/m^2 to 23.72 ± 6.66 W/m^2. The highest reading of 23.72 ± 6.66 W/m^2 was taken at W48, a small scale metal construction welder. Other relatively high values were recorded at other metal construction workshops, S49 and S53, that were welding coal pots and gates, respectively, at the time of the measurements. The average $E_{UV\text{-}A}$ was calculated to be 10.78 W/m^2, and 84.29 % of the measured $E_{UV\text{-}A}$ was above 5 W/m^2, which shows that relatively high UV-A was emitted from the SMAW. Figure 5 shows the $E_{UV\text{-}A}$ measured from the shielded arc metal welders.

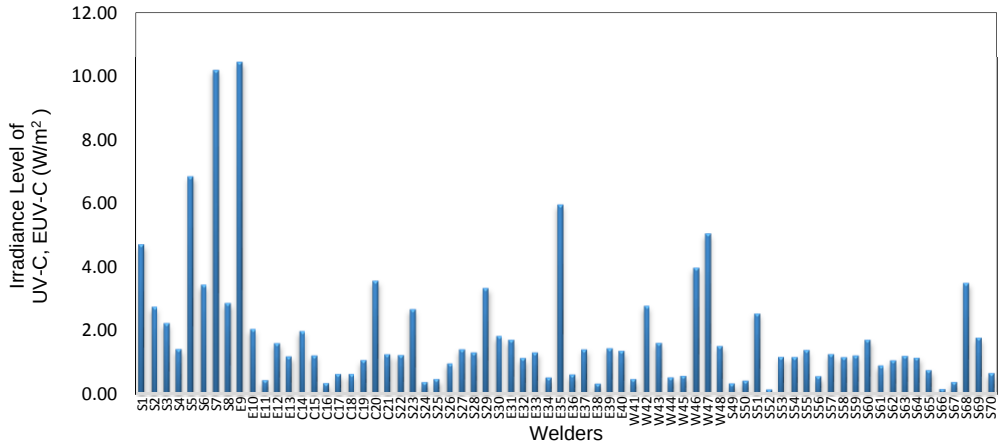

Fig. 4. Permissible exposure duration $t_{max\text{-}UV\text{-}C}$ for corresponding $E_{UV\text{-}C}$ of welders using SMAW.

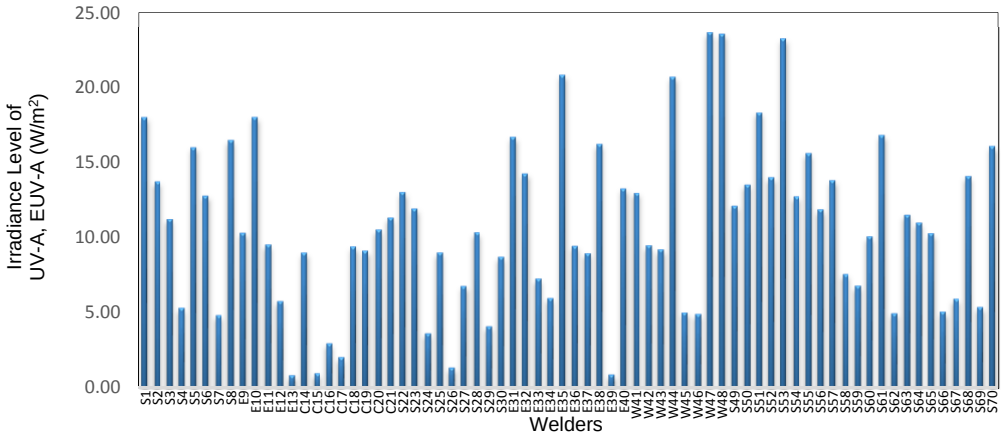

Fig. 5. Irradiance level of UV-A radiation $E_{UV\text{-}A}$ of various welders using SMAW.

Permissible exposure duration of UV-A

Due to the relatively high $E_{UV\text{-}A,}$ the permissible exposure duration $t_{max\text{-}UV\text{-}A}$ in relation to the UV-A was calculated to determine the recommended limits for each welder. This is graphically presented in Fig. 6.

The $t_{max\text{-}UV\text{-}A}$ had a range of 421.59 s to 11 363.64 s per day. The highest $E_{UV\text{-}A,}$ 23.72 ± 6.66 W/m^2, had the shortest permissible exposure duration of 7.03 min and the lowest $E_{UV\text{-}A,}$ 0.88 ± 0.03 W/m^2, had the longest permissible exposure duration of 189.39 min. The $t_{max\text{-}UV\text{-}A}$ has a relatively low average of 27.39 min per day but the total exposure time of the welders may be far more than this due to the nature of their work. This means that the UV-A measured from the SMAW may be sufficient to cause erythema, blistering, or prickling or burning sensations, and even cataracts and skin cancers, if the total exposure time frequently exceeds the $t_{max\text{-}UV\text{-}A}$ in a day and the suitable PPE is not worn.

Analysis of combined $E_{UV\text{-}A}$ and $E_{UV\text{-}C}$

The combined $E_{UV\text{-}A}$ and $E_{UV\text{-}C}$ from each welder using the SMAW process was shown as E_{eff}. This is not reflective of the true E_{eff}, since UVB was not detected due to the detection limits of the UV254SD radiometer. Hence, it might be underestimated; it does, however, give a rough idea of the total UV radiation from the SMAW process. Also, the total permissible exposure duration of the E_{eff} $(= E_{UV-A} + E_{UV-C})$, namely $t_{max,}$ was calculated using Eq. (1). This was done to give an estimate of the permissible exposure duration due to the total UV radiation from the SMAW process. A comparison of the $E_{UV\text{-}A}$ and $E_{UV\text{-}C}$ from each measurement is presented in Fig. 7, while the results of the E_{eff} and its corresponding t_{max} are shown in Figs. 8 and 9, respectively.

From Fig. 8, the obtained effective irradiance, E_{eff}, is in the range of 2.08 W/m^2 to 28.79 W/m^2 with the range of permissible exposure duration, t_{max}, of 1.04 s to 14.40 s per day (Fig. 9). This suggests that UV radiation from SMAW is actually hazardous to the eyes and skin. The average E_{eff} is 12.67 W/m^2 and the average t_{max} per day is 3.45 s. Although this might be an underestimation, it still suggests that UV radiation from SMAW may be hazardous to the skin and eyes.

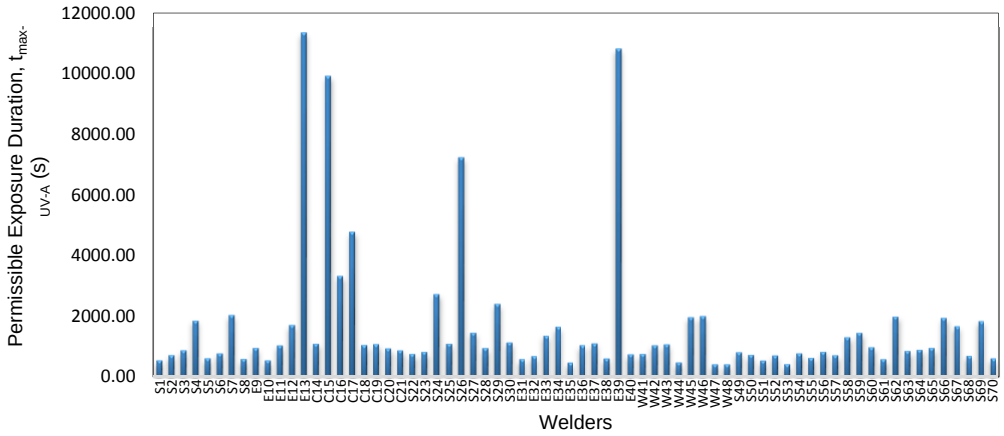

Fig. 6. Permissible exposure duration $t_{max\text{-}UV\text{-}A}$ for corresponding $E_{UV\text{-}A}$ of welders using SMAW.

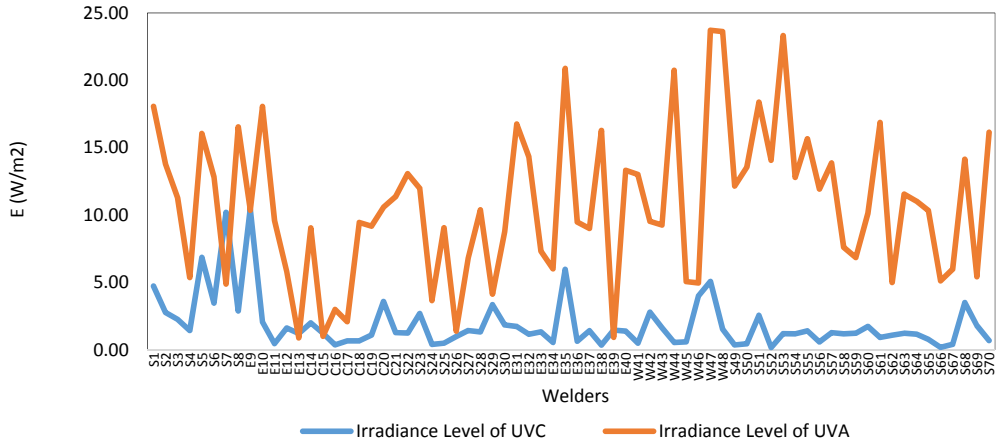

Fig. 7. Comparing UV-A and UV-C measurements from the various welders using SMAW.

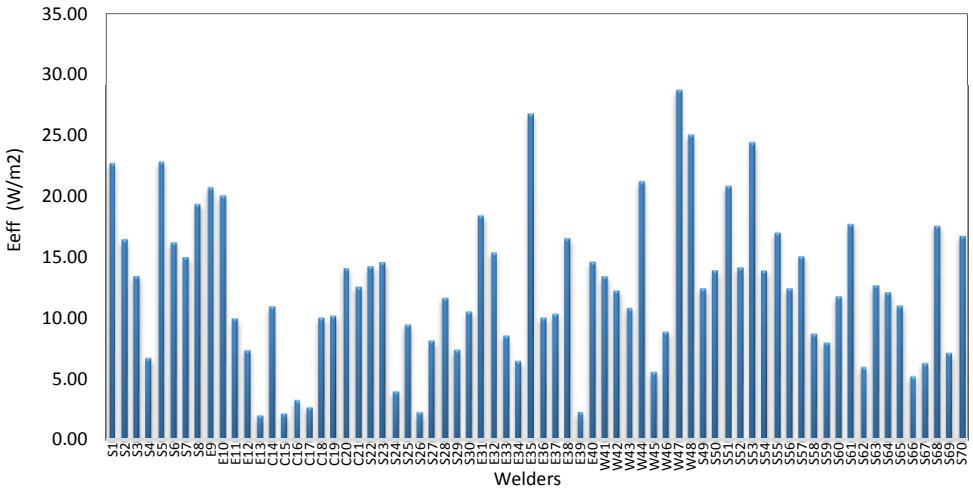

Fig. 8. E_{eff} (= $E_{UV\text{-}A}$ + $E_{UV\text{-}C}$) from the various welders using SMAW.

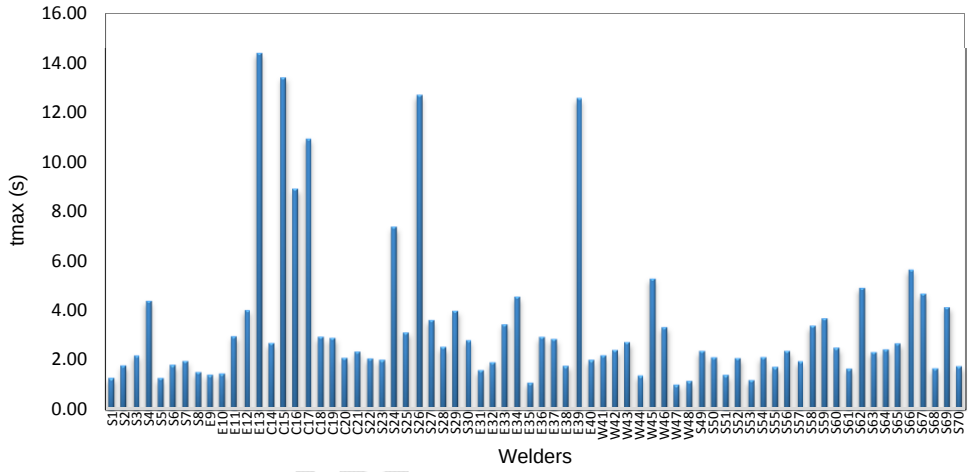

Fig. 9. Corresponding permissible exposure duration t_{max} per day for E_{eff}.

The UV-A and UV-C irradiance levels were 10 000 J/m^2 and 60 J/m^2 respectively. The irradiance measured received by welders emitting from various level of UV-C from the arc of SMAW ranged from SMAW arcs in Ghana. Their estimated number 0.16 ± 0.08 W/m^2 to 10.46 ± 1.96 W/m^2 under of hours of welding in a day was analyzed from the conditions of this study. The corresponding their responses as given in the questionnaire. permissible exposure duration per day range was The irradiance level from the welding UV-A and 5.74 s to 367.35 s. The irradiance level of the UV-A UV-C was measured with a radiometer whose ranged from 0.88 ± 0.03 W/m^2 to 23.72 ± 6.66 W/m^2 response to the different wavelengths is weighted with a permissible exposure duration of 421.59 s by the relative spectral effectiveness factor, $S(\lambda)$. to 11 363.64 s per day. An estimated effective The spectral weighting function for UV-A and UV- irradiance E_{eff} was calculated by combining the C measurements and evaluation followed ACGIH UV-A and UV-C irradiance levels from each arc of and ICNIRP guidelines. Occupational health and the SMAW and had a range from 2.08 W/m^2 to safety guidelines, regulations, and standards have 28.79 W/m^2 with the corresponding permissible been developed in several countries and by exposure duration, t_{max}, per day ranging from 1.04 s international organizations to protect workers and to 14.40 s. Since the welders total exposure time the general public from potentially hazardous may exceed the permissible per-day exposure exposure to ultraviolet radiation. The two most duration, multiplying their total time with the widely used guidelines are virtually identical. Both irradiance levels will greatly exceed the the ICNIRP and the ACGIH guidelines for human recommended guidelines. This suggests that UV exposure of the eyes and skin to UVR is 30 J/m^2 radiation from SMAW arc welding may actually be effective. The guidelines for UV-A and UV-C are hazardous to the eyes and skin. Comparing the

irradiance levels from SMAW in this research to that conducted by [17] in Taiwan suggests that UVR from SMAW arc welding is actually hazardous to the eyes and skin. They had an effective irradiance at 50 cm from the arc of SMAW in the range of 33.1 to 311.0 μW/cm^2 with a permissible exposure time per day of 9.6 to 90.6 s while the results of this study suggests the estimated effective irradiance at various distances ranges from 2.08 W/m^2 to 28.79 W/m^2 with a permissible exposure duration of 1.04 s to 14.40 s.

From the analysis of the questionnaire administered, most of the welders worked six days a week and above 7 hours a day. About 81.43 % of the welders stated they did not take any leave of absence in a year and sometimes only rested on public holidays. Most of the welders (80 %) attested to the fact that they sometimes weld without welding goggles, stating that the nature of some works do not permit them to, and it is possible that most of these goggles had an inappropriate shade number for the type of welding they performed since most did not take that into consideration when purchasing the gadget. Most of them confirmed that they frequently welded without protective coat, with some claiming the weather was too hot to put the coat on. This gives a general idea that safety practices among the welders was not adequate. The analysis of the open-ended questions suggested that 87.14 % of them had a fair knowledge about safety although only 18.57 % had attended any safety program or training before. Some stated lack of money as being the reason they could not practice adequate safety standards, indicating that the appropriate goggles were quite expensive and they could not afford those. It was also observed that symptoms such as redness of skin, prickling and burning, blisters, itchiness in the eye, cloudy vision, nausea, headache, and heart palpitations were mostly experienced only occasionally. Even so, not only should the immediate signs and symptoms be considered, but the long term effects such as skin cancers and cataracts should also be taken seriously. Since most of these symptoms are experienced by the welders and may be caused by their exposure to UV radiation and extremely low frequency (ELF)/medium frequency (MF) emission, there is a possibility that long term effects associated with these physical agents, especially UV radiation, may also develop. The welders must therefore take their skin and eye protection very seriously.

In this study, it was attempted to reduce recall bias to a minimum level. The subjects were requested to give their information as accurately as possible and the margin for error in reporting the welding duration was reduced by observing some of these welders thoroughly.

CONCLUSION

Two of the most widely used guidelines are virtually identical: the ICNIRP and ACGIH guidelines for human exposure of the eyes and skin to UVR is 30 J/m^2 effective. The guidelines for UV-A and UV-C are 10 000 J/m^2 and 60 J/m^2 respectively. The irradiance level of UV-C from the arc of SMAW ranged from 0.16 ± 0.08 W/m^2 to 10.46 ± 1.96 W/m^2 under the conditions of this study. The corresponding permissible exposure duration per day ranged 5.74 s to 367.35 s. The irradiance level of the UV-A ranged from 0.88 ± 0.03 W/m^2 to 23.72 ± 6.66 W/m^2 with a permissible exposure duration of 421.59 s to 11 363.64 s per day. Since the welders total exposure time may exceed the permissible exposure duration per day, multiplying their total time with the irradiance levels will greatly exceed the recommended guidelines. This suggests that UV radiation from shielded metal arc welding may actually be hazardous to the eyes and skin.

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