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PLASMA DIAGNOSTICS IN WELDING WITH CO₂ LASERS

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Abstract - The spectral emission of the laser induced plasma is investigated during the welding process of stainless steel (304 L), titanium (T 40), aluminium and aluminium based alloy (5083). The intensities of the spectrum lines which are emitted from a small area of the plasma are studied as a function of the distance from the surface, wavelength, time and processing parameters.

1.- Introduction

During welding with a CO₂ laser an induced plasma is always formed near the interaction area of the laser beam with the material. This plasma acts on two opposite ways, it absorbs and diffuses in part the laser beam and it transfers the energy to the materials. The plasma governs the efficiency of the welding process, i.e. the height and the width of the welded seam... Therefore the informations coming from the plasma must be related to the weld characteristics and could be used for on line control. With this aim, the light of a small area of the plasma has been recorded as a function of wavelength and time. The experiments have been carried out on stainless steel (304 L), titanium (T 40), aluminium (1050) and aluminium based alloy (5083, 5086).

2.- Experimental

The experimental set up (figure 1) consists of a lens which forms the image of a small area of the plasma (0,2 mm in diameter) at the end of an optical fiber, and at the other end of the fiber there are a grating spectrograph (1,8 nm mm⁻¹) and a linear photodiode array (OMA-detector head: 1024 diodes for 2,5 cm) or a photomultiplier (PM). With the OMA the spectrum is integrated and it yields only time-averaged data (intensity vs. wavelength). With the PM, a spectrum line is selected and its fluctuations can be recorded up to 4 MHz (intensity vs. time).

3. - Plasma

The plasma formation requires the vaporization of the material at the first step. The vaporization depends on materials properties : reflectance, thermal conductivity and diffusivity, specific heat, latent heats of melting and vaporization, melting and vaporization temperatures and on laser intensity and interaction time. For aluminium, high reflectance which ranges from 0,99 at room temperature to 0,87 at 1433 K, and high diffusivity (0,9 cm² s⁻¹) requires high intensity laser beams for vaporization.

Because of low ionization energy of metallic elements compared to shielding gas elements (Fe: 7,83 eV, Al: 5,96 eV, Ti: 6,81 eV, Ar: 15,69 eV, N: 14,47 eV), the vaporized metallic vapor becomes partially ionized. Electrons in the laser radiation field are accelerated by inverse Bremsstrahlung until the kinetic energy is high enough to ionize the metallic vapor, thus increasing the electron density by avalanche ionization. The plasma temperature is about 1 eV and its density ranges from 10¹⁶ to 10¹⁷ cm⁻³ /1/.

With the plasma a higher laser beam absorption takes place by three mechanisms /2,3/, electron heat

conduction inside the plasma, radiation of the plasma in short wavelength range which is more efficiently absorbed by metallic surfaces and condensation of vapor on the surface.

Fig. 1 - Experimental set up

Simultaneously, the laser beam is absorbed and refracted above the surface, reducing the welding efficiency as much as the electron density is high.

Therefore the plasma acts in two opposite ways: it enhances the energy coupling and it absorbs the laser beam. However this absorption can be influenced by the shielding gas. When the atoms of the shielding gas are light the recombination increases and the electron density decreases. That is the reason for the use of helium. In the same way, high flow rate of shielding gas increases the diffusion losses and the electron density decreases.

4. - Plasma spectrum results

Figure 2 shows a spectrum of stainless steel 304 L and the processing parameters. The main lines are from iron and chromium and seldom lines from argon. The intensity of the lines (time-averaged during less than one second) are constant. With other processing parameters there are always metallic lines every time that the plasma is induced, but the argon lines can disappear. The ionization of argon takes place if the plasma parameters, electron density and temperature, are high enough. The plasma parameters are influenced by the flow rate of shielding gas: with a high flow rate the diffusion losses are increased and therefore no argon lines are observed.

Fig. 2 - Spectrum of 304 L stainlesssteel

The radiation of iron, chromium and argon lines are more intense near the surface of the alloy (figure 3) in an interaction volume where the laser beam intensity, the electron and the metallic vapor density are high. This radiation of spectrum lines decreases with the distance above the surface, this decrease is as much steep as the welding processing parameters are far away from the optimum.

Fig. 3 - Intensity versus height of observation

Fig. 4 - Intensity versus focus position

Figure 4 shows that the intensity of the lines are correlated with the processing parameters, in this figure all the processing parameters are constant except the position of the laser beam focus and the observed plasma area is just on the surface of the material (height = 0). Intensity of the argon line is maximum when the focus is near the surface, i.e. when the depth of the seam is maximum; for metallic lines the intensity can have high values even for focus position far away from the surface.

For titanium T 40, the same kind of results have been obtained with argon shielding gas.

For aluminium 1080 and aluminium alloys 5083 and 5086 two shielding gas were used, argon and nitrogen. The depth of the seams is higher with nitrogen due to the energy of the reaction of aluminium with nitrogen and to the plasma behaviour. The spectrum lines (figure 6) with nitrogen shielding gas show a depression in the middle of lines due to a self-absorption, that means that the metallic vapor density is high.

The intensities of the lines (time averaged during less than one second) are not constant, the reason is a non constant depth of the seam.

Fig. 5 - Al 5083 spectrum with argon gas shielding

Fig. 6 - Al 5086 spectrum with nitrogen

With 5083 and 5086 aluminium-magnesium alloys, the spectra show intense magnesium lines because the vaporization of magnesium is easy. That can decrease the fraction of magnesium in the seam.

The fluctuations which have been recorded with the photomultiplier depend on the focus position and the height of the observed area above the surface. For titanium T 40, with the focus near the surface (figure 7), the fluctuations are very fast, less than one millisecond, no background can be seen and the signal is frequently modulated to zero; with focus above the surface, the fluctuations slow down and there is a background. The reason is for high laser intensity the absorption or the refraction by the plasma can interrupt the vaporization and for low laser intensity there is no interruption of the vaporization.

Fig. 7 - Plasma fluctuations for different positions of the focus of the laser beam (Titanium T 40, 2000 W, Ar : 40 l/mn, H = 1 mm, Line TiI 430, 18 nm)

5. - Conclusion

The plasma radiation can be used for on line control of the welding process. The processing parameters must be first experimentally determined and for this set of parameters, the intensity of the spectrum lines and their fluctuations are significantly related to the interaction of the laser beam with material, thus to the seam characteristics..

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