SECONDARY HAZARDS OF HIGH POWER LASER BEAM WELDING

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ABSTRACT

Hazardous UV-radiation and short-wavelength visible (blue) light is emitted by the high temperature plasma above the welding-keyhole. Ozone and NO_x is produced due to UV-induced photodissociation of oxygen and high temperature gas-phase reactions. 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. Similarly, measurements and models of the ozone and NO_x concentration show that the maximum workplace concentrations might be reached quickly if no appropriate exhaust and filter system is installed.

INTRODUCTION

With laser materials processing, direct exposure to the laser beam is usually not the main hazard. The high power laser beam is enclosed up to the surface of the workpiece and is usually directed towards the ground. Errant beams can be caused by uncontrolled reflections off the workpiece surface, however this happens rarely and protection is generally afforded by shields around the workstation. Secondary hazards such as UV-radiation, ozone and fume produced by the laser-workpiece interaction are more serious due to the every-day, long term exposure of the worker.

In this paper, hazards associated with the plasma of CO_2 laser beam welding are discussed. In laser beam deep penetration welding, a keyhole is formed throughout the base metal. The keyhole is held open by the vapour pressure of the vaporised 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 the spectrum.

The damage mechanism of short wavelength optical radiation 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, sunburn). As UV-C and UV-B radiation is absorbed by the outer parts of the eye, adverse effects are photokeratitis (inflammation of the cornea) and cataracts (clouding of the lens). Visible blue light (400 nm to 500 nm) on the other hand reaches the retina and induces photoretinitis (sunburn of the retina) which can lead to permanent loss of vision. As is characteristic for photochemical effects, 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.

As a result of the high-temperature plasma and the UV radiation emitted by the plasma, Ozone and NO_x is produced due to UV-induced photodissociation of oxygen and high temperature gas-phase reactions. Radiation in the wavelength region below 200 nm is strongly absorbed by oxygen and is highly effective in producing ozone by photodissociation of oxygene. As the toxic limit for ozone is quite small, it may be exceeded rapidly when the exhaust system is not efficient. Additionaly, nitrogen oxides are produced by high-temperature reactions in and near the plasma, however NO_x production is not as critical as ozone production as the threshold limit value for nitrogen oxides are at least a factor of 30 above the value for ozone.

RESULTS AND DISCUSSION

Short-wavelength optical radiation

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 m^2) 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.

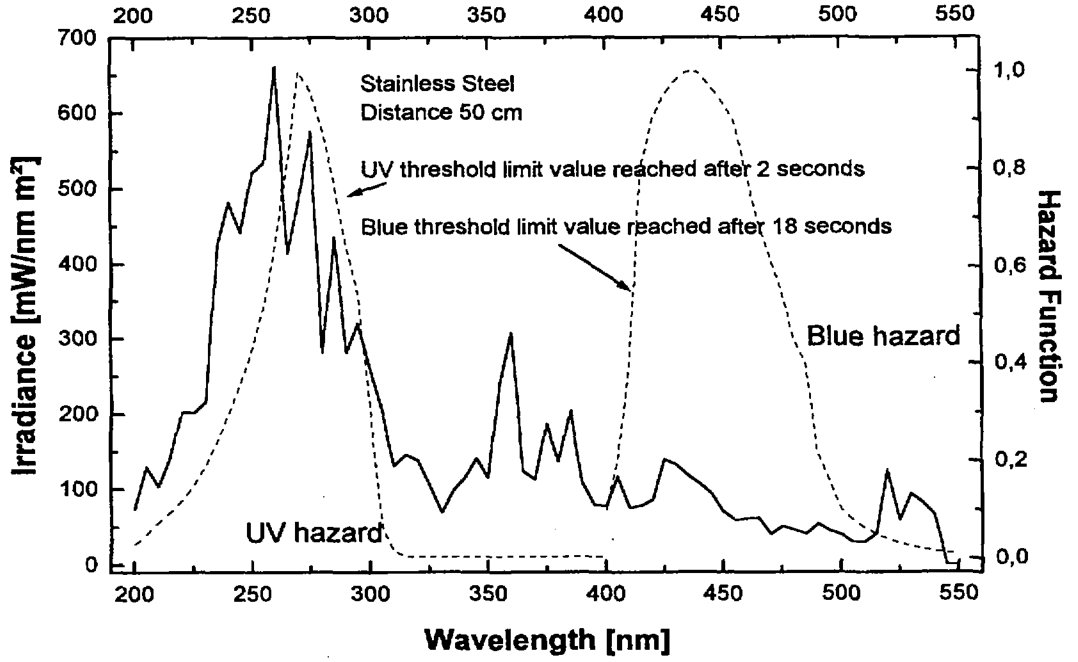

Fig. 1: Typical irradiance spectrum as measured during laser beam welding of stainless steel. The spectrum (——) has been multiplied with the hazard functions (- - - -) and by integration, the effective irradiance was obtained. With the allowed daily dose (threshold limit value), the allowed exposure time is obtained.

The allowed dose for an 8-hour period is 30 J/m^2 for UV radiation and 100 J/m^2 for blue light [1]. By deviding 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 relativily 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.

As most of the 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 if the plasma is to be viewed from a close distance.

Base Metal	Thickness (mm)	Shielding Gas (l/min)	Laser Power (kW)	$E_{eff,UV}$ W/m^2	t_{UV} (Sec.)	$E_{eff,b}$ W/m^2	t_b (Sec.)
SS	3	Ar 20	2,5	2,7	11,1	0,46	217
SS	3	He 20	2,5	1,3	22,73	0,25	400
SS	3	Ar 20	2,5	4,2	7,1	0,69	145
SS	3	Ar 20	4	10,8	2,8	3,38	30
mS	3	Ar 20	2,5	2,5	12,0	0,57	175
mS	3	He 20	2,5	2,2	13,6	0,45	222
mS	3	Ar 20	4	4,1	7,3	0,50	200
Al	5	Ar 20	4	7,3	4,1	1,23	81
Al	5	He 20	4	3,0	10,0	0,46	217
Al	6	Ar5/He15	6	3,6	8,3	0,75	133
Al	6	Ar10/He15	8	5,4	5,6	0,79	127
SS	3	Ar 20	8	19,3	1,6	5,63	18

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 reaches in less than 2 seconds, the allowed dose for blue light is reached in as short as 18 seconds.

Ozone and NOx

In order to measure the ozone and nitrogen oxide emissions during laser beam welding, the processing station was hermetically enclosed with a plastic foil. The nitrogen oxides were measured with a chemiluminescene analyser and the ozone was measured with a UV-photometer. The experiments were performed with a laser beam power of 2.5 kW and mild steel and aluminium alloy as base metals. The ozone and NOx emissions were measured as function of time. The dependence of the emissions on time was found to be linear and the corresponding emission rate is shown in Table 2.

Material	NOx (mg/s)	O_3 (mg/s)
Steel	0.88	0.21
Al	3.6	0.72

Table 2: Nitrogen oxides and ozone emission rates as measured during laser beam welding with a laser beam of 2.5 kW.

In occupational hygene, the Nominal Air Requirement, NAR, is frequently used to compare different emissions with respect to their toxicity. This number gives the amount of air per unit time (m^3/h) which is necessary to dilute the respective constituent to the defined threshold limit value. The NAR for processing of steel and aluminium as obtained with the above experimental parameters are given in Table 3.

The emissions of ozone and nitrogen oxides are in the range where the threshold limit values are quickly reached in the air surrounding the laser processing station. Therefore exhaust and filtration systems must be designed which can effectively remove these constituents. It should be pointed out, that efficient filtration systems are already widely used in order to remove metallic fumes such as Chromium, which are emitted during laser beam processing, however these filters might not be effective in removing Ozone and NO_x.

Material	NAR for NOx (m^3/h)	NAR for O_3 (m^3/h)
Steel	530	3800
Al	2200	13000

Table 3: Nominal Air Requirement for laser beam welding of stainless steel and aluminium alloy with a laser beam power of 2.5 kW. The threshold limit value for NO_2 and for ozone equals 6 mg/m^3 and 0,2 mg/m^3, respectively [3].

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