Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 74 (2018) 765–769

www.elsevier.com/locate/procedia

10th CIRP Conference on Photonic Technologies [LANE 2018]

Improving weld bead homogeneity in short arc GMAW processes applying low power diode lasers

Jan Leschke[a,*], Erik Zokoll[b], Jörg Hermsdorf[a], Stefan Kaierle[a]

[a]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany
[b]RWTH Aachen University ISF Welding and Joining Institute, Pontstraße 49, 52062 Aachen, Germany

* Corresponding author. Tel.: +49-511-2788-279; fax: +49-511-2788-100. *E-mail address:* j.leschke@lzh.de

Abstract

Using laser and arc power in equal parts, laser-arc hybrid welding processes are successfully adapted by the industry. This paper shows the stabilizing effects of diode lasers on short arc GMAW (gas metal arc welding) which deliver just a fraction of the supplied arc power. In a comprehensive comparison the stabilized and the sole GMAW processes are confronted and differences regarding process behavior and weld bead properties are pointed out. The tests were carried out with DC01 (1.0330) plates of 1 mm thickness deploying lasers using a mean laser intensity of 1,1 x10^4 W/cm². Adding this low amount of intensity provides stability to the weld process and results in weld beads of higher homogeneity. The process behavior is characterized by the transient current and voltage curves which are analyzed in regards to consistency and uniformity. Metallographic analysis is employed to compare the weld bead dimensions at different energy ratios.

Keywords: laser stabilization; diode laser; arc; low energy

1. Introduction

The combination of laser and GMAW processes is known and used since the late 1970s [1]. Since then several studies have been carried out to gain knowledge about the synergy between laser and electrical arcs. Although the exact mechanisms are not completely revealed, the interaction between laser radiation and arcs could be proved, even with low laser power of P_L = 10 W [2, 3]. Different theories have been developed over time, suggesting the effect caused for example by ionization or optogalvanic influences. A comprehensive listing of possible effects can be found in [4] and [5]. Wendelstorf et al. showed advantages for the GTAW (gas tungsten arc welding) process combining it with laser radiation, especially for welding thin sheets [6]. Kozakov et al. [7] attribute the impact of the laser radiation on the arc to the cause of the optogalvanic effect, as they were able to prove resonant laser absorption at a wavelength of 811 nm of a GTAW arc. A comparable approach with similar results using a Nd:YAG laser has been carried out in [8]. Regarding the practical application of the process combination, the laser arc-hybrid welding has become an established tool for the industry [9]. Combining laser and arc power at equal levels, the benefits of both processes add up. This leads to a gain in weld speed and penetration depth due to the advantages of the laser process and better potential for gap-bridging due to the involved arc weld process. The drawback of the hybrid procedure lies in the high costs of the high power laser source that is needed to meet the energy induced by the arc process. In order to make the method affordable for small and medium-sized enterprises, investigations were carried out to determine positive impacts of low powered laser sources. Different studies were realized revealing the possibility of stabilizing instable arc processes by adding laser radiation with powers ≤ 500 W [10, 8, 7, 4]. Hermsdorf [4] showed the advantages of the method, for example an increase in the

10.1016/j.procir.2018.08.014

possible weld speed of GMAW bead on plate welds of about 230 %. Hu [10] concentrates on energetic aspects and the physical effects, caused by the stabilizing interaction. In summary a lot of knowledge has been gained about the impact of laser radiation on instable GMAW welds, but a comparison to a stable GMAW process pointing out the differences and possible advantages in process behaviour and weld properties, is missing.

The scope of this paper is to close this gap by employing different analysis methods to achieve a comprehensive comparison between the sole GMAW and the laser stabilized GMAW process.

Nomenclature

f	frequency [Hz]
GMAW	gas metal arc welding
GTAW	gas tungsten arc welding
I	current [A]
L	laser
P_L	laser power [W]
U	voltage [V]
v_D	wire feed [m/min]
v_S	weld speed [m/min]

2. Experimental Setup

The experimental setup which is used for the investigations shown in this paper is depicted in Fig. 1. The torch which is connected to a Merkle HighPULSE 550 DW, is positioned in a 35° angle to give the laser beam access to the process zone. The scanner optics are used in static operation and are connected either to a 811 or a 1025 nm diode laser. The ratio of the optics is 3.17:1. The focus is positioned above the samples resulting in a spot diameter of about 2 mm on the surface. Regarding the welding direction of the table, marked with the red arrow, the laser is positioned in front of the arc process. The clamping system ensures the reproducibility of the sample position.

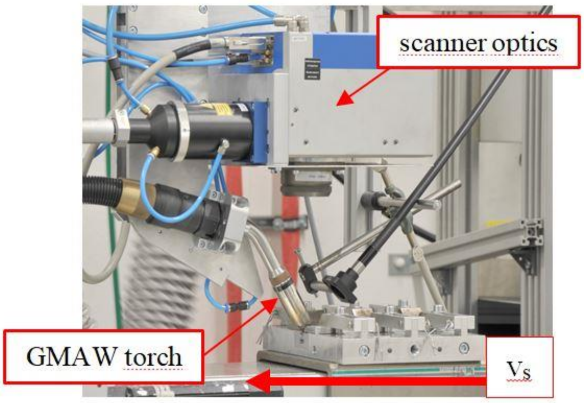

Fig. 1. Setup with 2 inch scanner optics. Neutral laser position, GMAW torch angled, welding direction marked with v_s

3. Methodology

The weld task that is chosen for the comparison is fillet welding of 1 mm DC01 plates. In order to achieve a practical comparison of the laser stabilized and the common short arc GMAW process, the properties of the welds should inhibit as equal properties as possible. The chosen approach for this methodology is to obtain a laser stabilized GMAW process for a given weld task and compare it with GMAW processes with similar properties. To obtain these standard GMAW processes, which meet the characteristics of the stabilized weld, the weld energy is raised by increasing the wire feed at a voltage trim of 0. To ensure the stability of both processes, a slow weld speed of $v_s = 0.6$ m/min is chosen. The measurements and weld results of these processes are then compared regarding the energy entry by measuring the transient signals, microsections and weld bead homogeneity. The scheme of the methodology is depicted in Fig. 2.

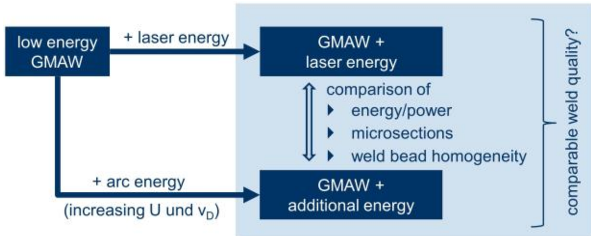

Fig. 2. Methodology for comparing the laser stabilized process with normal GMAW.

The boundary conditions are kept the same during the test execution, to ensure reproducibility. The sample positioning is defined by stop collars and the temperature regime is measured at the clamping system to ensure consistent boundary conditions. All tests were carried out with a start temperature of the clamping system ≤ 30° C, measured at two positions. The laser stabilized process uses 340 W laser power with both diode lasers. As it was figured out during the analysis that there were no noticeable differences between the results of both lasers, the corresponding values in the diagrams "2.3 + L" are averaged from the results of both laser units at $v_D = 2.3$ m/min for easier readability. The determination of the power output of the weld machine is calculated via the integral of the product from the instantaneous values of the measured voltage and current of the middle section of the weld. The respecting signals are metered at readout pins inside the weld machine.

4. Results and discussions

At a given welding speed of $v_s = 0.6$ m/min, the sample material was welded at 340 W laser power with the parameters of the GMAW machine set to U = 16.2 V and $v_D = 2.3$ m/min, resulting in a weld bead shown in Fig. 3.

Fig. 3. Microsection of a laser stabilized reference weld with $P_L = 340$ W, $v_s = 0.6$ m/min, U = 16.2 V, $v_D = 2.3$ m/min.

To obtain a comparable weld without the support of laser radiation, the wire speed v_D is raised in 0.1 m/min steps, which also leads to an increase of the target value of the voltage U at several increments due to the characteristic of the weld machine (Table 1).

Table 1. Wire speeds and corresponding voltage target values with voltage trim set to 0.

parameter	values									
v_D [m/min]	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2
U [V]	16.2		16.3		16.4		16.5		16.6	

As listed in the table, the wire feed was varied from 2.3 to 3.2 m/min, which leads to 10 GMAW parameter sets to be compared with the laser stabilization. The two diagrams in Fig. 4 show the averaged voltage (Fig. 4a) and current (Fig. 4b) which are measured when welding with the mentioned target values.

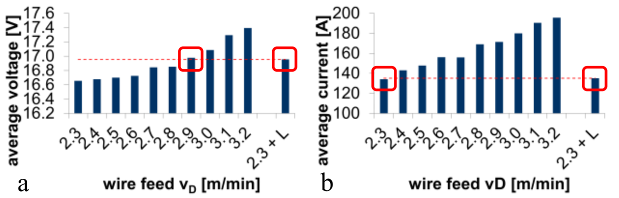

Fig. 4. Measured and averaged (a) voltage and (b) current of the used parameters, red line marks parameter with laser stabilization.

While the values of the averaged voltage show an overall offset from the target value induced by the characteristic of the welding machine, the weld voltage of the laser stabilized process experiences an additional raise of about 0.3 to 0.4 V. Compared with the GMAW processes this value corresponds to nonstabilized welds at U = 16.5 V and $v_D = 2.9$ m/min. The measurements in Fig. 4b show in contrary, that the weld current is not affected by the laser radiation, which leads to an averaged current of around I = 130 A. The corresponding solitary arc process using $v_D = 2.9$ m/min is deploying an increased current of approx. 170 A. An explanation for the raised voltage when using the laser stabilized process, can be found in the additional generation of metal vapour. In [11] similar behaviour is described in a plasma hybrid process when welding steel sheets. [12] explained the cooling of the arc by metal vapour which leads to a higher resistance, thus an increased voltage. These circumstances directly lead to differences in the power output of the weld machine, depicted in Fig. 5a.

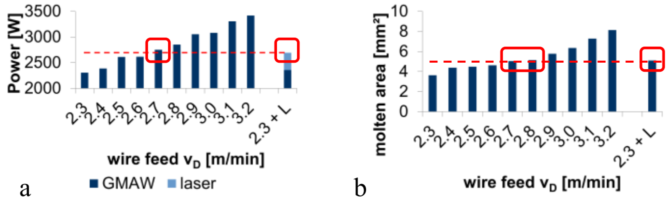

Fig. 5. (a) Measured power and (b) molten area of the compared processes relative to the wire feed.

Compared to the process without laser stabilization, the laser supported welding leads to a process with a raise in power of about 400 W (red mark). For this diagram the laser power of $P_L = 340$ W was simply added to the measured GMAW value, without regarding losses in form of reflection or process interaction. The remaining difference is suggested to be caused as a response of the GMAW process to the laser usage. A common GMAW process without laser generates a comparable gain in power when using a wire feed of $v_D = 2.6 – 2.7$ m/min. Fig. 5b shows the molten area induced by the given parameters, measured by micro sectioning the samples. The general characteristic of the amount of melt corresponds to the power measurements in Fig. 5a. The higher the power input, the higher the resulting weld bead volume. Regarding the laser stabilized process, this implies an increase of the molten area of approx. 1.5 mm² due to a laser power of $P_L = 340$ W. To achieve the same amount of melt with a common GMAW weld, the wire speed needs to be raised about 0.4 – 0.5 m/min. A more detailed evaluation of the microsections can be seen in Fig. 6, which gives an overview of the widths, heights and depths of the welds.

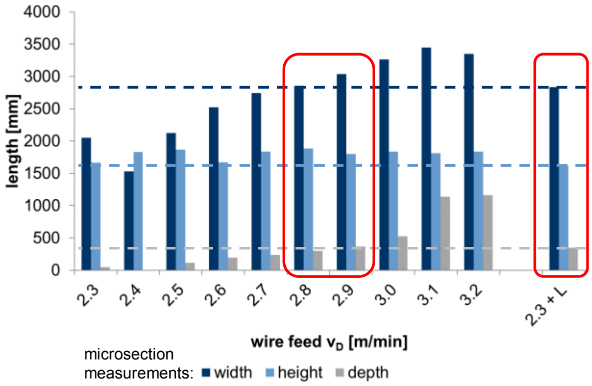

Fig. 6. Microsection measurements: width, height and depths of the weld beads, with dashed lines at the laser stabilized values

Focussing on the width of the welds, the diagram shows some inconsistencies at the lower wire feeds of 2.3 and 2.4 m/min, which is due to strong humping effects resulting in very inhomogeneous weld beads. This effect also influences the measured depth in the mentioned wire feed region. By raising the wire feed the process gets more stable and meets the width of the laser stabilized process at $v_D = 2.8$ m/min. While the height of the weld beads do not depend to the wire feed, the behaviour of the depth of the welds is similar to that of the width measurements. The corresponding weld depth to the laser supported process lies between $v_D = 2.8$ and 2.9 m/min. Wire feeds ≥ 3.1 m/min indicate a jump in the depth of the weld. This is caused by complete penetration of the bottom plate starting at this parameter. At v_D = 3.2 m/min the melt spreads towards the top plate making the width appear smaller in Fig. 6, though the molten area is increasing as it can be seen in Fig. 5b. To gain information about the homogeneity of the processes, the appearance of short circuits is investigated. Fig. 7 shows the frequency and the standard deviation of the appearance of the short circuits.

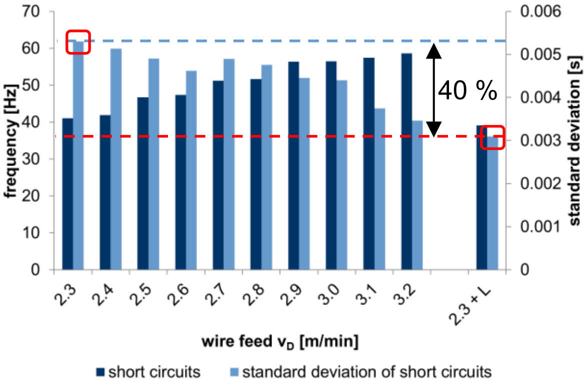

Fig. 7. Frequency of short circuits and standard deviation of their temporal occurrence.

The frequency of their occurrence depends on the amount of wire which is feed into the process. This leads to an increasing short circuit rate along the x-axis of the diagram. For the laser stabilized processes the wire feed is kept at v_D = 2.3 m/min, causing the frequency to stay at around f = 35 Hz. On the contrary, the standard deviation of the occurrence of short circuits shows an interesting behaviour. Regarding the GMAW processes, it tends to decrease when adding wire and thereby energy to the process. However, adding laser radiation to the process the standard deviation drops about 40 % compared with the start parameters of the sole GMAW process. Even when deploying the maximum wire feed tested, the arc process does not reach the same low level. Wire feeds which lead to comparable results in the foregoing investigations in Fig. 4 to 6 ($v_D \approx$ 2.7 – 2.8 m/min) cause standard deviations which are approx. 50 % larger than those obtained with the laser stabilized process. As a final comparison at static weld speed, the visual quality of the weld beads in terms of homogeneity is analysed. In order to obtain comparable values corresponding to bead homogeneity, the normalized discrepancy is introduced. The maximum and minimum widths are measured at defined positions and ranges on the top surface and subtracted to quantify the occurrence of humping. For the purpose of getting comparable data, the values are normalized with respect to the corresponding maximum width, which results in the normalized discrepancy. This method was executed on chosen parameters of the test range and the results are shown in Fig. 8a.

In an overall view the diagram shows the widening of the weld bead with raising energy entry represented by the blue bars. Furthermore the gap between maximum and minimum width is getting smaller, meaning the discrepancy (grey bars) is decreasing with increasing the wire feed. The white mark in the figure indicates a discrepancy of 20 % of the respective maximum weld width (measured on the top surface).

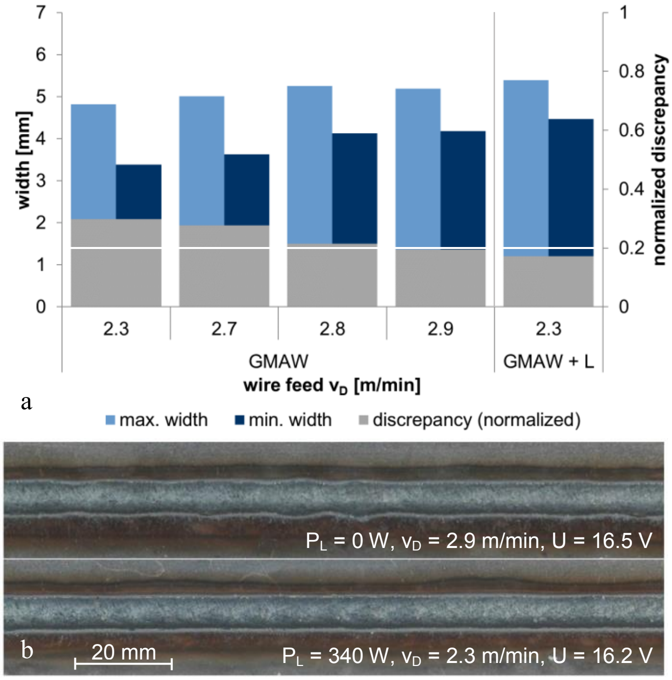

Fig. 8. (a) Maximum and minimum width on the top surface with normalized discrepancy of selected parameters; (b) top of exemplary GMAW and laser stabilized welds.

Comparing the laser stabilized process with the results of the GMAW processes it shows that the laser is affecting the homogeneity but also the width of the visible part on the top of the weld. The latter seems to be caused by an increase of the viscosity by adding heat to the weld zone via laser radiation, while the effect on the homogeneity appears to affect the arc process directly, regarding the dropped standard deviation in Fig. 7.

Even a wire feed of v_D = 2.9 m/min, inducing more energy than necessary to meet the process and weld properties in Fig. 4 to 6 is not able to induce a normalized discrepancy as low as the laser supported process. Fig. 8b shows pictures of the top of exemplaric weld beads at v_D = 2.9 m/min without and v_D = 2.3 m/min with laser stabilization. The higher discrepancy of the bead produced by unstabilized GMAW is depicted by the visible inhomogeneity of the bead shape.

To illustrate the stabilizing effect of the laser radiation on changes in weld speed, tests are carried out while v_s is raised during the weld process from 0.6 to 2 m/min allowing easy qualification of the effect. This test is executed with a GMAW process at the start parameters of v_D = 2.3 m/min, the laser stabilized process and a GMAW process with v_D = 2.9 m/min, which leads to a slightly higher energy input than the laser process as the results in this paper show. The front and back sides of exemplaric samples are depicted in Fig. 9.

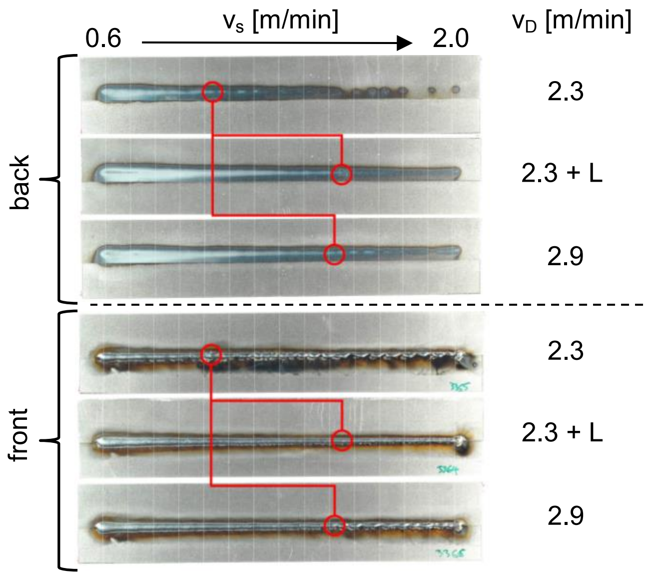

Fig. 9. Ramped weld speed v_s = 0.6 to 2 m/min applied on GMAW with the start parameter v_D = 2.3 m/min, the laser stabilized process and GMAW with raised energy. Red circles mark characteristics on the back sides of the samples and are transferred to the front sides.

Inspecting the back sides of the samples the change of the colour characteristics describe the energy induced into the sample. For better orientation red circles are drawn where the tempered colours change to the darker tone. While there is a difference of about 0.5 m/min in the characteristics of the sample welded with v_D = 0.6 m/min towards the others, the laser stabilized and the higher energy GMAW sample are visually comparable. Transferred to the front sides the GMAW samples show a lack of stability at the marked positions whereas the laser stabilized sample shows a clean weld through the whole process. Even though the energy per unit length will not be sufficient for proper joining of the plates at high weld speeds of 2 m/min, the results shows the increase in stability and robustness gained by the supporting laser radiation.

5. Conclusion and outlook

The presented investigations show a possibility to compare common short arc GMAW with laser stabilized GMAW related to practical use, as it observes the capabilities of both processes for a given task. The different approaches to compare the processes point out process and weld bead properties which are only shifted in energy by the supporting laser radiation. An effect that could also be achieved by adding arc energy and wire feed. This involves the energy input, respectively the power and the characteristics of the weld bead regarding the molten area and the bead geometry.

However, values telling about the homogeneity of the bead and the weld process, show higher consistency by adding laser radiation instead of arc energy. On the one hand there is the considerably lower standard deviation of the occurrence of short circuits and on the other hand the lower normalized discrepancy, indicating the stabilizing effect of the laser radiation on the GMAW process.

As the weld speed for these investigations are chosen quite low, to allow a comparison of stable processes, the stabilizing effect of the laser can also be used to expand the weld speed limits of the common GMAW process, which will be covered in further investigations. Additionally, studies on the abilities of the laser to affect the weld bead in terms of manipulating its position and geometry are already in progress.

Acknowledgements

The investigations have been carried out within the research project IGF 18.748 N within the program for sponsorship by Industrial Joint Research and Development (IGF) of the German Federal Ministry for Economic Affairs and Energy based on an enactment of the German Parliament. The authors would like to express their gratitude therefore.

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

References

[1] W. M. Steen und M. Eboo, „Arc augmented laser welding,“ *Metal Construction,* Nr. 7, p. 332, 1979.

[2] J. Eastman, K. Essenhigh, S. Merriman, I. V. Adamovich und W. R. Lempert, „Guiding of electric discharges by a continuous wave CO laser,“ in *30th Plasmadynamics and Lasers Conference*, Norfolk, 1999.

[3] P. Frost Gorder, „"Cold" Laser Beam Improves Arc Welding, Saves Money,“ The Ohio State University, 04 05 2001. [Online]. Available: https://news.osu.edu/news/2001/05/04/arclaser/. [Zugriff am 24 03 2018].

[4] J. Hermsdorf, *Laserstabilisiertes Metallschutzgasschweissen mittels fasergeführten Festkörperlasern,* Diss., Hannover, 2013.

[5] J. Hermsdorf, F. Otte und R. Kling, „Development of the LGS-GMA welding process,“ in *Proceedings of the Fifth International WLT-Conference on Lasers in Manufacturing 2009*, Munich, 2009.

[6] J. Wendelstorf, I. Decker und H. Wohlfahrt, „Laser-enchanced gas tungsten arc welding (Laser-TIG),“ *Welding in the World,* Bd. 34, pp. 395-396, 1994.

[7] R. Kozakov, B. Emde, A. V. Pipa, M. Huse, D. Uhrlandt, J. Hermsdorf und V. Wesling, „Change of electrical conductivity of Ar welding arc under resonant absorption of laser radiation,“ *J. Phys. D: Appl. Phys.,* pp. 1-11, 2015.

[8] J. Hermsdorf, A. Ostendorf, C. Stahlhut, A. Barroi, F. Otte und R. Kling, „Guidance and stabilisation of electric arc welding using Nd:YAG laser radiation,“ in *Proceedings of the 3rd Pacific International Conference on Application of Lasers and Optics*, 2008.

[9] U. Dilthey, F. Lueder und A. Wieschemann, „Technical and economical advantages by synergies in Laser Arc Hybrid Welding,“ in *Proceedings IIW International Conference "The Human Factor and it's Environment"*, Lisbon, 1999.

[10] B. Hu, *Ph.D. thesis: ND/YAG Laser-assisted arc welding,* Delft, 2002.

[11] M. Schnick, S. Rose, U. Füssel, A. Mahrle, C. Demuth und E. Beyer, „Numerische und experimentelle Untersuchungen zur Wechselwirkung zwischen einem Plasmalichtbogen und einem Laserstrahl geringer Leistung,“ in *DVS-Berichte, Band 258*, 2009, pp. 16-21.

[12] M. Schellhase, Der Schweißlichtbogen - ein technologisches Werkzeug, Berlin: VEW Verlag Technik, 1985.