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Benefits of optogalvanic effect and beam shaping for laser stabilized GMA welding

HERMSDORF Jörg, KAIERLE Stefan*
(*Laser Zentrum Hannover e. V.*, *Hannover* 30419, *Germany*)
* *Corresponding author*, *E-mail*: *s. kaierle@ lzh. de*

Abstract: To develop and refine the laser guided and stabilized (LGS) welding process, the conductivity of the electric arc must be maximized using laser radiation. The optogalvanic effect (OGE) is the leading factor in controlling it, and if optimized it will lead to the stabilization of the electric arc. The OGE raises the probability of ionization of the particles in the plasma, and thus, the conductivity of the electric arc. The interaction between the photons of the laser and the Argon atoms through electron-atom collisions create charged particles. The higher the rate of ionization is, the higher the conductivity of the electric arc. Many tests were conducted to discover how to make best use of this effect. The position of the focus of the beam in relation to the work piece, the shape of the beam, and the laser wavelength used were all taken into account.
Key words: optogalvanic effect; laser guided and stabilized welding; Rayleigh length

光电偶效应和光束整形对激光稳定气体保护焊接的增益

HERMSDORF Jörg, KAIERLE Stefan*
(汉诺威激光中心,汉诺威 30419,德国)

摘要:为了开发和改进激光诱导稳定焊接加工技术,需要通过激光辐射使电弧的导电率达到最大值。光电偶效应是控制该过程的主导因素,该过程的优化将会保证电弧的稳定性。光电偶效应提高了等离子体粒子电离的概率,从而提高了电弧的导电率。激光光子和氩原子之间的电子-原子碰撞相互作用产生了带电粒子。电离率越高,电弧的导电率就越高。为了充分利用光电偶效应,我们还应考虑工件上的光束焦点位置、光束形状和激光波长因素。
关 键 词:光电偶效应;激光诱导稳定焊接;瑞利长度
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1 Introduction

The industrial market demands stable welding processes with low investment cost and high process speeds. To fulfil these requirements, the laser guided and stabilized gas metal arc (LGS-GMA) welding process is developed. The objective for this process is to stabilize the electric arc using only minimal power requirements for the laser. To achieve this, the laser must increase the conductivity of the arc, which is directly linked to its stability. After careful testing of many different effects, it is found that for continnous wave lasers the optogalvanic effect(OGE) is the main reason for this positive interaction[1] and was the best factor that could be controlled to optimize it.

The state-of-the-art LGS process uses only the electric arc for welding and uses the laser for stabilisation and guidance[2]. The laser does not have enough power to create a welding process by itself, but together with the electric arc, this welding process can bridge gaps and weld at faster rates than conventional GMA processes.

Tungsten inert gas(TIG) welding also increases the stabilization of the electric arc, as researched by Cui and proven by experimental results[3-4]. The laser radiation was switched on during the welding process with an electric arc, which led to a drop of the discharge voltage and a simultaneous rise of the arc current. This change in the discharge characteristics can be attributed to an increased conductivity of the arc in the overlap volume of the laser beam and arc column. The increased conductivity leads to a higher energy input into the work piece because less electric power is transferred into the plasma. This energy input stabilizes and guides the electric arc. To achieve this benefit, only 10 to 20% of the total power input is required from the laser, and the engaged laser radiation is used exclusively for the stabilisation and guidance of plasma plumes from the electric arc. The heat input from the laser is low because of the minor continuous radiation. The interaction between the laser and the electric arc increases the probability of ionization in the volume of overlap of the two power sources(see Section 2). As the frequency of the ionization increases, the conductivity of the arc does as well. Therefore, for maximum stability, the OGE must be optimized.

The beam size and shape can be changed to control the overlap area and focus of the laser. These changes affect the OGE. Since the intensity of the laser remains constant during these changes, it is found that by defocusing the beam and adjusting the profile more parallel, the area of overlap between the beam and the electric is increased. This counter-intuitive method increases the number of interaction between the photons of the laser and the Argon atoms, which increases the conductivity of the arc. Other laser processes also defocus the laser beam to ameliorate the results, and in laser welding aluminium, a high power density at the focus of the laser beam causes the aluminium to evaporate, which produces spatters on the surface and poor bead appearance[5]. By defocusing the laser beam, the power density decreases and therefore, the weld quality and appearance improves.

2 Optogalvanic effect

The OGE occurs when plasma is irradiated with a laser beam. The laser light changes the population density of the excited states of the atoms, which results in a change of the arc discharge current. Optogalvanic spectroscopy in gas discharge plasma can be used for wavelength calibration[6]. It is different from other charged particle detection techniques because of the presence of a sustained discharge with an electron gas at relatively high temperature (5 800 – 116 000 K)[7]. The basic mechanism of the OGE can be described briefly as follows:

In a self-sustained discharge, the electron gas temperature is high enough to populate the excited levels where free electrons and atoms or molecules are in dynamic equilibrium. The result is a distinct impedance and current. If the discharge is irradiated with laser light that is resonant with the atomic or molecular transition of the species, the atoms or molecules are pushed towards the metastable levels. Once the particles populate these levels, it is unlikely that they return to their original states. Therefore, the rate of ionization of those species increases due to laser perturbed collisional ionization. The change in electrical properties of plasma results in higher arc currents or lower voltages depending on the power supply.

As a result, the OGE leads to an increase in conductivity of the electric arc and therefore directly stabilizes the discharge. The OGE depends strongly on the wavelength of the laser, since the laser light is only absorbed if the photon energy matches the energy gap between two atomic energy levels.

In order to optimize this effect, and therefore maximize the stabilization and guidance of the electric arc, two factors must also be optimized: the area of overlap between the laser beam and the electric arc and the wavelength of the laser.

3 Experimental setup

Originally, TIG welding was used. No filling wire was used to better observe the interaction between the laser beam and the electric arc. The TIG needle was in contact with the work piece to ignite the electric arc, and was then lifted up to a predefined distance above the work piece. The laser head was mounted at 26° to the perpendicular direction to realize the maximum area of the overlap between the electric arc and the laser beam.

In the GMA welding setup, the welding head was mounted at 60° to the work piece surface while the laser radiation was installed upright from the top, as seen in Fig. 1. This also maximized the overlap area.

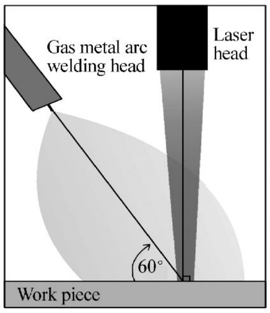

Fig. 1 Experimental GMA welding setup

The different laser systems used in the tests are described in Tab. 1. All tests were carried out with a the laser beam in a leading postion. The distance between electrical arc torch and laser beam was between 1.0 and 2.0 mm. Corgon gas, a mixture of carbon dioxide and Argon gases, was used during all welding experiments.

Tab. 1 Laser sources parameters

	Nd:YAG lamp pumped	Diode laser(1)	Diode laser(2)
Wavelength/nm	1 064	808	811
Used laser power/W	400	360	380
Beam quality/(mm mrad)	25	66	44

4 Experimental results

To optimize the stability in the electric arc, many parameters were tested. Preliminary tests were done using TIG welding. This was done to better observe the interaction between the laser beam and the electric arc. Once proven that the laser stabilized and guided the electric arc, the process was changed to GMA welding. The main arc parameters were a current of 90 A and a voltage of 17.7 V. With this process parameters a maximum welding speed of 0.7 m/min was possible.

4.1 Beam focus position

Initially, the position of the focus was tested. All investigations were conducted using the Nd:YAG laser and the diode laser (see Tab. 1).

Using the reasoning that the higher the intensity of the laser, the better the resulting weld, the laser beam was focused directly on the work piece with a diameter of 0.6 mm, as shown in Fig. 2. This increased the welding speed and also the weld quality when compared to ordinary GMA welding, as was expected.

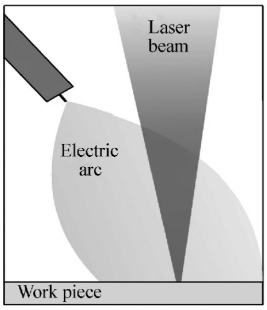

Fig. 2 Beam focus position on work piece surface

Raising the focus position to 4 mm above the work piece, as shown in Fig. 3, the diameter of the beam was between 1 and 2 mm on the work piece surface. The focus diameter remained 0.6 mm.

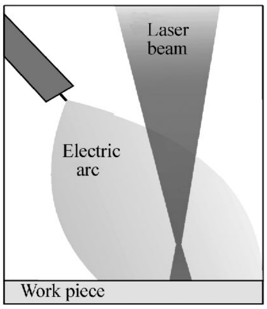

Fig. 3 Beam focus position above work piece surface

Although the intensity of the laser decreased in this setup, the weld unexpectedly had superior quality. This can be attributed to either the increase of interactions between the Argon atoms and the photons due to the increase of overlapping area, or the improvement of the interaction between the laser and the work piece surface.

The focus of the beam was then moved to a negative position into the work piece, which is illustrated in Fig. 4.

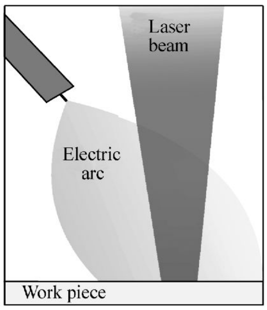

Fig. 4 Beam focus position below work piece surface

The area of overlap was smaller, but the area of the beam on the surface of the work piece remained the same. This test did not result in a better weld, so the conclusion was that the interaction between the laser and the surface of the work piece was negligible with respect to the welding results, whereas the area of overlap between the laser beam and the electric arc was important. Therefore, the interactions between the Argon atoms and the photons of the laser were a driving force behind the increase in conductivity of the electric arc.

The focus position was raised again until the intensity of the laser decreased sufficiently that even though the area of overlap was quite large, there was not enough interaction between the photons and the Argon atoms to increase the conductivity of the arc.

4.2 Beam profile

Using a beam expander, the beam profile was adjusted more parallel. This means the depth of the focus (Rayleigh length), which is the length of the beam between the two points where the intensity is 50% lower than the full intensity, is quite large. The more parallel the beam, the longer the Rayleigh length. This shape change increased the area of interaction between the photons in the laser and the Argon atoms. However, as the area increased, the intensity decreased since the energy of the laser remains the same. Once the intensity was too low, the frequency of collisions between the atoms and electrons was also too low. This resulted in low conductivity and the stabilization of the arc decreased.

The optimum beam geometry is shown in Fig. 5 and was found to be a beam with a long Rayleigh length, with the focus anywhere in the overlapping area.

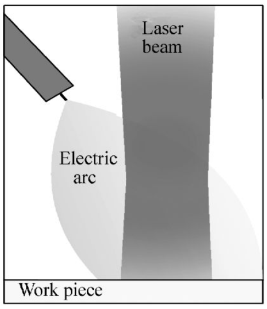

Fig. 5 Optimum beam geometry: the beam is almost parallel, with a long Rayleigh length

Since the Rayleigh length is quite long, the intensity(W/cm^2) of the focus of the beam is not considerably larger than the intensity of the points at a short distance from the focus. This means that as long as the focus is somewhere in the overlapping area, the conductivity of the arc will be optimized regardless of where the focus actually is.

4.3 Laser wavelength

The OGE depends strongly on the wavelength of the laser[1]. The laser light is only absorbed if the photon energy matches the energy gap between two atomic energy levels[6]. The Argon atoms easily absorb wavelengths of 810 – 811 nm, with relative intensities of 20 000 – 35 000 [8]. Relative intensities provide a qualitative description of what the emission spectrum of a particular element in a particular(low-density) source looks like. The higher they are, the higher the chance of ionisation of the particles with the corresponding wavelength. Contrastingly, the relative intensity for the absorption of 1 064 nm wavelength is approx. 7 and therefore it much smaller than that for 810 – 811 nm.

All previous experiments were done with a Nd:YAG laser at 1 064 nm wavelength and a diode laser at 808 nm wavelength. Both lasers showed an improvement to the weld quality by a smoother surface and less welding sparks. Compared to conventional GMA welding, the welding speed was improved to 1.0 m/min by using the wavelength of 1 064 nm and 1.5 m/min by using the wavelength of 808 nm. The laser was then changed to a diode laser at a wavelength of 811 nm, which showed an even greater increase in welding speed to 1.8 m/min.

5 Conclusion

As experimental results show, the optimization of the OGE leads to higher conductivity in the electric arc and therefore, better stabilization. The OGE is affected by the area of overlap between the photons from the laser and the Argon atoms, the intensity of the laser, and the wavelength of used laser. It can be manipulated by changing the position of the focus in relation to the work piece, changing the shape of the beam, and using different wavelengths.

There is minor interaction with the laser and the surface of the work piece, so the best focus position is above the work piece. Although the intensity of the laser decreases as the focus position is raised, the area of overlap increases. This contributes to a higher OGE and therefore raises the conductivity of the electric arc.

A beam that is almost parallel(one with a long Rayleigh length) also increases the area of overlap without compromising too much of the intensity. This geometry also maximizes the OGE.

Because Argon atoms absorb 810 – 811 nm wavelengths quite easily, the diode laser (2), as described in Tab. 1, maximized the conductivity in the electric arc.

By capitalizing on the OGE, it is possible to increase the conductivity in the electric arc and therefore put more power into the work piece without the energy being absorbed into the plasma. The result is a stable, even weld that can be guided and operated at greater welding speeds.

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Author's biography:

HERMSDORF Jörg received his degree at the college of higher education in 1996. He then worked in the building industry as a project and welding engineer. In 2001, he started working at the Laser Zentrum Hannover(LZH) e. V. as a research scientist. 2009 he took over the position as the group leader of the Machines and Controls group. 2013 he earned a PhD in mechanical engineering at the Leibniz University of Hannover. He has significant experience in arc and laser welding of steel, aluminium and other materials. E-mail: j. hermsdorf@ lzh. de

KAIERLE Stefan studied electrical engineering and went on to do his PhD in mechanical engineering at RWTH Aachen University. In 1998 he entered Fraunhofer ILT as a department head for system technology. In this role, his main research was focused on laser system technology, laser materials processing, laser process control and optics, as well as related fields like eco-efficiency, automation and laser engineering. In 2012, Stefan Kaierle moved to Laser Zentrum Hannover(LZH) and assumed responsibility for the department of Materials and Processes. From 2003 to 2013 he was President of the European Laser Institute ELI and currently is Member of the Board of Directors of Laser Institute of America (LIA). E-mail: s. kaierle@ lzh. de