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Hazardous Ultraviolet and Blue-Light Emissions of CO_2 Laser Beam Welding

Karl Schulmeister[1], Ch. Schmitzer[1], K. Duftschmid[1], G. Liedl[2], K. Schröder[2], H. Brusl[3] and N. Winker[3]

1) Dpt. of Radiation Protection, Austrian Research Centre, A-2444 Seibersdorf, Austria
2) Institute f. High Power Beam Techn., TU Vienna, Arsenal Obj. 207, A-1030 Wien, Austria
3) Allgemeine Unfallversicherungsanstalt, A.-Stifter-Str. 65, A-1201 Wien, Austria

During high power laser beam welding, hazardous UV-radiation and short-wavelength visible (blue-) light is emitted by the high temperature plasma above the welding-keyhole. Spectral measurements of the plasma emission show that the allowed dose for UV-radiation and blue-light exposure per work day can be exceeded in as short as a few seconds. Even more hazardous UV emissions are produced when the welding processing parameters are not optimised and plasma shielding occurs.

Introduction

With laser materials processing, direct exposure to the laser beam may not be the main hazard. The high power laser beam is generally enclosed up to the surface of the workpiece and is usually directed towards the ground. Secondary hazards such as UV-radiation, ozone and fume produced by the laser-workpiece interaction may represent a more serious hazard due to the every-day, long term exposure of the worker.
In this paper, hazards of the optical radiation emitted by the plasma during CO_2 laser beam welding are discussed. In laser beam deep penetration welding, a keyhole is held open throughout the workpiece by the vapour pressure of the vapourised base metal. Due to laser radiation-induced ionisation of the metal vapour, a plasma is formed above the keyhole. On the one hand the plasma enables efficient absorption of the laser beam energy, on the other hand it is a source of hazardous UV- and blue-light radiation. Model calculations indicate a plasma temperature of about 10 000 to 13 000 K, therefore a substantial part of the optical radiation is emitted in the ultraviolet and blue region of spectrum.

The damage mechanism of short wavelength optical radiation (200 nm to about 550 nm) is photochemical in nature. A common effect of UV-C and UV-B radiation (200 nm to 320 nm) on the skin is reddening (erythema). As UV-C and UV-B radiation is absorbed by the outer parts of the eye, photokeratitis and cataracts can result. Visible short wavelength radiation ('blue-light', 400 nm to 550 nm) on the other hand reaches the retina and induces photoretinitis which can lead to permanent loss of vision. It is characteristic for these photochemical effects that the absorbed dose (J/m^2) is the important hazard figure as there is a reciprocity between irradiance (W/m^2) and exposure duration: the same injury can be produced by a low irradiance lasting for a prolonged period of time or by a high irradiance lasting for only a short time.

Results and discussion

Spectroradiometric measurements

A Rofin Sinar RS 10000 CO_2 laser was used to weld mild steel, stainless steel and aluminium alloys with laser beam powers of up to 8 kW with different shielding gases. The short-wavelength optical radiation emitted by the welding plasma has been measured with a double-monochromator spectroradiometer (Bentham DM150) from 200 nm to 550 nm. A typical spectrum for stainless steel is shown in figure 1. The spectral irradiance (mW/nm m²) was measured at a distance of 50 cm from the plasma. The spectra were recorded by a computer and multiplied with the biological hazard weighing functions for UV- radiation and for blue-light (see figure 1)[1]. Subsequent integration over wavelength gives the values for effective irradiance for UV and blue light $E_{UV,eff}$ and $E_{b,eff}$, respectively.

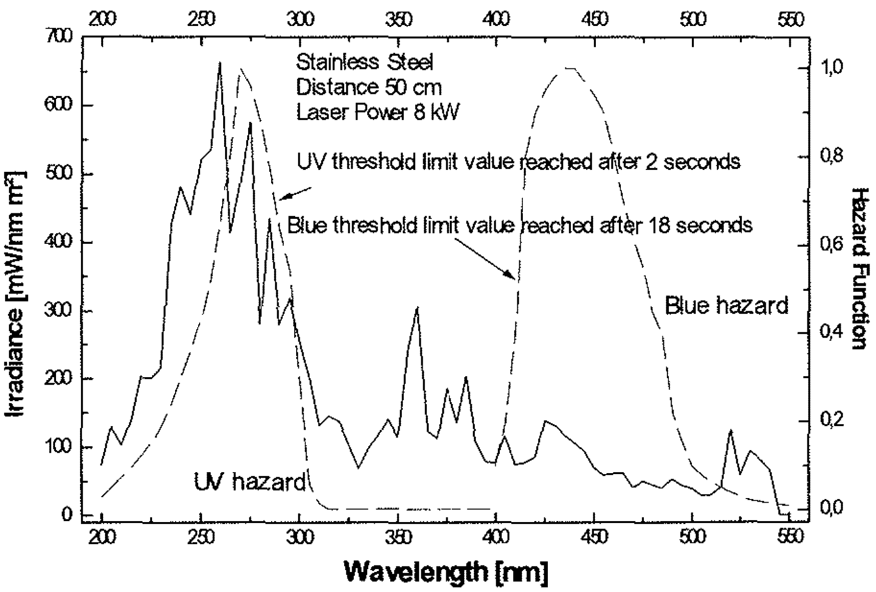

Figure 1. Typical irradiance spectrum as measured during laser beam welding of stainless steel. The spectrum (——) has to be multiplied with the hazard functions (- - - -) for UV and blue-light and subsequently integrated over wavelength in order to obtain the respective effective irradiance. With the allowed daily dose (threshold limit value) for UV radiation and blue-light, the allowed exposure time is obtained.

At a distance of 50 cm, the plasma plume is seen under an angle α of less than 11 mrad. For small sources where $\alpha < 11$ mrad, the allowed dose for an 8-hour period is 30 J/m² for UV radiation and 100 J/m² for blue-light[1]. By dividing the allowed dose with the calculated effective irradiance, the maximum allowed daily exposure duration, t_{UV} and t_b, is obtained. As can be seen in table 1, for highest laser powers the allowed dose for UV radiation can be reached in less than two seconds and the corresponding blue-light dose is reached in less than 20 seconds.

As has been shown in a comparative study with conventional welding methods[2], laser welding can exceed the effective irradiance typical for TIG and MMA welding, depending on the base metal. It also has to be noted that the irradiance contained in the visible part of the spectrum is relatively low, which can lead to a feeling of false security. It is possible to look directly into the plasma for a prolonged period of time without closing the eyes.

Table 1. UV and blue-light emissions as measured at a distance of 50 cm from the welding plasma. For highest laser powers, the allowed daily dose for UV irradiation is reached in less than 2 seconds, the allowed dose for blue-light is reached in as short as 18 seconds.

Base Metal	Laser Power (kW)	Welding speed (mm/s)	Thickness (mm)	Shielding Gas (l/min)	$E_{eff,UV}$ (W/m²)	t_{UV} (sec.)	$E_{eff,b}$ (W/m²)	t_b (sec.)
Al	4	20	5	Ar 20	7,3	4,1	1,23	81
Al	4	20	5	He 20	3,0	10,0	0,46	217
Al	6	30	6	Ar5/He15	3,6	8,3	0,75	133
Al	8	40	6	Ar10/He15	5,4	5,6	0,79	127
mS	2,5	20	3	Ar 20	2,5	12,0	0,57	175
mS	2,5	20	3	He 20	2,2	13,6	0,45	222
mS	4	20	3	Ar 20	4,1	7,3	0,50	200
SS	2,5	20	3	He 20	1,3	22,7	0,25	400
SS	2,5	20	3	Ar 20	4,2	7,1	0,69	145
SS	4	20	3	Ar 20	10,8	2,8	3,38	30
SS	8	20	3	Ar 20	19,3	1,6	5,63	18

Plasma shielding

If the welding processing parameters are not optimised, too much laser power is absorbed by the plasma and plasma shielding may occur. As the laser energy is shielded, not enough base material is vaporised and the plasma is lifted off the workpiece. This happens periodically, as the welding process is reinitiated after the shielding plasma plume has dissipated.

To obtain information on the time dependence of the emissions during welding, a broad band meter with measuring heads for UV-C, UV-B, UV-A and VIS-B (Gröbel UV-Meter RM-2) has been used. By comparison of the spectra obtained with the spectro-radiometer and the measurements with the broad-band meter a correction factor for the integrating heads has been obtained. It has been found that the measurements with the UV-C and VIS-B heads correspond well with the effective UV and blue-light irradiance respectively for all investigated materials, shielding gases and parameters.

Figure 2 shows a graph of the effective UV and blue-light irradiance as obtained with the broad-band meter for welding of stainless steel with 2 kW laser power. As the processing parameters were not optimised, repetitive plasma shielding occured during the welding process. In comparison to welding with optimised welding parameters, the maxima of UV emissions during plasma shielding were increased by up to a factor of 4.

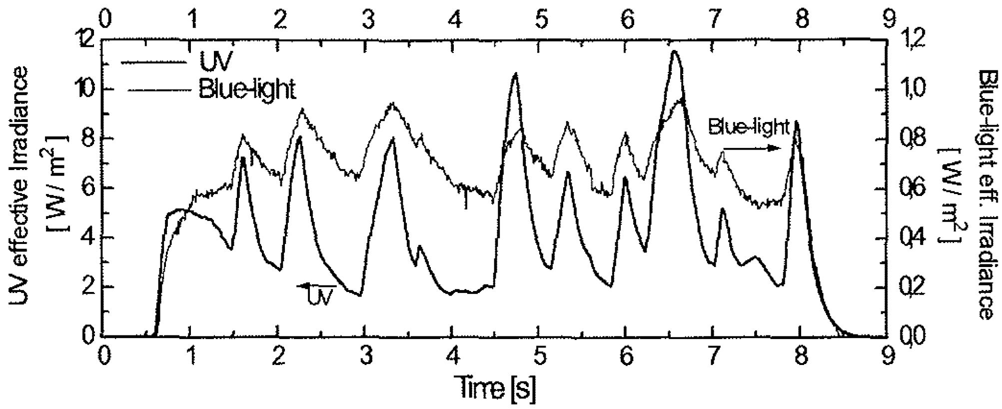

Figure 2. The irradiance maxima result from plasma shielding, where emissions particularly in the UV are greatly increased; the irradiance minima are equivalent to the values as obtained with optimised processing parameters.

Safety control measures

It is not very likely that the welding process with an 8 kW laser is viewed from a distance of 50 cm, however especially during research and development the process is often intentionally viewed and although the irradiance follows a square dependence with distance, the allowed dose for a work-day can be soon exceeded. As most of the actinic UV radiation is absorbed by ordinary glass and plastics, protection is usually afforded by conventional CO_2 laser safety glasses and barriers. However, these materials transmit visible light and hence special filters might have to be used to protect against excessive amounts of blue-light.

Acknowledgements

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