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Optical radiation during CMT and ColdArc welding and braze welding

Abstract: It has been presented results of measurements of UV and IR radiation and the radiance of visible light during welding of X5CrNi18-10 chromium-nickel austenitic steel and X6Cr17 chromium ferritic steel by CMT and ColdArc methods as well as during braze welding of DX 54D AND DP600X steels covered with protective layer of pure zinc or zinc-iron alloy. It has been shown that the optical radiation intensity increases together with the increase in welding current and arc voltage. Moreover, the radiation intensity is affected by welding/braze welding methods and the kind of shielding gases whereas the influence of parent materials kind is difficult to assess.

keywords: optical radiation, welding, braze welding, X5CrNi18-10, X6Cr17;

Introduction

The development of welding technologies entails launching new joining methods aimed at increasingly convenient joining of new materials using energy-saving methods. For many years a dominant arc welding process has been MIG/MAG welding. Owing to works of leading manufacturers of welding equipment, new variants of MIG/MAG welding such as CMT and ColdArc methods have come into industrial practice. These processes are particularly useful for joining thin materials and are characterised by reduced energy consumption and a lower number of spatters during welding.

A question which arises is what hazards are connected with new welding technologies and what measures should be taken to ensure safe conditions for welders and other people in the vicinity of welding stations. Particularly interesting is the determination of a relationship between the technological conditions of welding processes and emitted optical radiation. Frequent exposure to excessive welding arc radiation may lead to lens opacity or a permanent lesion of the retina or cornea, rated among occupational diseases. The greatest incidence of occupational diseases tied to optical radiation is observed among welders [1]. For this reason it is necessary to provide appropriate prevention, which in turn requires knowledge of the degree of personnel exposure to such radiation. The spectrum and intensity of emitted radiation depends on welding method (technology), metal being welded, welding arc length, welding current, observation direction, as well as on the concentration of gases and dusts on a welding station [2].

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The tests described in this article were carried out within the project "Assessment of chemical, dust and physical hazards in a work environment related to innovative methods for joining various structural materials as activity supporting the assurance of safe work conditions" [3]. The project constitutes the research part of the 2nd stage of the long-term programme "Improving occupational safety and work conditions" implemented in the years 2011-2013. The objective of the tests was to determine the technological conditions-dependent level of ultraviolet, visible and infrared radiation emitted during welding and braze welding of stainless steels and steels with z protective anticorrosive coatings by means of innovative low-energy CMT and ColdArc methods.

Biological effect of optical radiation

Optical radiation includes ultraviolet (UV), visible (VIS) and infrared (IR) radiation. The most hazardous optical radiation is generated during welding, as in such cases the spectrum of radiation contains UV, blue light and IR. The temperature of gas torches does not exceed 2000 K and their spectrum does not contain UV, whereas the temperature of oxy-acetylene and oxy-hydrogen torches slightly exceeds a temperature of 3000 K, and as a result long-wave ultraviolet can be emitted in addition to infrared radiation and light. Figure 1 presents the ranges of optical radiation accompanying welding processes.

Excessive optical radiation may cause numerous eye and skin diseases. The most common result of skin exposure to ultraviolet is erythema. The most active bands in this respect are UVB (280-315 nm) and UVC (200-280 nm) [4]. A threshold dose of UV causing erythema is between 40 J/m² to over 600 J/m², depending on the type of skin, adopted criteria and the sensitivity of a testing method. Long-term skin exposure to intensive ultraviolet may trigger precancerous or cancerous changes, particularly in poorly-pigmented skin. The UV carcinogenic efficiency spectrum is similar to that of erythematous efficiency.

An acute symptom of eye exposure to ultraviolet is keratitis and conjunctivitis which usually appears after a few-hours' latency. The most hazardous in triggering keratitis are waves with a length of 270 nm with the threshold irradiation value for this symptom amounting to 40 J/m². The maximum efficiency of triggering keratitis characterises waves with a length of 260 nm, for which the threshold irradiation value amounts to 50 J/m². UV radiation in excess of 300 nm reaches the eye's lens where it is strongly absorbed, and may cause a cataract. The highest cataract-triggering efficiency is probably the 300-325 nm band.

Eye and skin exposure to ultraviolet radiation is presently assessed in the USA, EU countries and in Poland according to a spectral efficiency curve S_λ [5] being a resultant curve of eye keratitis and conjunctivitis and of skin erythema (Fig. 2).

Light and infrared may cause skin or eye lesions, where waves from the 400-1400 nm range can damage the retina, whereas longer ones can

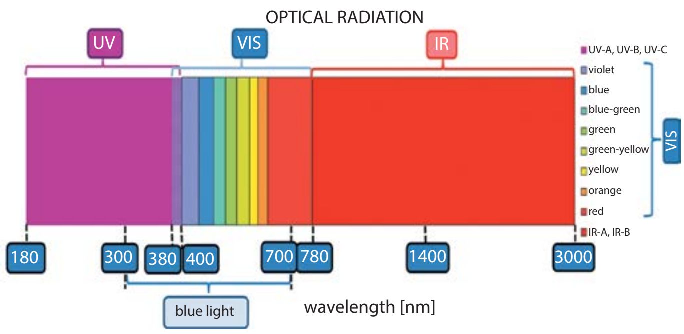

Fig. 1. The range of optical radiation accompanying welding and allied processes [3]

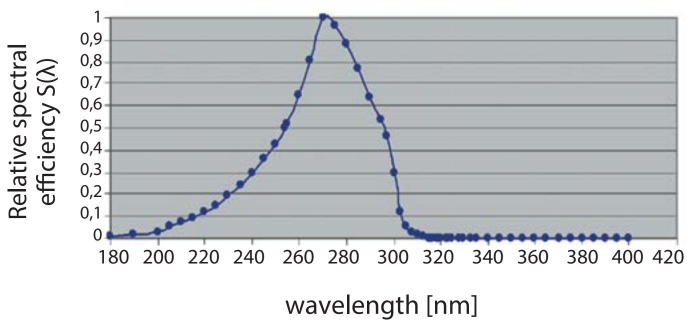

Fig. 2. Relative spectral efficiency S_λ of eye and skin exposure to UV radiation [5]

damage the cornea. If the exposure of a specific eye fundus area exceeds 10 seconds, particularly to radiation from the 400-500 nm range of so-called blue light, the photochemical damage of retina is dominant. Shorter exposure times increase the probability of evoking thermal lesions. In practice, damage to the retina is usually photochemical in nature [2]. The risk of a photochemical retinal damage is assessed according to efficiency B_λ , whereas that of thermal damage – according to efficiency R_λ (Fig. 3).

The most common eye condition connected with exposure to infrared radiation is cataract or the lens opacity. Despite many tests on this subject, the mechanism of cataract generation caused by infrared radiation has not yet been explained nor have efficiency spectrum or threshold values been determined [7]. Table 1 lists eye and skin diseases caused by excessive exposure to optical radiation.

Test rig and testing methodology

The tests involved measurements of UV and IR radiation intensity as well as measurements of blue light radiance by an electric arc during welding and braze welding with CMT and ColdArc [3] methods. A test rig used in the tests is presented in Figure 4. A gas ventilating hood with a capacity of 1000 m³/hour was placed above the welding site, 0.6 m away from the welding torch. The tests aimed at determining the dependence between the intensity of ultraviolet, blue light and thermal radiation as well as welding and braze welding methods and the technological parameters of those processes.

Radiation measurements were carried out using an IL 1800 International Light (USA) radiometer provided with appropriate measuring probes. UV radiation was measured with a probe

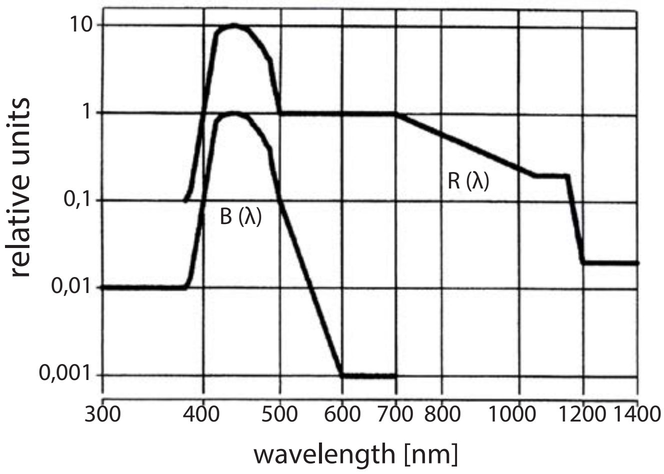

Fig. 3. Relative spectral efficiency of hazardous photochemical (B_λ) and thermal (R_λ) exposure of eye retina to blue light [6]

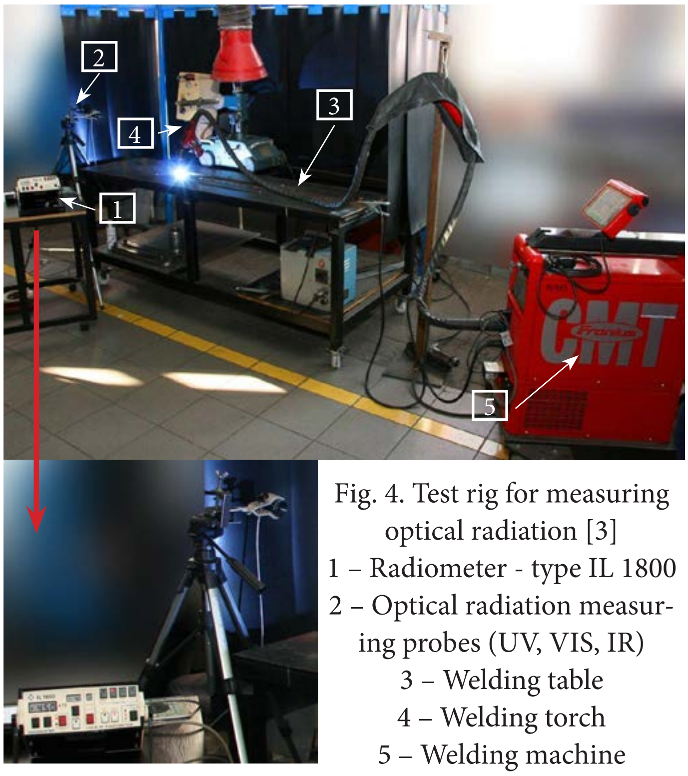

Fig. 4. Test rig for measuring optical radiation [3]
1 – Radiometer - type IL 1800
2 – Optical radiation measuring probes (UV, VIS, IR)
3 – Welding table
4 – Welding torch
5 – Welding machine

Table 1. Diseases caused by excessive optical radiation

Radiation range	Type of damage	
	eye	skin
UV-B, UV-C	Keratitis, conjunctivitis	Erythema, burns, skin pigmentation, photoageing, precancerous and cancerous skin changes
UV-A	Photochemical cataract	
VIS	Photochemical and thermal retinal damage	Thermal damage
IR-A	Thermal retinal damage	Thermal damage
IR-A, IR-B	Thermal cataract	
IR-A, IR-B, IR-C	Cornea burns and damage	

consisting of a SED240 detector, an ACT4 filter and a wide-angle W type diaphragm. The spectral distribution of the probe sensitivity corresponded to the efficiency curve S_{λ}.

Radiance was measured with a probe consisting of an SED033 detector, SCS395 and TBLU filters as well as a narrow-angle R type diaphragm with a view angle of ±1.5°. The proper spectral sensitivity corresponded to the efficiency curve B_{λ}. Infrared radiation was measured with a probe having flat (unselective) characteristics in the wavelength range of 700-4200 nm, composed of an SED623 detector, an SCS695 filter and a K9 type diaphragm with a diameter aperture of 9 mm.

The probes, directed towards a welding arc, were placed 1 m from the arc, at a height of 0.3 m above a welding plane. The time of measurement was 5-10 seconds for each welding/braze welding variant. Extreme (minimum and maximum) values of meter indicators present in the measurement period were recorded.

Table 2. Results of radiation parameter measurements during CMT welding of stainless steels [3]

Steel sheet grade Electrode wire	Shielding gas	Technological parameters			UV irradiation intensity [W/m²]	Blue light radiance [W/cm² sr]	IR irradiation intensity [W/m²]
		Vdr [m/min]	Vsp [mm/min]	I [A]/ U [V]			
X5CrNi18– 10 1.4301 thickness 1.5 mm 308L– Si/MVR dia.1.2 mm	Ar	2.4	350	68/11.9	0.63-0.82	2.0-3.0	35.00-50.00
		2.9	450	75/12.4	0.65-0.80	1.4-7.0	32.00-43.00
		3.3	580	80/12.8	0.78-1.00	5.5-7.0	38.00-54.00
		5.3	950	120/15.4	1.90-2.00	1.8-6.4	140.00-160.00
	97.5%Ar+ 2.5%CO_2	2.4	350	68/10.6	0.18-0.40	0.1-0.8	39.00-52.00
		2.9	450	75/11.5	0.75-0.82	0.5-0.6	49.00-58.00
		3.3	580	80/12.7	0.78-0.91	0.4-1.1	100.00-110.00
		5.3	950	121/17.5	2.40-2.60	4.8-6.4	210.00-250.00
	98%Ar+ 2%O_2	2.4	350	68/10.3	0.39-0.68	0.13-0.18	30.00-40.00
		2.9	450	75/11.4	0.75-0.82	2.0-2.8	39.00-48.00
		3.3	580	80/12.8	0.89-1.00	1.0-1.8	46.00-62.00
		5,3	950	120/16,9	1,30-10,0	1,0-1,4	110,00-140,00
X6Cr17 1.4016 thickness 1.5 mm SKWA– IG dia. 1.2 mm	98%Ar+ 2%O_2	2.4	350	68/11.0	0.68-0.76	0.3-0.35	70.0-80.00
		2.9	450	75/12.1	0.84-0.94	0.55– 0.72	69.00-84.00
		3.3	580	80/12.6	1.00-1.20	0.69-0.9	70.00-78.00
		5.3	950	121/17.1	2.90 - 3.50	1.2-1.3	150.00-180.00
	97.5%Ar+ 2.5%CO_2	2.4	350	68/10.5	0.38-0.41	0.22– 0.28	20.00-29.00
		2.9	450	75/11.8	0.50-0.60	0.28– 0.32	29.00-37.00
		3.3	580	80/12.6	0.77-0.91	7.50– 8.90	25.00-29.00
		5.3	950	121/17.8	2.80-3.00	9.00– 22.0	78.00-90.00
	82%Ar+ 18%CO_2	2.4	350	68/12.7	1.00-1.30	0.75– 0.95	30.00-45.00
		2.9	450	75/14.0	1.30-1.70	4.8-5.2	30.00-53.00
		3.3	580	80/15.6	1.40-1.60	1.2-4.6	47.00-74.00
		5.3	950	120/18.5	2.70-3.30	20- 36	60.00-100.00
	90%Ar+ 5%CO_2+ 5%O_2	2.4	350	68/12.5	0.70-0.86	1.8-2.6	38.00-53.00
		2.9	450	74/13.0	0.80-1.00	1.4-3.6	49.00-58.00
		3.3	580	80/14.2	0.90-1.10	3.6-9.0	58.00-74.00
		5.3	950	122/19.6	1.80-3.00	13.0– 28.0	80.00-120.00

Table 3. Results of radiation parameter measurements during ColdArc welding of stainless steels [3]

Steel sheet grade Electrode wire	Shielding gas	Technological parameters			UV irradiation intensity [W/m²]	Blue light radiance [W/cm² sr]	IR irradiation intensity [W/m²]
		Vdr [m/min]	Vsp [mm/min]	I [A]/ U [V]			
X5CrNi18– 10 1.4301 thickness 1.5 mm 308L– Si/MVR dia.1.2 mm	Ar	2.4	350	83/15.7	0.27 – 0.33	0.4 – 1.1	23.00 – 28.00
		2.8	450	93/16.2	0.50 – 0.63	0.9 – 1.3	37.00 – 39.00
		3.2	580	105/17.1	0.40 – 0.70	1.2 – 1.4	47.00 – 58.00
		4.8	950	143/18.0	0.70 – 0.90	1.9 – 3.2	58.00 – 85.00
	97.5%Ar+ 2.5%CO_2	2.4	350	86/15.5	0.29 – 0.50	1.3 – 2.5	20.00 – 30.00
		2.8	450	98/15.9	0.48 – 0.64	2.6 – 3.2	12.00 – 20.00
		3.2	580	108/17.1	0.40 – 0.70	4.0 – 4.8	27.00 – 30.00
		4.8	950	145/18.3	0.70 – 1.10	4.9 – 5.4	20.00 – 100.00
	98%Ar+ 2%O_2	2.4	350	83/15.0	0.18 – 0.23	0.19 – 0.37	28.00 – 43.00
		2.8	450	95/15.6	0.20 – 0.29	1.3 – 1.5	44.00 – 56.00
		3.2	580	105/16.7	0.30 – 0.35	1.0 – 1.4	40.00 – 65.00
		4.8	950	149/18.2	0.40 – 0.79	1.0 – 1.2	53.00 – 100.00
X6Cr17 1.4016 thickness 1.5 mm SKWA– IG dia. 1.2 mm	98%Ar+ 2%O_2	2.4	350	84/14.4	0.13 – 0.19	0.24 – 0.41	40.00 – 48.00
		2.8	450	94/15.2	0.23 – 0.36	1.7 – 2.2	39.00 – 52.00
		3.2	580	107/15.7	0.26 – 0.48	1.0 – 1.3	47.00 – 50.00
		4.8	950	150/18.6	0.70 – 1.20	2.0 – 4.0	80.00 – 120.00
	97.5%Ar+ 2.5%CO_2	2.4	350	83/16.8	0.24 – 0.37	0.9 – 1.4	29.00 – 43.00
		2.8	450	95/17.1	0.65 – 0.70	2.5 – 3.9	34.00 – 52.00
		3.2	580	107/17.9	1.00 – 1.20	2.4 – 9.7	50.00 – 70.00
		4.8	950	149/19.8	0.44 – 0.68	3.5 – 10.0	30.00 – 60.00
	82%Ar+ 18%CO_2	2.4	350	81/17.7	0.65 – 0.79	6.0 – 8.0	28.00 – 54.00
		2.8	450	91/18.6	0.80 – 0.89	4.3 – 6.0	35.00 – 62.00
		3.2	580	108/19.2	0.80 – 1.10	5.4 – 11.0	49.00 – 77.00
		4.8	950	140/19.9	0.20 – 0.47	19.0 – 30.0	60.00 – 110.00
	90%Ar+ 5%CO_2+ 5%O_2	2.4	350	79/17.6	0.40 – 0.54	6.0 – 7.0	18.00 – 37.00
		2.8	450	90/18.3	0.46 – 0.60	3.2 – 3.9	28.00 – 48.00
		3.2	580	102/19.1	0.38 – 0.60	13.0 – 16.0	40.00 – 53.00
		4.8	950	145/20.0	0.20 – 0.80	30.0 – 60.0	72.00 – 79.00

Measurement results

The results of ultraviolet and infrared intensity measurements as well as of blue light luminance during welding and braze welding of various structural materials with low-energy methods are presented in Tables 2-5.

Ultraviolet radiation

The graphic analysis of selected UV radiation measurement results is presented in Figures 5-7.

The measurements revealed that the intensity of UV radiation during welding and braze welding increases exponentially along with an increase in welding/braze welding current. This increase depends on the type of shielding gas, the grade of a sheet being welded and on the selected welding or braze welding method. In the case of CMT welding of an X5CrNi18-10 sheet the intensity of UV radiation increases most significantly when the shielding gas is a mixture of 98%Ar+2%O_2 and is the lowest when the shielding gas is argon. During CMT welding of an X6Cr17 steel UV radiation intensity has the highest values for a gas mixture 82%Ar+18%CO_2

Table 4. Results of radiation parameter measurements during CMT braze welding of steel sheets provided with protective coatings [3]

Steel sheet grade	Electrode wire/ Shielding gas	Technological parameters			Designation range		
		Vdr [m/min]	Vsp [mm/min]	I [A]/ U [V]	UV irradiation intensity [W/m²]	Blue light radiance [W/cm² sr]	IR irradiation intensity [W/m²]
DX54 D Z 100 MBO	CuSi3 dia.1.0 mm/ Ar	2.7	225	34/11.1	0.30 – 0.43	0.09 – 0.13	8.50 – 15.00
		4.3	290	62/11.7	0.45 – 0.82	0.2 – 0.3	19.00 – 26.00
		5.1	330	82/11.9	0.89 – 1.00	0.5 – 1.0	18.00 – 24.00
DX54 D ZF 140 RBO		2.7	225	34/10.6	0.32 – 0.38	0.1 – 0.23	13.00 – 14.00
		4.3	290	61/11.3	0.78 – 0.87	0.3 – 1.3	34.00 – 38.00
		5.1	330	81/11.7	0.39 – 1.00	0.65 – 1.4	40.00 – 45.00
DP 600X ZF 100 RBO		2.7	225	34/11.3	0.23 – 0.37	1.2 –1.8	8.00 – 9.80
		4.3	290	62/11.5	0.69 – 0.83	3.7 – 4.8	29.00 – 34.00
		5.1	330	80/11.9	0.90 – 1.10	1.1 – 4.9	42.00 – 49.00
DX54 D Z 140 MBO		2.7	225	34/11.2	0.33–0.43	0.1–0.5	11.00–15.00
		4.3	290	62/11.4	0.57–0.73	0.2–1.0	22.00–28.00
		5.1	330	81/11.9	0.88–1.08	0.4–1.6	26.00–29.00

Table 5. Results of radiation parameter measurements during ColdArc braze welding of steel sheets provided with protective coatings [3]

Steel sheet grade	Electrode wire/ Shielding gas	Technological parameters			Designation range		
		Vdr [m/min]	Vsp [mm/min]	I [A]/ U [V]	UV irradiation intensity [W/m²]	Blue light radiance [W/cm² sr]	IR irradiation intensity [W/m²]
DX54 D Z 100 MBO	CuSi3 dia.1.0 mm/ Ar	2.9	225	64/13.8	0.11 – 0.13	0.32 – 0.33	6.00 – 8.00
		4.2	290	75/15.6	0.17 – 0.20	0.7 – 0.9	6.00 – 10.00
		4.9	330	87/16.6	0.23 – 0.30	1.3 – 1.6	6.00 – 11.00
DX54 D ZF 140 RBO		2.9	225	65/13.7	0.13 – 0.16	0.2 – 1.0	4.00 – 6.00
		4.2	290	79/14.9	0.26 – 0.40	0.6 – 1.2	4.00 – 9.00
		4.9	330	89/16.1	0.30 – 0.43	1.2 – 1.7	9.00 – 10.00
DP 600X ZF 100 RBO		2.9	225	65/13.7	0.17 – 0.19	0.55 – 1.0	4.00 – 6.00
		4.2	290	75/15.5	0.20 – 0.30	0.10 – 0.8	12.00 – 14.00
		4.9	330	87/16.5	0.37 – 0.47	0.5 – 1.6	15.00 – 21.00
DX54 D Z 140 MBO		2.9	225	65/13.8	0.13–0.15	0.4–0.6	8.00–10.00
		4.2	290	76/15.3	0.18–0.22	0.7–1.1	9.00–13.00
		4.9	330	88/16.5	0.25–0.29	1.4–1.8	11.00–14.00

and for the mixture 98%Ar+2%O_2 mentioned above. The most convenient, as regards the reduction of UV radiation accompanying CMT welding of stainless steels, is the use of a gas mixture of 97.5%Ar+2.5%CO_2 and of argon. During ColdArc welding of stainless steels the effect of the type of shielding gas differs from that related to the use of the aforementioned CMT method. During ColdArc welding of an X5CrNi18-10 austenitic steel the highest UV radiation intensity is connected with the use of a shielding gas of 97.5%Ar+2.5%CO_2, and the lowest when a mixture 98%Ar+2%O_2 is used. A similar dependence can be observed during ColdArc welding of chromium ferritic steel X6Cr17.

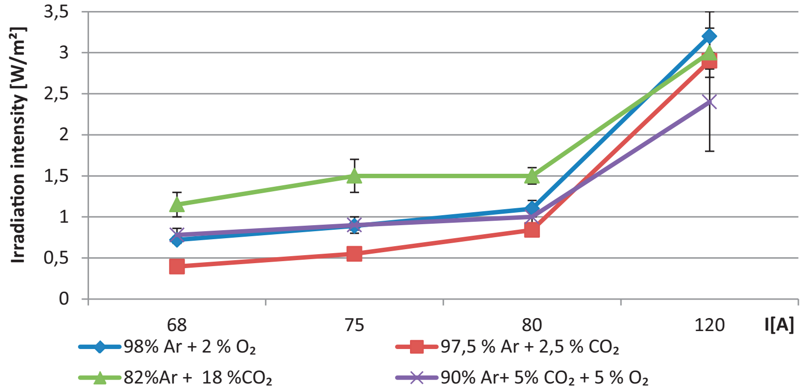

Fig. 5. Results of ultraviolet radiation measurements during CMT welding of X6Cr17 steel in various shielding gases [3

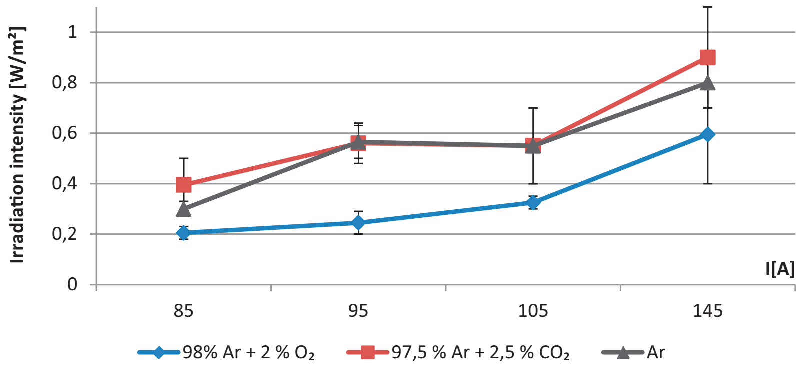

Fig. 6. Results of ultraviolet radiation measurements during ColdArc welding of X5CrNi18-10 steel in various shielding gases [3]

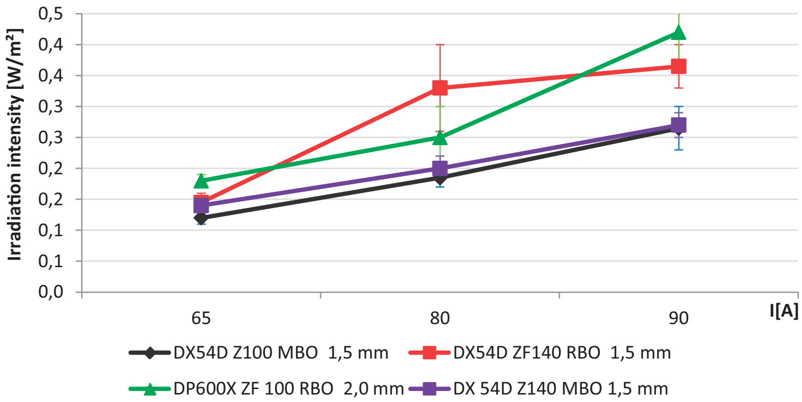

Fig. 7. Results of ultraviolet radiation measurements during ColdArc argon-shielded braze welding of coated steel [3]

The effect of the type of protective coating on UV radiation during braze welding is difficult to determine explicitly. It is possible to observe the tendency that during braze welding of sheets provided with zinc coatings the intensity of UV irradiation is lower than in the case of coatings made of a zinc + iron alloy.

The intensity of UV irradiation is also connected with the type of welding/braze welding method used. The results of measurements have revealed that from the UV radiation reduction point of view during braze welding of coated steels it is more advantageous to use the low-energy ColdArc method. In many cases the intensity of UV irradiation was lower for the ColdArc method than when the CMT method was applied.

Blue light

The graphic analysis of the test results related to blue light radiance is presented in Figures 8-10.

The measurements of blue light radiance accompanying CMT and ColdArc welding and braze welding have revealed that radiance increases along with an increase in welding/braze welding current. This growth depends on a few factors such as the type of shielding gas, the type of sheet being welded/weldbrazed, as well as on the selected welding or braze welding method. During CMT welding of an austenitic sheet (X5CrNi18-10) an increase in the radiance of blue light is the highest when argon is used as a shielding gas. During CMT welding of chromium ferritic steel, (X6Cr17) the highest values of radiance can be observed when a gas mixture of 82%Ar+18%CO_2 is used. The most convenient, as regards the reduction of blue light radiance during CMT welding of stainless steels, is a gas mixture of 98%Ar+2%O_2. The most convenient, as regards the reduction of blue light radiance during ColdArc welding of stainless steels, is a gas mixture of 98%Ar+2%O_2, whereas the highest values of radiance accompany the use of shielding gas mixtures of 97.5%Ar+2.5%CO_2 and 82%Ar+18%CO_2.

Braze welding steel sheets having protective coatings also entails an increase in blue light radiance for higher voltage-current process parameters. The effect of the type of anticorrosive coating on radiance is difficult to assess explicitly, yet it is possible to observe the tendency of blue light radiance accompanying the welding of zinc-coated sheets to be lower than that present during the welding of sheets provided with zinc + iron coatings.

The level of blue light radiance also depends on the choice of a welding/ braze welding method. The tests have revealed that more convenient blue light radiance levels can be observed during the braze welding of coated steels using the low-energy CMT method. In turn, it proves difficult to determine the impact of a method (CMT or ColdArc) on blue light radiance during welding of stainless steels. The selection of a given method should be therefore related to the grade of stainless steel, the type of a shielding gas and the precise adjustment of current-voltage parameters.

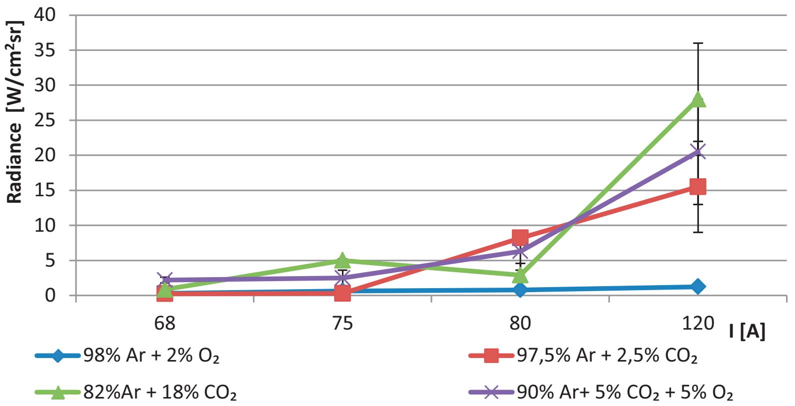

Fig. 8. Results of blue light radiance measurements during CMT welding of X6Cr17 steel in various shielding gases [3]

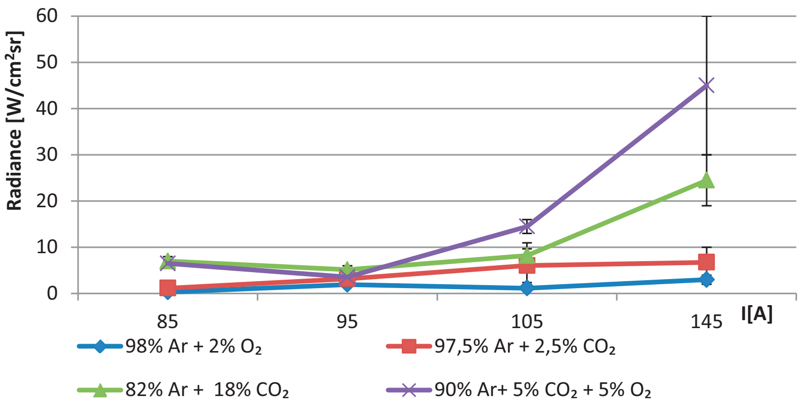

Fig. 9. Results of blue light radiance measurements during ColdArc welding of X6Cr17 steel in various shielding gases [3]

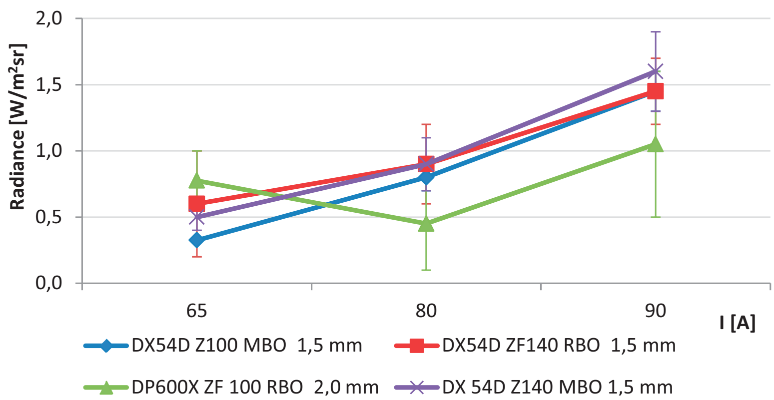

Fig. 10. Results of blue light radiance measurements during argon-shielded ColdArc braze welding of coated steels [3]

Infrared radiation

The graphic analysis of the test results related to infrared radiation during welding and braze welding is presented in Figures 11-13.

The measurement results obtained indicate that the intensity of infrared radiation irradiation rises along with increasing welding current. This increase depends on several factors such as the type of a shielding gas, the type of a sheet being welded and a welding method selected. During CMT welding of austenitic steel (X5CrNi18-10) the intensity of thermal radiation irradiation is the highest when the mixture of 97.5%Ar+2.5%CO_2 is used as a shielding gas. During CMT welding of chromium ferritic steel (X6Cr17), the highest values of IR irradiation intensity can be observed for the gas mixture 98%Ar+2%O_2. During ColdArc welding of stainless steels the greatest reduction of the intensity of infrared radiation irradiation requires the use of the triple-component mixture 90%Ar+5%CO_2+5%O_2, whereas the highest values of IR irradiation intensity accompany the use of the mixture 82%Ar+18%CO_2.

During braze welding of steel sheets provided with protective coatings the intensity of infrared radiation irradiation depends on current

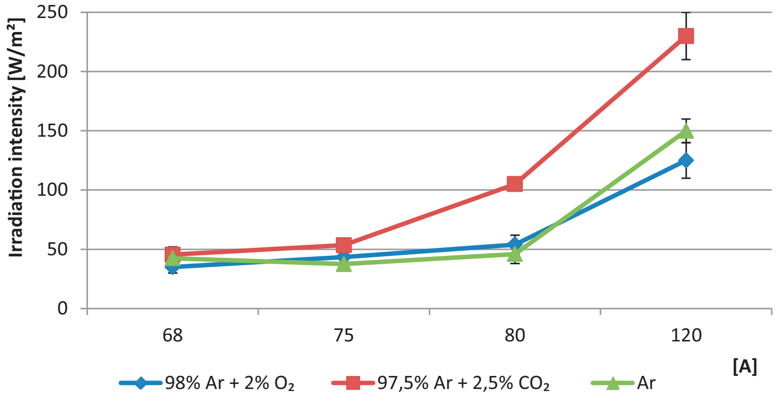

Fig. 11. Results of infrared radiation measurements during CMT welding of X5CrNi18-10 steel in various shielding gases [3]

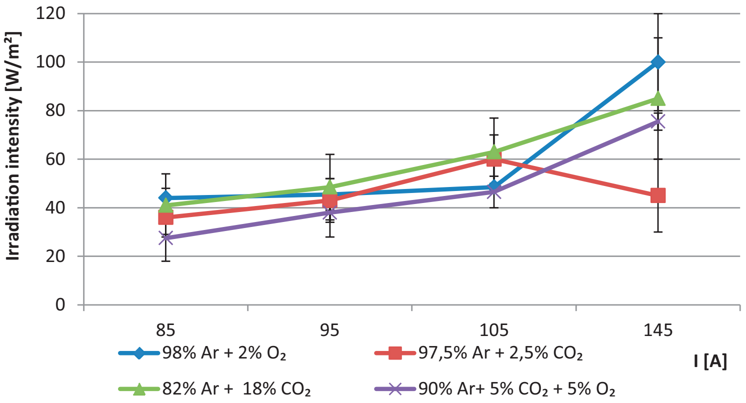

Fig. 12. Results of infrared radiation measurements during ColdArc welding of X6Cr17 steel in various shielding gases [3]

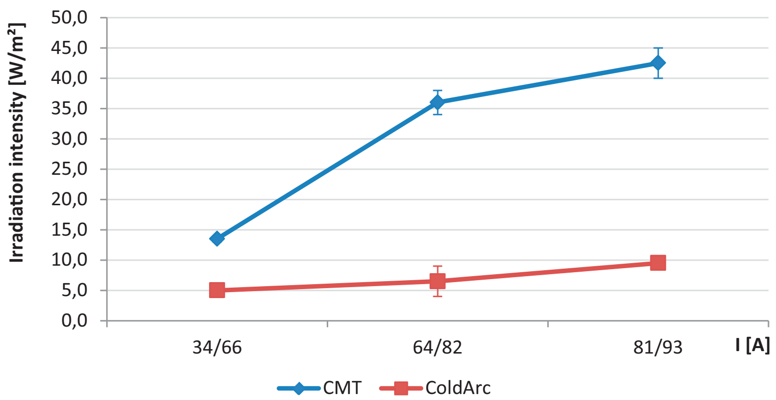

Fig. 13. Results of infrared radiation measurements during argon-shielded braze welding of DX 54D ZF140 RBO steel using various methods [3]

intensity and arc voltage – an increase in braze welding process current-voltage parameters is accompanied by an increase in irradiation intensity. The influence of an anticorrosive coating on IR radiation is similar as in the case of UV radiation and blue light. It is possible to observe a tendency that during braze welding of zinc-coated sheets the intensity of infrared radiation irradiation is lower than in the case of zinc + iron types of coatings.

The value of IR irradiation intensity also depends on a welding/braze welding method. The test results have revealed that the use of the ColdArc method is more convenient as regards the reduction of infrared radiation irradiation intensity during braze welding of coated steels. During welding stainless steels it is difficult to explicitly determine the effect of a selected method (CMT, ColdArc) on the intensity of infrared radiation.

Maximum permissible exposure (MPE) to optical radiation

The tests of the intensity of UV and IR radiation irradiation and of blue light radiance carried out in the vicinity of a welding arc during welding/braze welding of various base metals using low-energy methods were conducted in order to determine the correlation between the technological parameters of joining methods and the hazards mentioned above. In accordance with the testing methodology presented, the time of measurement was 5-10 seconds for each welding/braze welding variant. The measurement results were the extreme (maximum and minimum) values of the meter recorded in the measurement period. The analysis of the measurement results obtained included the maximum, minimum and mean values for the variables measured (UV and IR radiation irradiation intensity [W/m²] and blue light radiance [W/cm² sr]).

The maximum permissible exposure (MPE) of personnel to optical radiation is specified in a decree by the Minister of Labour and Social Policy [8]. In order to characterise the welding and braze welding methods in view of personnel exposure to optical radiation, Table 6

Table 6. Maximum values of exposure to optical radiation and allowed time of exposure to radiation during welding and braze welding [3]

Type of radiation	MPE	Measured radiation intensity	**Permissible time of exposure to radiation**
ultraviolet	eye and skin exposure 30 [J/m²]	CMT welding 0.38-3.5 W/m² ColdArc welding 0.13-1.2 W/m² CMT braze welding 0.23-1.1 W/m² ColdArc braze welding 0.11-0.47 W/m²	**8.5-79 s** **25-230 s** **27-130 s** **63-272 s**
blue light	eye exposure - for exposure time > 10 000 s (2 h 46 min. 40 s) during work shift 0.01 [W/cm² sr] - for shorter time $10^2/t$ [W/cm² sr]	CMT welding 0.1-28 W/cm² sr ColdArc welding 0.19-60 W/cm² sr CMT braze welding 0.09-4.8 W/cm² sr ColdArc braze welding 0.2-1.7 W/cm² sr	**3.5-1000 s** **1-526 s** **20-1111 s** **58-500 s**
infrared	eye exposure - for the time of single exposure > 1000 s (16 min 40 s) 100 [W/m²] - for shorter time 18 000x $t^{-0.75}$ [W/m²]	CMT welding 20-250 W/m² ColdArc welding 12-120 W/m² CMT braze welding 8-49 W/m² ColdArc braze welding 4-21 W/m²	**from 5 to over 17 min** **from 13 to over 17 min** **unrestricted** **unrestricted**

presents the permissible time of exposure for the joining methods tested, determined on the basis of the aforesaid decree of the Minister of Labour and Social Policy.

The values of irradiation intensity and of radiance show that the highest health hazard is caused by exposure to ultraviolet radiation and blue light. For the welding/braze welding methods tested, the allowed time of exposure to ultraviolet is between 8.5 and 272 seconds, whereas for blue light the allowed time of exposure is between 1 and 1111 seconds. For the methods tested the exposure to infrared radiation was significantly lower. During CMT and ColdArc braze welding of coated sheets the time of exposure did not require any restrictions, whereas during welding it was between 5 and more than 17 minutes.

The greatest exposure to UV radiation during the welding of corrosion-resistant steels accompanies the use of the CMT method. The greatest exposure to blue light during welding of corrosion-resistant steels accompanies the use of the ColdArc method. The intensity of infrared radiation irradiation adopted the highest values during CMT welding of stainless steels. Due to lower current intensity values the process of braze welding is characterised by lower exposure of work environment to ultraviolet, blue light and infrared radiation.

Concluding remarks

The test results related to the intensity of ultraviolet and infrared radiation as well as blue light radiance during welding of corrosion-resistant steels and braze welding of coated steel sheets using low-energy methods constitute a very interesting material of preliminary research. The results obtained and their analyses have enabled the formulation of the following conclusions:

1. During the welding of corrosion-resistant steels using low-energy methods the intensity of ultraviolet and infrared radiation irradiation and blue light radiance increases with increasing welding current and arc voltage.

2. During welding of stainless steels the intensity of ultraviolet and infrared radiation irradiation and blue light radiance depend on the type of shielding gas and the selected welding method.

3. Higher current-voltage parameters of

braze welding steel sheets having protective coatings cause an increase in the intensity of UV and IR radiation irradiation as well as an increase in blue light radiance.

4. The impact of the type of a protective coating on ultraviolet, infrared and blue light emission is difficult to define explicitly. It is possible to observe the tendency that during braze welding of zinc-coated sheets the intensity of UV and IR irradiation as well as blue light radiance are lower than in the case of coatings made of a zinc + iron alloy.

5. The greatest hazard of exposure to ultraviolet radiation accompanies the use of the CMT method, whereas the greatest hazard of exposure to blue light is present during ColdArc welding of corrosion-resistant steels.

6. The intensity of infrared radiation irradiation is the highest during CMT welding of stainless steels.

7. In comparison with other welding processes, the braze welding of coated steel sheets causes lower hazard to the work environment as far as ultraviolet, blue light and infrared radiation is concerned.

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Publication developed on the basis of the results of the 2nd stage of the long-term programme "Improving occupational safety and work conditions" financed in the years 2011-2013 within the scope of research and developmental works by the Ministry of Science and Higher Education/National Centre for Research and Development.

Programme Coordinator: Centralny Instytut Ochrony Pracy – Państwowy Instytut Badawczy /Central Institute for Labour Protection – National Research Institute/