Agnieszka Wolska, Andrzej Rybczyński, Mariusz Wisełka, Jolanta Matusiak

Scattered UV Radiation Hazards in the Vicinity of the Arc Welding Station

Abstract: The requirement to assess risks to workers' health arising from the use of artificial optical radiation is imposed by Directive 2006/25 /EC and the regulations implementing the aforesaid directive in Poland. Research works concerning the above-named hazards have been focused on the assessment of the welders' exposure to direct ultraviolet radiation emitted by welding arc, yet they have not been concerned with persons working in the vicinity of the welding station. Part of optical radiation emitted by arc is reflected and scattered in the vicinity of welding station, thus reaching beyond welding screens or other collective protective equipment. Persons working behind the screens may be exposed to reflected UV radiation characterised by levels exceeding maximum permissible exposure (MPE). The article presents results of tests concerning the level of scattered UV radiation in the vicinity of welding arc during MAG, MAG-Pulse and TIG welding processes (in relation to selected welding parameters). The test results revealed the existence of potential risks in relation to the health of workers performing activities in the vicinity of welding stations, also in cases where protective screens are in place.

Keywords: UV radiation, scattered radiation hazard, exposure level, health hazards

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Introduction

Welding arc is the source of optical radiation from ultraviolet (UV), visible (VIS) and infrared ranges (IR). The UV and VIS ranges of radiation, emitted during arc welding processes, belong to the strongest non-laser radiation sources and, as such, pose various hazards to welders' health [1, 2, 4, 8]. In addition to direct optical radiation emitted by electric arc there is also radiation reflected against surfaces located both in a work environment and on materials subjected welding. The spectrum of optical radiation emitted during arc welding processes depends on the welding method and process parameters including, among other things, current, arc voltage, arc length, arc temperature, the distribution of temperature in arc, materials and diameters of electrodes (or filler metal wires), types of shielding gases as well as types of materials subjected to welding [10].

dr hab. inż. Agnieszka Wolska, mgr. inż. Mariusz Wisełka – Central Institute for Labour Protection - National Research Institute; mgr inż. Andrzej Rybczyński – GL OPTIC Polska Sp. z o.o. Sp.k;
dr inż. Jolanta Matusiak – Łukasiewicz Research Network – Institute of Welding

Optical radiation and its health-related consequences

Optical radiation has a detrimental effect on eyes and skin. The primary photochemical hazards which must be taken into account in relation to arc welding stations include:

- photochemical hazard affecting the cornea and the conjunctiva, posed by UV radiation (180–400 nm, the so-called actinic hazard),
- photochemical hazard affecting the lens, posed by UVA radiation (315–400 nm),
- photochemical hazard affecting the retina, posed by radiation restricted within the range of 300 nm to 700 nm (the so-called blue light).

In accordance with the Regulation of the Ministry of Labour and Social Policy of 29 July 2010 on the highest acceptable concentration and intensity of factors harmful for health in a work environment [15] and the Regulation of the Ministry of Labour and Social Policy of 27 May 2010 on health and safety at work in occupations exposed to optical radiation [16], UV radiation-related hazards are considered in terms of possible photochemical damage affecting skin and eyes. The two criteria concerning the assessment of health hazards caused by UV radiation and corresponding values of maximum permissible exposure (MPE) [14, 15] are the following:

- prevention of factors harmful for the cornea, the conjunctiva and skin – the highest permissible actinically effective value of eye and skin exposure to radiation restricted within the range of 180 nm to 400 nm (H_s) within daily working hours, regardless of duration, should not exceed 30 J/m^2,
- prevention of photochemical cataract – the highest permissible total (non-selective) radiation affecting the eye and restricted within the range of 315 nm to 400 nm (H_{UVA}) within daily working hours, regardless of duration, should not exceed 10 000 J/m^2.

In accordance with information contained in reference publications, the highest exceeding of maximum permissible values of exposure is concerned with photochemical hazards – UV radiation [5, 9, 12, 13]. Photochemical processes result from the molecular absorption of radiation in tissues and even in relation to low power density combined with the simultaneous high absorption of radiation by the tissue are responsible for damage affecting the latter. The biological effect depends on the amount and the wavelength of absorbed radiation as well as types of tissues exposed to radiation (eyes, skin). The photochemical effect is of summation nature, which means that pathological changes may result from a series of doses of UV radiation. For this reason, when determining the time of exposure in relation to photochemical hazard it is necessary take into account the total time of exposure during a working shift. Harmful effects connected with photochemical reactions occurring in the tissues of eyes and skin, broken down into acute and chronic ones, are presented in Table 1. Acute effects usually remain for a maximum of 24 hours following exposure. In turn, chronic effects appear significantly later – usually as a result of multi-annual exposure to radiation.

The International Agency for Research on Cancer (IARC) [5] states that there is a very strong correlation between the incidence of eye melanoma among welders and UV radiation emitted during the welding process. Because of this, the aforesaid radiation is rated among carcinogens of group 1. The aforesaid data confirm the necessity of assessing risk connected with exposure to UV radiation in relation welding stations. In spite of using personal protective equipment, welders suffer from occupational diseases and other harmful effects related to exposure to UV radiation. Not all of the above-presented harmful effects (Table 1) related to exposure to UV radiation and "blue light" ("blue light range" contains partly UV radiation from the range of 300 nm to 400 nm) are listed as occupational diseases connected with exposure to the above-named radiation. In Poland, occupational diseases rated among those caused by the aforesaid radiation include [17]: UV-triggered acute conjunctivitis, far ultraviolet-induced cataract, central degenerative changes of the retina and of the choroid caused by visible radiation from the range of blue spectrum, occupational photodermatosis (simultaneous effect ultraviolet radiation and photosensitising or phototoxic factors present in a work environment), skin cancer (non-melanoma types of cancer and skin melanoma). Related Polish data reveal a relatively small number of cases of the above-named occupational diseases. For instance, in the years 2006–2016, according to the Central Register of Occupational Diseases, the total number of cases amounted to 49, including 44 cases of cataract (41 cases among welders and 2 cases among welding practitioners), 1 case of photodermatosis, 1 case of skin cancer, 2 cases of diseases affecting the retina (diagnosed in 1 welder) and 1 case of contact dermatitis (diagnosed in a welder's assistant).

It should be noted that the data from the register of occupational diseases lack the most "popular" diseases, i.e. acute effects of exposure to ultraviolet radiation, i.e. conjunctivitis and keratitis. Interview-based surveys (conducted by the Central Institute for Labour Protection - National Research Institute and involving a group of 149 welders) focused on, among other things, vision-related ailments, revealed that more than 80% of surveyees reported symptoms of conjunctivitis and keratitis. In addition, the surveyees admitted that they had not reported the ailments to their employers. As a result, the aforesaid cases were not recorded and the welders were not sent to physicians of occupational medicine in order to undergo medical tests. In view of the foregoing it can be assumed that, in spite of vision-related ailments, welders suffering from such problems do not report them to physicians of occupational medicine. As a result, the aforesaid problems are not recorded. In accordance with data of the Central Register of Occupational diseases, welders constitute the largest occupational group suffering from diseases induced by exposure to optical radiation (e.g. cataract or diseases of the retina and those of the choroid). In spite of test results confirming the correlation between exposure to optical radiation emitted during electrical welding and the incidence of various types of

Table 1. Types of optical radiation-triggered photochemical damage (based on [13])

Range	**Organ**	**Types of photochemical damage**		**Remarks**
		Acute effect	**Chronic effect**	
UV 180 – 400 nm	Eye: cornea	Keratitis	Pterygium	Welders suffer from actinic keratitis and conjunctivitis
	Eye: conjunctiva	Conjunctivitis	-	
	Eye: lens	-	Photochemical cataract	Primarily UVA (range of 315 nm to 400 nm)/ among welders [7]
	Eye	-	Eye melanoma	Among welders[5]
	Skin	• Erythema • Sunburn • Photodermatosis	Photoaging, actinic keratosis, skin cancer (basal-cell and squamous cell skin cancer)	Welders suffer from basal-cell cancer and actinic keratosis [3]
"Blue light" 300 – 700 nm	Eye: retina	Photochemical damage affecting the retina (retinitis and degenerative changes of the retina)	AMD – age-related maculopathy	Welders suffer from photochemical damage to retina [6]

skin cancer [3, 5], Polish statistics for the past 11 years do not contain such cases.

Optical radiation hazardous to workers staying in the vicinity of welding stations

The intensity of ultraviolet radiation emitted by welding arc depends both on welding methods (MMA, TIG, MIG, MAG) and welding conditions (welding current, types of materials and thicknesses of electrodes/filler metal wires, types of materials subjected to welding, welding arc length, etc.). The greatest optical radiation-related risks affect welders as their body parts exposed to radiation (eyes and skin) are located nearest to the source of radiation, i.e. welding arc. For this reason, welders are provided with appropriate personal protective equipment because measured levels of exposure indicate significant occupational (photochemical) risks as regards eyes and skin. Although the intensity of ultraviolet radiation decreases along with the growing distance from welding arc, levels of UV radiation (either emitted directly by welding arc or reflected against some elements located in a work environment) present in in the vicinity of welding stations may still be harmful for workers (present in such an area) involved in other activities. Ultraviolet radiation reflected against surrounding elements reaches nearly every area in a workroom and, although its intensity is much lower, the daily dose of radiation may exceed values of maximum permissible exposure (MPE).

Regulations of Directive 2006/25/EC [14] and related regulations of the Ministry of Labour and Social Policy [16] oblige employers to identify stations where UV radiation is present and assess related occupational hazards. However, in cases of workers who are not welders but perform their tasks near welding machines, the harmful factor of UV radiation is not taken into account during the aforesaid identification and assessment. As a result, workers are often unaware of hazards resulting from exposure to invisible ultraviolet radiation. Because of chronic exposure, workers, as they are not equipped with appropriate protection measures, may develop diseases resulting from the harmful effect of ultraviolet radiation both in terms of vision (cataract, keratitis or conjunctivitis) and skin (cancerous lesions and skin melanoma). Due the lack of an identified risk factor affecting the aforesaid workers (i.e. direct or reflected welding arc UV radiation), the scope of preventive tests does not include ophthalmological and dermatological tests focused on the recognition of harmful factors affecting workers' health (by contrast with workers, in relation to whom exposure to hazardous factors has been identified (e.g. welders)).

In accordance with data possessed by the Łukasiewicz Research Network – Institute of Welding, the number of welders in Poland amounts to approximately 90 thousand, whereas the number of persons employed in welding supervision service amounts to approximately 30 thousand. However, it is not possible to estimate the number of workers performing their activities (on a permanent or temporary basis) near welding stations. Regrettably, such workers' unawareness of risks resulting from staying near welding stations without using appropriate personal protective equipment is a relatively common phenomenon.

Previous publications [4, 12, 13] are nearly exclusively concerned with levels of exposure related to welders staying near arc. However, there is no information about publications concerning risks resulting from exposure to scattered radiation in the vicinity of welding stations. In accordance with the photometric law of distance, the intensity of irradiation of direct radiation emitted by arc decreases along with a squared distance. However, in cases where a person is located, e.g. 2 metres away from welding arc, it is necessary to take into account radiation reflected against elements of the welding station and those located in the room. Because of the additivity of direct and reflected radiation, the intensity of irradiation on exposed biological tissues may exceed specified limit values in relation to a given time of exposure. A safe distance from the area where the welding process is performed varies in relation to individual welding techniques and parameters as well as in terms of reflection parameters of a given work environment. As can be seen, it is important to identify safe areas when preparing workstations near welding stations and take the above-presented aspects into consideration. Although in the Polish register of occupational diseases the number of reported and recorded UV-related diseases is very small in relation to the number of welders, as many as 89% of recorded cases were registered in relation to this occupational sector. Regrettably, it remains unknown if and how many UV exposure-related diseases have been recorded in relation to other employees performing their tasks in an arc welding process-affected environment. The aforesaid factor is not entered in the occupational risk assessment chart and not monitored during medical tests. As a result, workers unaware of existing risks do not use appropriate protective equipment.

This article aims to present test results concerning the level of scattered ultraviolet radiation in the vicinity of welding arc during MAG, MAG-Pulse and TIG welding processes, in relation to selected process parameters.

Method of measuring the intensity of irradiation by scattered radiation in the vicinity of welding arc

Areas subjected to measurements

Research-related measurements were performed in laboratories of Łukasiewicz–Instytut Spawalnictwa (Łukasiewicz Research Network – Institute of Welding) during welding processes performed using a semiautomatic welding machine (MAG and MAG Pulse) and a welding robot (TIG). The application of the semiautomatic welding machine or the welding robot enabled the obtainment of the constant (robot) or slightly variable (semiautomatic welding machine) length of welding arc during the welding process; welding parameters were adjusted and controlled accordingly. As regards the robotic welding station, the position of welding arc did not change in relation to the previously selected place of measurement as the workpiece was rotated along its axis during the welding process. During the welding process performed using the semiautomatic welding machine, welding arc moved at a constant travel rate.

Measurement equipment and methodology

The intensity of actinically effective irradiation of scattered UV radiation in the vicinity of welding arc was measured using two radiometers, i.e. ILT 1700 and ILT 1400 (International Light), equipped with two probes. The measurements were performed in accordance with the PN-EN 14255-1 standard [18]. The tests were carried out behind a protective welding screen, approximately 4 metres away from arc (located at a height of 0.76 m above the base). The above-presented approach made it possible to eliminate (from the measurements) the component of direct welding radiation. The measurement height corresponded to the worker's standing position. The measurements were performed at two heights, i.e. 1.8 m above the floor (in the horizontal plane – at the height of the top of the head) and 1.6 m above the floor (in the vertical plane – at the height of the face; the face being directed towards the protective screen, behind which the test welding station was located). Each measurement variant (in relation to appropriately adjusted welding parameters) involved at least 20 readouts. The analysis involved the average value based on 20 measurements.

Welding parameters

During the measurements performed using the TIG method and the welding robot, the length of arc amounted to 3 mm, the electrode diameter amounted to 2.4 mm, whereas welding current was restricted within the range of 20 A to 200 A (with a step of 20 A). The shielding gas used in the test was argon, whereas the material subjected to welding had the form of a copper strip. During the measurements performed using the MAG method and the KEMPPI PRO5200 semiautomatic welding machine, the technological and material conditions of the welding process included an arc length of 12.2 mm, 8 mm thick steel ARMOX 500T (material subjected to welding), an OK Autorod 12.51 filler metal wire having a diameter of 1.2 mm and a welding current of 70 A, 100 A, 120 A, 180 A and 240 A. The welding process was shielded using three various gas mixtures, i.e. Ar+8%CO_2, Ar+18%CO_2 and Ar+12%CO_2+2%O_2. During the measurements performed using the MAG-Pulse method, the technological and material conditions were the same as those applied during the measurements performed using the MAG method.

Analysis of test results

The results obtained in the measurement of actinically effective irradiation were used to calculate their average value (based on 20 readouts). The formula used to determine permissible times of exposure $t_{perm.}$ was the following:

$$t_{perm.} = \frac{H_{MPIcs}}{E_e} = \frac{30}{E_e}$$

where E_e – actinically effective irradiation by scat tered UV radiation – average value, H_{MPIcs} – maximum permissible irradiation of the eye cornea and skin, amounting to 30 J/m2, [14, 16].

During the TIG welding process, in the vicinity of the welding area behind the protective screens, the average values of actinically effective irradiation striking the top of the head did not exceed 0.4 mW/m². The values measured at the top of the head were approximately four times higher than those measured near the face (not exceeding 0.11 mW/m²) In relation to the above-presented welding parameters, the values of actinically effective irradiation striking the top of the head were restricted within the range of 002 mW/m² to 0.4 mW/m². The values of actinically effective irradiation measured near the face were restricted within the range of 0 mW/m² (i.e. values undetected by means of the measurement equipment applied in the tests to 0.11 mW/m². The coefficient of the variability of actinically effective irradiation (calculated as the quotient of the standard deviation from the average test value) was restricted within the range of 25.6% to 58.3% (average value being 35.6%).

The results concerning the permissible time of exposure ($t_{perm.}$) determined in relation to the exposure of the face were restricted within the range of approximately 75 hours to approximately 731 hours. In turn, as regards the exposure of the top of the head, permissible times of exposure were more than 3 times shorter and restricted within the range of approximately 21 hours to approximately 242 hours.

During the MAG welding process, in the vicinity of the welding area behind the protective screens, the average values of actinically effective irradiation near the face were restricted within the range of 1.3 mW/m² to 11.4 mW/m², whereas those at the top of the head were restricted within the range of 2.7 mW/m² to 22.1 mW/m². The values measured near the face were lower than those measured at the top of the head. The diagrams presenting the measured values of actinically effective irradiation striking the face and the head, in relation to various values of welding current, various shielding gases and the filler metal wire having a diameter of 1.2 mm are presented in Figure 1. The results indicate the linear nature of an increase in the actinic irradiation of scattered UV radiation along with an increase in welding current, regardless of the type of shielding gas. The coefficient of the variability of actinically effective irradiation was restricted within the range of 12.6% to 53.3% (average value being 28.8%).

The results concerning the permissible time of exposure ($t_{perm.}$) in relation to the face were restricted within the range of approximately 44 minutes to approximately 396 minutes (6.6 hours). In turn, as regards the top of the head, the permissible time of exposure was approximately shorter by twice and restricted within the range of approximately 22 minutes to approximately 185 minutes (3.08 hours).

During the MAG-Pulse welding process, in the vicinity of the welding area behind the protective screens, the average values of actinically effective irradiation near the face were restricted within the range of 3.4 mW/m^2 to 40.4 mW/m^2, whereas those at the top of the head were restricted within the range of 11.7 mW/m^2 to 98.2 mW/m^2. The values measured near the face were lower than those measured at the top of the head. The diagrams presenting the values of actinically effective irradiation striking the face and those near the head, in relation to various values of welding current, various shielding gases and the filler metal wire having a diameter of 1.2 mm are presented in Figure 2. The results indicate the linear nature of an increase in the actinic irradiation of scattered UV radiation along with an increase in welding current, regardless of the type of shielding gas. The coefficient of the variability of actinically effective irradiation was restricted within the range of 5.8% to 45.8% (average value being 18.6%).

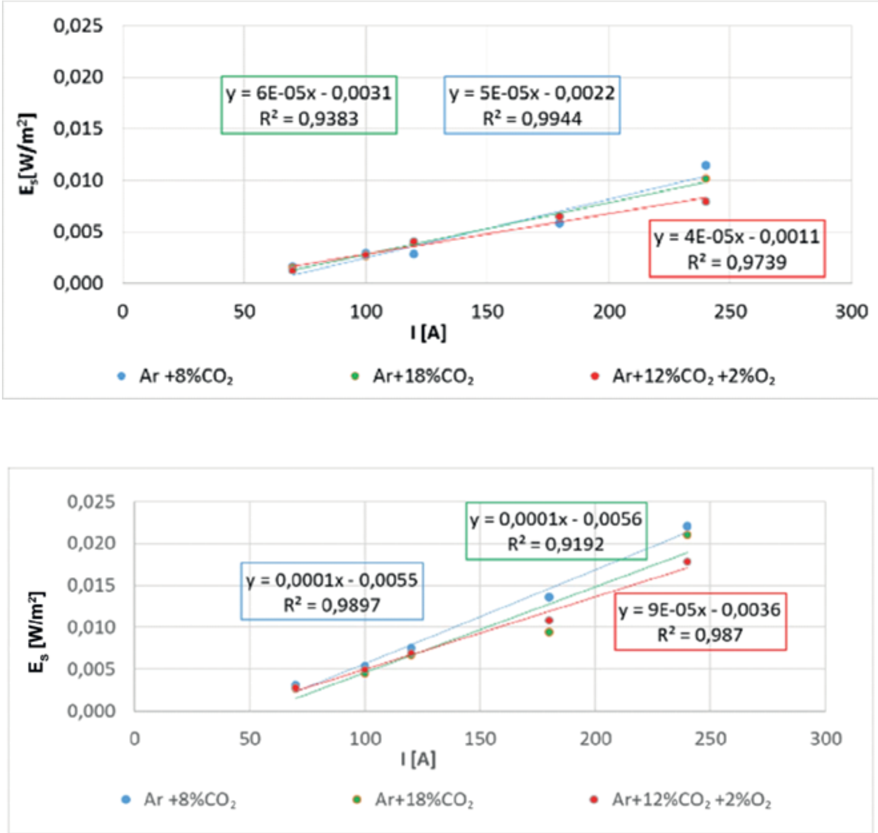

Fig. 1. Actinically effective irradiation identified in the vicinity of the MAG welding station, behind the protective screens: a) near the face and b) at the top of the head

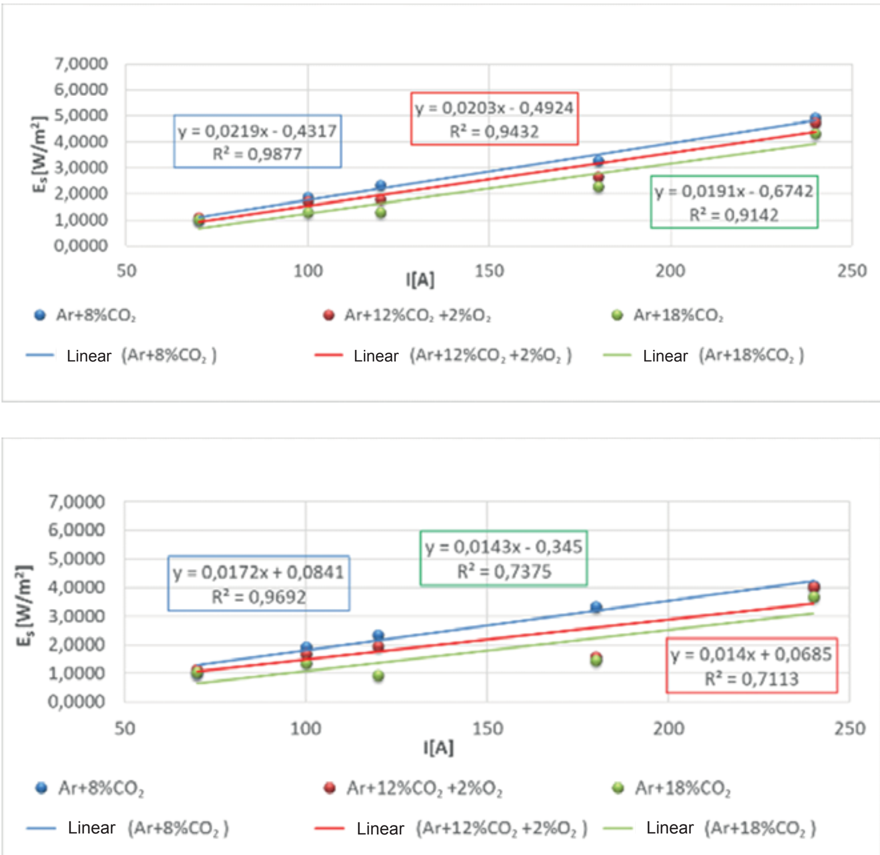

Fig. 2. Actinically effective irradiation identified in the vicinity of the MAG-Pulse welding station, behind the protective screens: a) near the face and b) at the top of the head

The results concerning the permissible time of exposure ($t_{perm.}$) in relation to the face were restricted within the range of approximately 12 minutes to approximately 145 minutes (2.4 hours). In turn, as regards the top of the head, the permissible time of exposure was shorter approximately by twice and restricted within the range of approximately 5 minutes to approximately 42 minutes.

Discussion

The radiometric measurement results concerning the actinic irradiation of UV radiation revealed that the lowest irradiation intensity values were obtained in relation to the TIG welding process, whereas the highest irradiation values were measured during the MAG-Pulse welding process. The significant differences as regards irradiation values in relation to the TIG method and the MAG and MAG-Pulse methods resulted primarily from various levels of UV radiation emitted by welding arc (UV emission during the MAG-Pulse welding process was by approximately 21.3 times higher than that accompanying the TIG welding process and 1.3 times higher than that during MAG welding) as well as from the cubic capacity and reflection properties of the rooms were the welding process was performed.

The values of irradiation intensity determined behind the protective screens resulted, among other things, from multiple reflections against the walls, the ceiling and other elements present in the room. The values measured at the top of the head (horizontal plane) were by between 2 and 3 times higher than those measured near the face (vertical plane). The above-presented values changed along with an increase in welding current (in cases of the MAG and MAG-Pulse methods) as the fraction of reflected radiation was proportional to UV radiation emitted by welding arc. In addition to the reflection properties of elements located in the vicinity of the welding station, an important factor was the location of arc in relation to the surfaces of the aforesaid elements. The longer the distance between welding arc and the reflecting surfaces, the lower the values of reflected radiation reaching the worker located in the room, even behind the protective screens. In cases of the MAG and MAG-Pulse processes, performed in the same welding room and in relation to the same geometric arrangement of the measurement probes, the values measured near the standing worker's head, behind the protective screens and approximately 4 metres away from welding arc, constituted between 0.5% and 1.5% of the values measured before the protective screen and 2.4 metres away from welding arc. In terms of the TIG welding process, performed in a high welding workshop, where irradiation intensity values before the protective screen were significantly lower than those accompanying the MAG and MAG-Pulse process, the values measured at various distances behind the protective screen amounted to a maximum of approximately 0.02% of the values measured before the protective screen at a distance of 2 metres. In accordance with the identified values of irradiation, the values of permissible times of exposure (in relation to persons no using appropriate protective equipment) varied depending on the welding methods subjected to the test. As regards hazards affecting the cornea, the conjunctiva and skin, the permissible time of exposure was restricted within the range of 5 minutes (MAG Pulse) to 731 hours, i.e. 30 days of continuous exposure (TIG). The analysis of the welding methods and process parameters applied in the tests, the geometry of rooms as well as the reflection properties of elements located in the rooms justified the conclusion that the TIG welding process did not pose the hazard related to radiation reflected in the vicinity of the welding station. However, the above-named hazard was present in relation to the MAG and MAG-Pulse processes, also behind protective welding screens.

Conclusions

The above-presented results obtained in the tests concerning the TIG, MAG and MAG-Pulse welding processes indicated the presence of hazards potentially affecting the health of workers performing their tasks in the vicinity of welding stations even if protective welding screens were used. Levels of radiation reaching various parts of the worker's body depended on the following factors:

- welding methods and technological and material conditions of the welding process,
- reflection properties of a work environment (walls, the ceiling, elements reflecting UV radiation in a directional manner, located on the welding station and in its vicinity, e.g. steel sheets),
- location of the welding station in relation to reflecting planes,
- presence and location of protective screens,
- worker's location/position in relation to the welding station.

An increase in welding current was accompanied by an increase in the fraction of the reflected component in the measured level of irradiation intensity. Depending on the worker's location/position in relation to the welding station, the reflected component could vary significantly and, consequently, affect the level of radiation reaching the worker.

The test results discussed in the article were used to develop a database containing measured values of irradiation intensity in relation to various welding techniques and process parameters. The results were also used to develop a computational algorithm (and a mobile application which followed) making it possible to determine levels of UV radiation at various distances from welding arc, taking into account reflections against elements located in the vicinity of the welding station. The mobile application enables the determination of the potentially hazardous exposure of workers (located in the vicinity of electric welding stations) to scattered ultraviolet radiation as well as allows employers to assess occupational hazards and take appropriate measures reducing related hazards. The application constitutes a tool making it possible to calculate the intensity of irradiation by UV radiation in various configurations of welding arc–exposed person system, taking into account components reflected against various surfaces of the room [11]. The mobile application can be downloaded on a free of charge basis from the following website: www.ciop.pl/CIOPPortalWAR/file/90263/20200703020565&weld.apk

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