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Assessment of Effective Irradiance from UV Radiation in Some Welding Workshops within Ogbomoso, Nigeria

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ABTRACT

Background: Arc welding process emits different types of radiations such as ultraviolet, visible light and infrared radiation. It has been discovered that ultraviolet radiation (UVR) causes acute eye injuries such as photokeratitis with accompanying symptoms such as ocular pain, tearing, and a sensation of sand in the eye. This research aimed to assess impact of ultraviolet radiation on ocular tissues due to varied welding activities.
Methods: The irradiance from the UVR emitted from imported welding machine (MMA-250), and a locally constructed welding machine were measured using ultraviolet radiometer calibrated at 365 nm. Measurements were taken at 25 - 350 cm during continuous welding to maintain consistent estimated effective irradiance.
Results: The irradiances at 25 cm for locally constructed welding machine were in the range of 3.00 - 5.69 mW/cm^2, and has a corresponding time limit of 0.53 - 1.0 s while irradiance at 25 cm for imported welding machine varied between 1.32 - 2.06 mW/cm^2 and has a corresponding time limit of 1.5 - 2.3 s. At 50 and 100 cm, the irradiance for both locally constructed and imported welding machine are 1.23- 1.87 mW/cm and 0.58 - 1.16 mW/cm^2 respectively. The irradiances at 25 - 100 cm for both welding machines were above the permissible exposure limits recommended by the American Conference of Governmental Industrial Hygienists (1.0 mW/cm^2 for 16 s). The ANOVA test (p = 0.658) carried out on the effective irradiances from local and imported machines revealed that there is no significant difference between them.
Conclusion: The welding activities using locally and imported welding machines may pose radiological damage to the eyes of welders and cause severe damage to the tissue of the eyes. Hence, welders should be encouraged to comply with the safety guidelines of welding activities.

Keywords: Ultraviolet Radiation (UVR), welding workshop, welders, irradiance.

INTRODUCTION

Radiation is the emission or transmission of energy in the form of waves or particles via space or a material medium. It can originate from unstable atoms or be manufactured by machines. Resources both natural and man-made are sources of radiation. Natural radiation sources can be found in space as cosmic, in the ground as terrestrial, and within human bodies as internal radiation that can be ingested or inhaled.[1] (Ruhal *et al.*, 2021). High-level electromagnetic radiations are produced by artificial sources and are commonly found in medical equipment such as Positron Emission Tomography (PET), Radiation Therapy, Chemotherapy, Immunotherapy, X-ray Computed Tomography (CT), Laser Lithotripsy, and Magnetic Resonance Imaging (MRI).[2] (Sidra *et al.*, 2019).

Radiation comes in many different forms, some of which we are all familiar with: radioactivity, nuclear power, and atomic energy. Additional forms are radio and television transmissions, sound, visible light, UV radiation (which tans skin), and infrared radiation (which is a type of thermal energy).[3] (CNSC, 2012). Electromagnetic radiation is typically used to describe energy that is conveyed over space or another medium.[4] (ASER, 2020).

Applying extreme heat between two metal parts leads them to melt together and intermix, which is the process of welding. The construction of shipyards, civil engineering projects, the mining sector, the petrochemical sector, and the metallurgy sector all heavily rely on welding operations.[5] (Christopher, 2013). Welding is a frequent activity seen in a variety of vocational settings, but it is also employed as "home practice" by many people. First, it was determined to measure welding emitting AOR (UV, visible, and IR) in the controlled laboratory conditions of the Welding Laboratory of the Naval Architecture and Marine Engineering School of the NTUA in order to model and quantify the variety of the welding activities.[6] (George *et al.*, 2016).

A significant aspect of the human environment is the workplace. The working environment has a significant impact on employees' productivity and well-being in any given firm. It is a well-established fact that there is always a possibility of danger in any activity. There are certain risks that arc welders and others around them may encounter.[7] (Taylor and Francis, 2023). When appropriate operating procedures are followed and enough precautions are taken to shield the welder from potential risks, arc welding is a safe technique.

According to the World Health Organization (WHO), around 250 million incidents of work-related injuries occur each year worldwide. Welding is one of the jobs that cause these occupational injuries, particularly in developing nations.[8] (Chauhan *et al.*, 2014). In addition to being a regular and necessary procedure in engineering tasks, welding is linked to a number of health risks. Welding activities produce gasses and microscopic solid particles, collectively known as welding smoke. The majority of this is produced by arc welding.[9] (Pankaj, 2015). Welders may face serious risks from arc rays and sparks, electric shock, and fumes and gasses if these risks are disregarded.

The arcs associated with arc welding emit high levels of ultraviolet radiation (UVR), and there are a number of workers at risk from such exposure. These include not only professional welders 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.[10] (Bohs and Richard, 2001).

Arc welding produces the full spectrum of UVR including UVA (400–315 nm), UVB (315–280 nm), and UVC (280–100 nm). UVA penetrates the skin more deeply than

UVB or UVC, but is less associated with DNA damage.[11] (Horneck, 2010). However, epidemiological data indicate that UVA may be an important factor for the development of malignant melanoma.[12] (Moan *et al.,* 2008). UVB is responsible for erythema and most of the DNA damage within skin cells, and consequently most of the resultant skin cancers.[13] (Gallagher and Lee, 2006). Humans are rarely exposed to UVC, as solar UVC is readily absorbed in the atmosphere before it reaches the earth's surface. In contrast, welders could also be exposed to UVC, as the short distance between the arc and the welder's skin may not be sufficient to absorb most of the UVC.[14] (Baxter, 2010). The influence of ultraviolet radiation on the organism of a human being is mostly expressed by the influence on the eyes, skin and immune system. Excessive eye exposure to ultraviolet radiation in a short amount of time can result in injuries to the eyes. Symptoms include pain and redness of the eye, sensitivity to light, and a gritty feeling in the eye. Various symptoms are sometimes referred to as 'Welder's Flash', 'Arc Eye', or 'Snow-blindness'. Prolonged exposure to certain UV wavelengths can increase your risk of cataracts.[7] (Taylor and Francis, 2023). The permeability of the hazardous effects of ultraviolet radiation has initiated a great number of researches during the recent 20 years.[15] (Vander *et al.,* 2011). Exposure to ultraviolet radiation is a significant risk factor for ocular disease especially the cornea. Acute UVR exposure in man can cause photokeratitis characterized by apoptosis and exfoliation of the corneal epithelium, formation of punctate ulcers, inflammation, edema, and pain.[16] (Cullen, 2002). Lifetime exposure to chronic UVR has been directly associated with the development of cortical cataracts in man, and the World Health Organization has reported that as much as 20% of cataract-associated blindness may be due to UVR exposure.[17] (Robman and Taylor, 2005).

MATERIALS AND METHOD

Sources of radiation

The research was carried out in Ogbomoso, Oyo State. Ogbomoso, a densely populated urban area in Nigeria, is characterized by a high prevalence of welding workshops where various welding processes are routinely performed. Majority of the welders in Ogbomoso make use of electrical welding machine and the most common electrical welding machine used is the Maxmech Inverter (MMA250) welding machine because it's an inverter welding machine and do not consume much electricity. Eight welding workshops that make use of electrical welding machine were randomly chosen for this study. The workshops were chosen with a fair representation of each region within Ogbomoso. Four workshops with locally constructed welding machine and four workshops with imported welding machine (MMA250) were considered for this study.

Measurement of Irradiance

The ST513 UVAB radiometer was used to measure the irradiance in this research work. The meter is a portable, handheld UV irradiation measurement tool. With a calibration point of 365 nm, the apparatus was made to detect ultraviolet radiation intensity (irradiance or power density) in the UVAB range, which is 280 nm to 400 nm. Plate 1 illustrates the radiometer's digital readout in radiometric units and its wide illumination range from 1 μW/cm^2 - 40.00 mW/cm^2. Additionally, the calibration of the radiometer can be traced back to the National Institute of Standards and Technology (NIST), USA. The meter was used to measure the irradiance from an electric arc of imported welding machine (MMA 250) and a locally constructed welding machine at various distances of the arc from the radiometer. The meter's probe was kept one centimeter from the measurement region. The measurement was not tampered with by noting and recording the background radiation value with great care. The sensor head is calibrated at a wavelength of 365 nm and records UV radiation in the region between 290 and 400 nm. Using a meter rule, the meter was moved across each predetermined distance (25 cm intervals), and all measurements were made while the welding process continued continuously to maintain the same intensity level. The result was recorded and the procedure was repeated for all the selected workshops for this study.

Plate 1: ST513 UVAB Radiometer (www.sentrytek.com)

Estimation of the Effective Irradiance

In general, the American Conference of Governmental Industrial Hygienists' (ACGIH) recommendations are followed when assessing the risks associated with ultraviolet light. According to ACGIH guidelines, the effective irradiance obtained for each interval from each of the selected workshops was estimated using the following equation.

$$E_{eff} = \sum_{180}^{400} E_{\lambda} . S(\lambda). \Delta\lambda \quad (1)$$

In this equation, the effective irradiance is expressed as E_{eff} in (W/cm^2), the spectral irradiance at wavelength λ is expressed as E_{λ} in W/(cm^{2}. nm), the relative spectral effectiveness at wavelength(λ) is expressed as $S(\lambda)$, and $\Delta\lambda$ is the wavelength bandwidth (in nm).

The integral of the effective irradiance for eight hours a day, or TLV at 270 nm, is 3 mJ/cm^2. Equation (2) can therefore be used to determine the maximum exposure duration, or tmax (s) per day, versus the effective irradiance when UVR is applied to exposed skin or eyes.

$$\text{Tmax (s)} = \frac{3mJ/cm2}{E_{eff}} \quad (2)$$

The daily exposure to UV radiation is calculated using the weighted average exposure time, which is averaged to an 8-hour workday while accounting for average substance levels and time spent in the area (ACGIH, 2015).

$$\text{TWA} = I_{max} \times t\ (s) \quad (3)$$

From equation (3), I_{max} = maximum intensity, t (s) = time

RESULT

Effective Irradiance

Tables 1-4 show the result of the measured irradiance from locally constructed welding machine for different locations. Tables 4.5-4.8 show the result of the measured irradiance from MMA250 welding machine for different locations.

Table 1: The Effective Irradiance and the Maximum Exposure Time for locally constructed welding machine for Oja Aro, Oke Aanu area.

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	4.90	4.90	0.61
2	50	1.48	1.48	2.03
3	75	0.82	0.82	3.66
4	100	0.72	0.72	4.17
5	125	0.69	0.69	4.35
6	150	0.59	0.59	5.08
7	175	0.55	0.55	5.45
8	200	0.52	0.52	5.77
9	225	0.44	0.44	6.82
10	250	0.40	0.40	7.50
11	275	0.39	0.39	7.69
12	300	0.36	0.36	8.33
13	325	0.30	0.30	10.00
14	350	0.28	0.28	10.70

Table 2: The Effective Irradiance and the Maximum Exposure Time for locally constructed welding machine for Sawmill Apake

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	3.00	3.00	1.00
2	50	1.60	1.60	1.88
3	75	1.50	1.50	2.00
4	100	1.16	1.16	2.59
5	125	0.73	0.73	4.11
6	150	0.42	0.42	7.14
7	175	0.31	0.31	9.68
8	200	0.27	0.27	11.1
9	225	0.24	0.24	12.5
10	250	0.22	0.22	13.6
11	275	0.20	0.20	15.0
12	300	0.19	0.19	15.8
13	325	0.17	0.17	17.6
14	350	0.14	0.14	21.4

Table 3: The Effective Irradiance and the Maximum Exposure Time for locally constructed welding machine for Ori Oke community high school, Igbo Agbanyin

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	5.69	5.69	0.53
2	50	1.23	1.23	2.44
3	75	0.84	0.84	3.57
4	100	0.58	0.58	5.17
5	125	0.54	0.54	5.56
6	150	0.47	0.47	6.38
7	175	0.42	0.42	7.14
8	200	0.41	0.41	7.32
9	225	0.38	0.38	7.89
10	250	0.36	0.36	8.33
11	275	0.35	0.35	8.57
12	300	0.34	0.34	8.82
13	325	0.30	0.30	10.0
14	350	0.26	0.26	11.5

Table 4: The Effective Irradiance and the Maximum Exposure Time for locally constructed welding machine for Saw mill area, Pakiotan

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	5.47	5.47	0.55
2	50	1.87	1.87	1.60
3	75	1.07	1.07	2.80
4	100	0.89	0.89	3.37
5	125	0.76	0.76	3.94
6	150	0.68	0.68	4.41
7	175	0.59	0.59	5.08
8	200	0.49	0.49	6.12
9	225	0.40	0.40	7.50
10	250	0.36	0.36	8.33
11	275	0.31	0.31	9.68
12	300	0.29	0.29	10.3
13	325	0.26	0.26	11.5
14	350	0.22	0.22	13.6

Table 5: The Effective Irradiance and the Maximum Exposure Time for MMA 250 welding machine for Igbo Agbanyin Community

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	1.32	1.32	2.27
2	50	0.76	0.76	3.94
3	75	0.68	0.68	4.41
4	100	0.55	0.55	5.45
5	125	0.48	0.48	6.25
6	150	0.41	0.41	7.31
7	175	0.40	0.40	7.50
8	200	0.38	0.38	7.89
9	225	0.37	0.37	8.11
10	250	0.36	0.36	8.33
11	275	0.34	0.34	8.82
12	300	0.32	0.32	9.38
13	325	0.30	0.30	10.0
14	350	0.26	0.26	11.5

Table 6: The Effective Irradiance and the Maximum Exposure Time for MMA 250 welding machine for Randa Area

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	1.70	1.70	1.76
2	50	1.14	1.14	2.63
3	75	1.04	1.04	2.88
4	100	0.77	0.77	3.89
5	125	0.65	0.65	4.62
6	150	0.55	0.55	5.45
7	175	0.48	0.48	6.25
8	200	0.43	0.43	6.98
9	225	0.36	0.36	8.33
10	250	0.29	0.29	10.3
11	275	0.25	0.25	12.0
12	300	0.23	0.23	13.0
13	325	0.20	0.20	15.0
14	350	0.15	0.15	20.0

Table 7: The Effective Irradiance and the Maximum Exposure Time for MMA 250 welding machine for Afro junction, Maryland

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	2.06	2.06	1.46
2	50	1.19	1.19	2.52
3	75	1.02	1.02	2.94
4	100	0.80	0.80	3.75
5	125	0.66	0.66	4.55
6	150	0.58	0.58	5.17
7	175	0.55	0.55	5.45
8	200	0.52	0.52	5.77
9	225	0.44	0.44	6.82
10	250	0.43	0.43	6.98
11	275	0.40	0.40	7.50
12	300	0.36	0.36	8.33
13	325	0.31	0.31	9.68
14	350	0.22	0.22	13.6

Table 8: The Effective Irradiance and the Maximum Exposure Time for MMA 250 welding machine for Pakiotan Community

S/N	Distance (cm)	Measured irradiance (mW/cm^2)	Effective irradiance (mW/cm^2)	Maximum Exposure time (tmax) (s)
1	25	1.68	1.68	1.79
2	50	1.02	1.02	2.94
3	75	0.94	0.94	3.19
4	100	0.76	0.76	3.95
5	125	0.72	0.72	4.17
6	150	0.60	0.60	5.00
7	175	0.56	0.56	5.36
8	200	0.50	0.50	6.00
9	225	0.46	0.46	6.52
10	250	0.42	0.42	7.14
11	275	0.38	0.38	7.89

12	300	0.32	0.32	9.38
13	325	0.28	0.28	10.7
14	350	0.20	0.20	15.0

DISCUSSION

The effective irradiances for various workshops using locally constructed welding machine measured in this study at a distance of 25 cm from the arc were in the range of 3.00 mW/cm^2 – 5.69 mW/cm^2. The allowable daily exposure times corresponding to 3.00 mW/cm^2 – 5.69 mW/cm^2 were 1.0 s – 0.53 s. The allowable exposure time recommended by American Conference of Governmental Industrial Hygienist.[17] (ACGIH, 2015) is 1.0 mW/cm² for 16 s. Therefore, if this effective irradiance value is received over a long time by the unprotected worker, it would certainly amount to a significant risk.

A 40-hour workweek and 8-hour workday make up the weighted average exposure duration. Even when exposed to such working conditions on a regular basis, the majority of workers do not experience any negative health repercussions.[18] (ACGIH, 2018). Based on the energy-power relationship, an effective irradiance of 5.69 mW/cm^2 measured for one second is equal to 5.69 mJ/cm^2, and for one hour, it is equal to 20,484 mJ/cm^2. This indicates that the highest effective irradiance of 5.69 mW/cm^2 recorded by the sensor at 25 cm from the source during the four-hour exposure time mentioned above will be comparable to 81,936 mJ/cm^2, meaning that an individual would have been exposed to 163,872 mJ/cm^2 for eight hours. Long-term exposure to this value by an unprotected worker poses a significant risk.[18] (ACGIH, 2018). The unprotected skin or eye should not be exposed to more than 3.0 to 1000 mJ/cm² within an 8-hour period in the ultraviolet spectrum region (200-315 nm), which includes half of the UVC and most of the UVB.

For workshops using MMA 250 welding machine, the effective irradiance measured in this study at a distance of 25 cm from the arc were in the range of 1.32 mW/cm² – 2.06 The allowable daily exposure times corresponding to these values were 1.5 – 2.3 s. These values if received over a long time by the unprotected worker would certainly amount to significant risk. Using the same relationship, the effective irradiance of 2.06 mW/cm^2 recorded for one second will be equivalent to 2.06 mJ/cm^2 and for 1-hour it will be equivalent to 7,416 mJ/cm^2 and 59,328 mJ/cm² for 8-hour period of exposure. This effective irradiance value also shows a substantial risk to the worker.

The significant change in effective irradiance at 25 cm between the two welding machine having effective irradiance values of (5.69 mW/cm², 5.47 mW/cm², 4.90 mW/cm² and 3.00 mW/cm²) for locally constructed welding machine, and (2.06 mW/cm² , 1.70 mW/cm², 1.68 mW/cm², and 1.32 mW/cm²) for imported welding machine (MMA 250), could be attributed to various factors, and indeed, the electrode type and the MMA 250 welding machine being an inverter welding machine may be major contributing factors.

The MMA 250 inverter welding machines are renowned for their advanced engineering, which provides enhanced control and efficiency during the welding process. These devices frequently run at higher frequencies, which could have an impact on the radiation produced while welding. When compared to conventional welding machines (locally produced), the inverter welding machine's design and features may result in varying radiation levels.

Also, measurement from Sawmill Apake shows a lower irradiance at 25 cm (3.00 mW/cm²) despite being a locally constructed welding machine, the reason for this may be due to the electrode type used for the welding. Some welding electrodes may create more intense radiation during the welding process than others due to differences in their compositions and qualities. Comparing one electrode type to another, for instance, certain electrode coatings may produce more UV and infrared radiation than others. So, differences in the effective irradiance may result from changing the type of electrode.

Moreover, at distance 50 cm, an irradiance value of (1.87 -1.23 mW/cm²) were recorded for locally constructed welding machine. The allowable daily exposure times corresponding to these values are 1.6 – 2.4 s. And for distance 100 cm, the irradiance values are (1.16 – 0.58 mW/cm²). The allowable daily exposure times corresponding to these values are 2.6 – 5.2 s. At distance 50 cm, MMA 250 welding machine shows an irradiance value of (1.19 – 0.76 mW/cm²) and the allowable exposure times corresponding to this is 2.5 – 3.9 s.

At distance 100 cm, the effective irradiance ranges from (0.55 – 0.80 mW/cm²) corresponding to 3.75 – 5.5 s. This indicates that both locally constructed welding machine and imported welding machine are still showing significant danger, as the radiation intensity is still high and above the recommended threshold value of 1.00mW/cm². It also indicates that not only welders at work are exposed to UV danger but also people within the workshop.

The radiation intensity assessments of both the locally constructed welding machine and inverter welding machine at 25 cm interval reveal ultraviolet radiation level above the recommended exposure limits of 1.0 mW/cm^2 for period less than 16 s, and weighted average exposure time exceed 3.0 to 1000 mJ/cm² within 8-hour period recommended by the American Conference of Governmental Industrial.[18] (ACGIH, 2018), indicating the need for appropriate protective measures. Additionally, the arc welding worker's trunk was found to be closer to the UV source when he was seated than when he was standing, with an average distance of about 50 cm between them. The results of the measurements made at 25 and 50 cm distances from the source make it abundantly evident that the electric arc welders would be subjected to high intensity levels of all types of UV radiation. To lessen the risk of optical radiation in the welding workshops at Ogbomoso, control measures and safety procedures must be put in place during this period.

The results of the ANOVA carried out reveals that there is no significant difference between the irradiance of both locally constructed and imported welding machine ($p = 0.548$, $F = 0.370$, $F_{crit} = 4.22$). The fact that F is less than F_{crit} reinforce that fact that there is no significant difference between the irradiances measured by both locally and imported welding machines. Thus, the local equipment are not is not significantly inferior or superior to the imported equipment.

CONCLUSION

Assessment of Effective Irradiance from UV Radiation in some Welding Workshops within Ogbomoso for both imported and locally welding machine was carried out using portable, handheld ST513 UVAB radiometer. The irradiances measured at 25 cm for locally constructed welding machine were in the range of 3.00 - 5.69 mW/cm^2 and has a corresponding time limit value of 1.0 s - 0.53 s. Irradiances measured at 25 cm for imported welding machine were in the range of 1.32 - 2.06 mW/cm² and has a corresponding time limit value of 1.5 s– 2.3 s. The irradiance at 25 cm – 100 cm for both welding machine were above the permissible exposure limit (PEL) recommended by the ACGIH (1.0 mW/cm² for 16 s). The results of the ANOVA carried out reveals that there is no significant difference between the irradiance of both locally constructed and imported welding machine ($p=0.658$). This shows that the effective irradiance from both welding machines at 25 cm – 100 cm were capable of causing a significant risk to the welder's eyes.

Declaration by Authors

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APPENDIX

Table 1: Table of ANOVA for Irradiances from Local and Imported Welding Machines.

SUMMARY						
Groups	***Count***	***Sum***	***Average***	***Variance***		
Column 1	14	8.84	0.631429	0.149029		
Column 2	14	12.17	0.869286	1.990653		
ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.396032	1	0.396032	0.370179	0.548186	4.225201
Within Groups	27.81586	26	1.069841			
Total	28.2119	27				

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