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Influence of Welding Current and Focal Position on the Resonant Absorption of Laser Radiation in a TIG Welding Arc

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Abstract

The work presents the influence of welding current and focal position on the resonant absorption of diode laser radiation in a TIG welding arc. The laser beam is guided perpendicular to the electrical arc to avoid an interaction with the electrodes. Laser power measurements have shown a reduction of the measured laser power up to 18 % after passing the electrical arc. This reduction results from the interaction of argon shielding gas atoms and laser radiation at 810.4 nm and 811.5 nm. The interaction is strongly affected by the adjusted welding current and the adjustment of the laser beam and the electrical arc. Lowering the welding current or shifting the laser beam out of the centerline of the electrical arc reduces the ionization probability. An increased ionization is necessary to decrease the resistance of the electrical arc.

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Keywords: TIG arc; resonant absorption; laser radiation

1. Introduction

The combination of laser radiation and an arc welding process is known for about 30 years (Steen and Eboo, 1979). In the recent years laser hybrid welding got increasingly attractive for industries like transport- or pipeline industry. Laser hybrid welding provides high welding speed and high penetration depth, but it is also stamped by high investment costs for the laser source and the system components.

Laser stabilized arc welding processes use laser powers much less than 1000 W and do not provide penetration welds, but the benefits like gap bridging and high welding speed are still present (Hermsdorf et al., 2009b). Further experiments were realized with CO_2- (Cui, 1991; Decker et al., 1995) and Nd:YAG-laser (Hu, 2002; Hu and den Ouden, 2005; Stute et al., 2007). The laser stabilizes the electrical arc which allows increasing the welding speed without a reduction of the welding depth (Cui et al., 1992). The root of the electrical arc is also fixed to the laser beam. Thus it is possible to affect the position of the electrical arc (Schnick et al., 2012; Hermsdorf et al., 2009a). The additional energy of the laser radiation leads to an increase of metal vapor in the electrical arc which increases

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the amount of the metal ions (Hu, 2002). A change in the resistance of the electrical arc leads to a change in the arcs voltage and current (Steen, 1980).

Next to investigations with Nd:YAG-laser, Hermsdorf et al. (2009b) also carried out experiments with diode lasers with a center wavelength of 808 nm and 811 nm and a laser power of about 400 W. They figured out, that a laser wavelength close to the wavelength of absorption lines of the shield gas argon allows an optimization of the welding process. Argon has two transitions at 810 nm and 811 nm (NIST, 2014). Hermsdorf et al. (2009b) suppose, that resonant absorption of the laser radiation increases the probability of ionization in the volume of the electrical arc which leads to an increased conductivity of the electrical arc. In their experiments the laser beam was oriented almost coaxial to the electrical arc which causes a permanent irradiation of the melting zone. In fact, Hermsdorf et al. (2009b) could not distinguish the effect of an interaction of the laser beam and the arc from the effect of an additional heating of the melting pool. Matsuta et al. (2010) demonstrated that resonant absorption of laser radiation is causing a change of the discharge current in an argon filled glow-discharge tube.

This paper reports the influence of the welding current and the focal position on the resonant absorption of laser radiation in a TIG welding arc. Beam guiding perpendicular through the centerline of the electrical arc eliminates the irradiation of the melting zone. So it is possible to analyze the interaction between laser radiation and the electrical arc by laser power measurements and measurements of the arc voltage.

2. Experimental Setup

The experimental setup is shown in Fig. 1. The used welding equipment is an industrial 300 A AC/DC current controlled TIG welding source. Selecting the internal actual value signal of the welding source allows an analysis of the arc voltage. The 8 mm long TIG welding arc burns on a cooled copper plate. A diode laser with a maximum power of 367 W and a center wavelength of 811.3 nm was used. Tuning the laser power allows to shift the center wavelength between 803.5 nm and 811.3 nm. The center wavelength was computed as the center of mass of the lasers power spectrum at a given laser power.

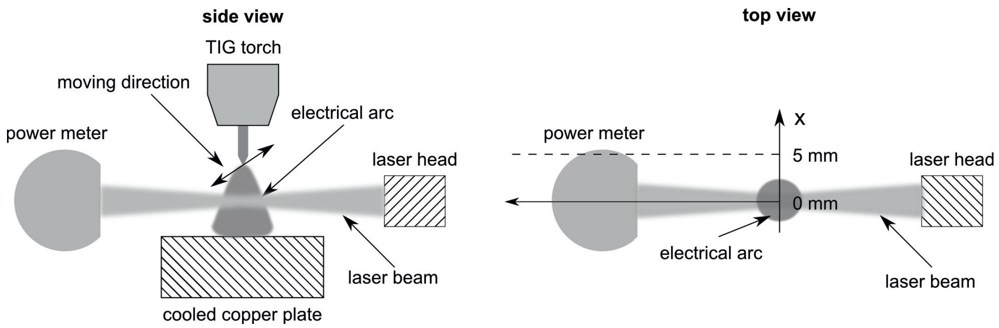

Fig. 1. Experimental setup.

The cooling water temperature of the laser was kept constant throughout the experiments. The laser spectrum overlaps the argon absorption lines at 810.4 nm and 811.5 nm at the maximum laser power. Decreasing the laser power also reduces the overlap between the spectrum of the laser and the argon absorption lines. The laser beam passes the electrical arc parallel to the copper plate in 4 mm height to avoid an irradiation of the copper plate and the electrode. The electrical arc was moved by a linear axis to examine the effect of the spatial overlap of the laser beam and the electrical arc. The laser power was measured after passing the electrical arc to get information about the interaction of the laser radiation and the electrical arc. The distance between the arc column and the calorimetric power meter was chosen with respect to the possible optical effects of the arc plasma. Table 1 gives an overview on the used parameters. A compact spectroscope allows the analysis of the power spectrum of the laser and the emission spectrum of the electrical arc within the wavelength range from 311 nm to 867 nm. The distribution of the excited argon atoms was detected with a CMOS camera in combination with a bandpass filter (Table1).

Table 1. Parameters.

Welding	
Current	120 A
Gas	Ar 4.6
Gas flow	10 l/min
Gas pressure	2 bar
Laser	
Max output power	367 W
Center wavelength range	803.5 - 811.3 nm
Linewidth (FWHM) at max power	2.5 nm
Focus diameter (measured)	2.4 mm
power detector (calorimetric)	
1 kW power detector diameter	35 mm
Distance from arc	150 mm
Bandpass filter	
Center wavelength	810 ± 2 nm
Linewidth (FWHM)	10 ± 2 nm

3. Experiments

The detected laser power after passing the electrical arc is shown in Fig. 2. The black curve shows the detected optical power at a center wavelength of 811.3 nm. At this center wavelength the laser power spectrum completely overlaps the argon absorption lines. At the beginning of the measurement both the laser and the electrical arc were active and a power of 318 W was measured. This power includes the laser power as well as the optical power of the electrical arc of 9 W which was measured before this experiment. When the electrical arc was deactivated the measured power rose up to the adjusted laser power of 367 W. Thus 58 W (16 %) of the inset laser power was not transmitted to the power meter due to the presence of the arc. The slow rise in Fig. 2 was caused by the calorimetric measurement principle of the used power meter.

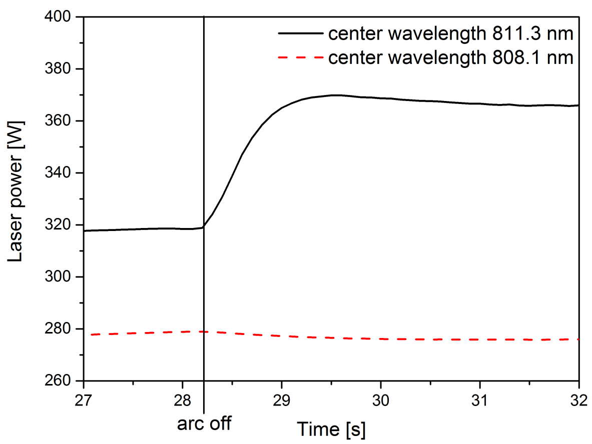

Fig. 2. Measured laser power difference as function of time.

To control if this power loss is based on a resonant absorptive mechanism, the center wavelength of the laser was detuned to 808.1 nm by reducing the laser power (red curve in Fig. 2). At this center wavelength the laser power spectrum and the argon absorption lines do not overlap. As before, the laser and the electrical arc were activated at the beginning of the experiment and a laser power of 279 W was measured. In this case the deactivation of the electrical arc did not cause a rise in the measured power but a slight decrease because of the missing optical power of the arc which indicates an underlying resonant absorption mechanism.

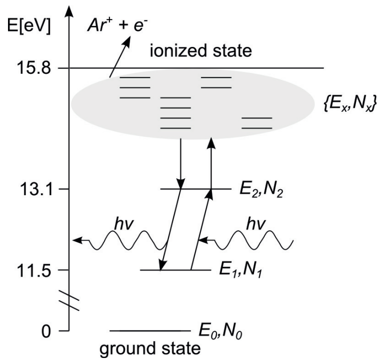

Fig. 3. Schematic energy levels and transitions in the argon schema.

The absorption of the resonant laser radiation transfers argon atoms from the metastable E_1 state into the energy state E_2 and therewith increases the population of the energy level E_2 (Fig. 3). So there are more higher excited argon atoms which might be ionized by secondary processes. This additional ionization leads to a decreased resistance of the electrical arc.

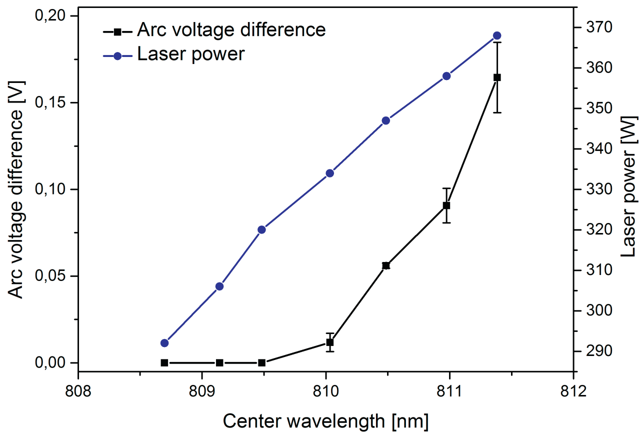

Fig. 4. Voltage difference as function of the center wavelength (welding current 120 A).

Because of the active stabilization of the welding current, changes in the resistance of the electrical arc are observed as changes of the arcs voltage. The irradiation of the electrical arc with laser radiation with a laser power of 367 W at a center wavelength of 811.3 nm induces a reduction of the arc voltage of 0.16 V. Fig. 4 shows the measured voltage difference as function of the center wavelength. Each measurement was repeated 3 times. The center wavelength was detuned by means of the laser power. Although the disadvantage of this method is that two parameters are changed at the same time. The reduction of these parameters leads to the same result: the density of the laser photons in the absorptive spectral range of the argon atoms is changed accordingly. A reduction of the center wavelength in the range of 809.5 nm and 811.4 nm leads to a decreased voltage difference, whereas below 809.5 nm no change in the arc voltage was observed.

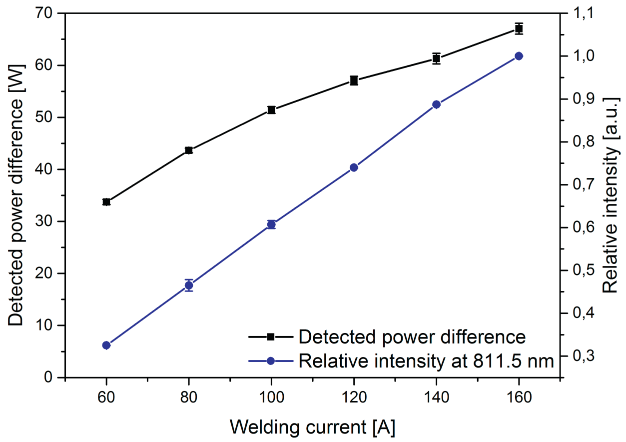

Fig. 5. Laser power difference and intensity of the argon absorption line at 811.5 nm as function of the welding current.

The measurements of the arc voltage difference show, that the interaction between argon atoms and laser photons is strongly affected by the density of the laser photons in the absorptive spectral range of the argon. But the population N_1 of the energy level E_1 also has a significant influence on the interaction (Fig. 3), since an interaction only can occur if there are enough electrons at the energy level E_1. Changing the welding current induces a change of the intensity of the emitted radiation at 811.5 nm of the spontaneous E_2 to E_1 transition in Fig. 5. Such change only can occur, if the population N_2 of the energy level E_2 also has changed. Besides driving the emissive transition the welding current also affects the inverse absorption process. This is implied by the dependency of the detected power difference on the welding current which is also depicted in Fig. 5. An increased welding current results in a higher detected power difference which indicated additional interaction events of laser photons and argon atoms. For a welding current of 160 A, a power difference of 65 W was detected, which is 18 % of the emitted laser power. In summary the interaction between laser beam and the argon atoms depends on two factors, the laser photon density in the absorptive spectral range of the argon atoms and also by the density of the excited argon atoms in the E_1 energy state which are able to absorb the laser photons.

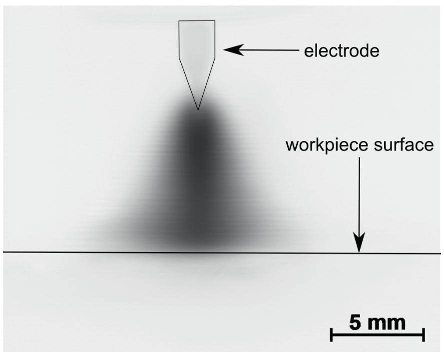

Fig. 6. Image of the radiation emitted by the argon atoms at 805-815 nm.

The density of the argon atoms is not uniformly distributed across the electrical arc. Fig. 6 presents the radiation which was emitted by the argon atoms in the range at 805-815 nm. The image was inverted and filtered to improve the representation. The emitted radiation decreases with a growing radius.

The used setup allows different adjustments between the electrical arc and the laser beam (Fig. 1). The detected power difference for different overlaps is shown in Fig. 7. The maximum detected power difference of 58 W is reached at x = 0 mm and an arc current of 120 A. When moving the electrical arc in x direction out of the laser the detected power difference decreases. In Fig. 7 the detected power difference is fitted by a gauss function (red curve). The diagram also shows the mean grayscale value of the original picture at the height of the laser beam depending on the arcs position (blue curve). Due to the applied optical bandpass filter the grayscale values represent the density of the argon atoms emitting in the 805-815 nm wavelength range which decreases in the radial direction.

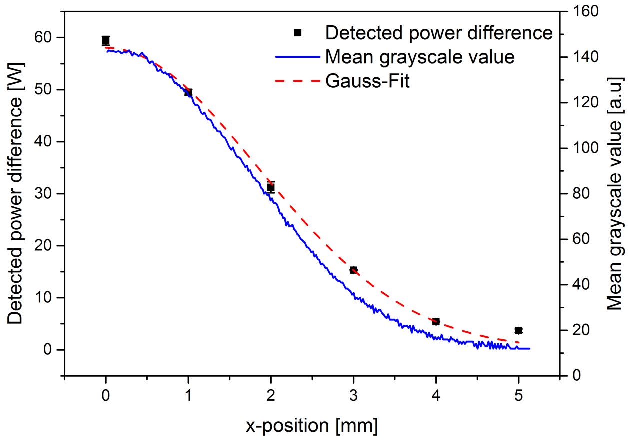

Fig. 7. Laser power difference as function of the adjusted electrical arc position.

4. Conclusion

The experiments have shown that a noticeable amount of laser photons were not transmitted to the power meter through the electrical arc if the laser power spectrum overlaps the absorption lines of argon at 810 nm and 811 nm. In case of 160 A arc, a laser power difference of 65 W was detected. Measurements of the arc voltage indicate that the interaction of the laser radiation and the argon atoms induces a change in the resistance of the electrical arc. The change is affected by the laser beams spectral power density in the absorptive spectral range of the argon atoms, which in turn depends on the center wavelength, the laser power and the linewidth of the laser spectrum.

Next to the laser photon density, the amount of excited argon atoms which are able to absorb the laser photons also has a significant influence on the interaction. Increasing the welding current raises the frequency of collision processes and causes a higher population of the energy level at 11.5 eV. So there are more excited argon atoms which fulfil the prerequisite for absorbing the laser photons. This fact is reflected by a higher detected power difference in case of an increased welding current.

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