Available online at www.sciencedirect.com

SciVerse ScienceDirect

Physics Procedia 41 (2013) 249 – 254

Physics Procedia

Lasers in Manufacturing Conference 2013

A novel approach for high deposition rate cladding with minimal dilution with an arc - laser process combination

A. Barroi [a]*, J. Hermsdorf [a], U. Prank [b], S. Kaierle [a]

[a]*Laser Zentrum Hannover e.V., Hollerithalle 8, 30163 Hannover, Germany*
[b]*Merkle Schweissanlagentechnik, Industriestasse 3, 89359 Koetz, Germany*

Abstract

First results of the process development of a novel approach for a high deposition rate cladding process with minimal dilution are presented. The approach will combine the enormous melting potential of an electrical arc that burns between two consumable wire electrodes with the precision of a laser process. Separate test for the plasma melting and for the laser based surface heating have been performed. A steadily burning arc between the electrodes could be established and a deposition rate of 10 kg/h could be achieved. The laser was able to apply the desired heat profile, needed for the combination of the processes. Process problems were analyzed and solutions proposed.

Selection and/or peer-review under responsibility of the German Scientific Laser Society (WLT e.V.)

Keywords: cladding; high-deposition rate; arc; laser; low dilution

1. Introduction and State of the Art

Wear of tools during production is a common problem in industry which results in high costs due to breaks in production for repair or replacement. Hardfacing of tool parts which are subject to intensive wear helps to prolong the lifetime of such tools. Especially when tools are very costly, repair welding is a common technique applied for refurbishing of worn parts. The technology described in this paper aims for hardfacing and repair of big parts. These can be found in the automotive and mining industry. Parts in these industry braches need coating areas which often are bigger than 1 m² and therefore need high deposition rate processes in order to be cost effective.

These kinds of protective coatings are mainly produced by gas-metal-arc (GMA), plasma transferred arc (PTA) or submerged arc welding (SAW). Another emerging process capable of depositing high volumes is laser cladding. This promising technology benefits from latest developments of high power laser sources.

* Corresponding author. Tel.: +49-511-2788-174; *E-mail address:a.barroi@lzh.de*

Selection and/or peer-review under responsibility of the German Scientific Laser Society (WLT e.V.)
doi:10.1016/j.phpro.2013.03.076

The GMA process is a very cost effective process which can be performed manually or automatically. For big areas and best results the process should be automated. The major disadvantages of the process are the high levels of dilution and enormous heat input into the workpiece. In the literature the dilution ranges from 10 – 50 % depending on the used process gas and material. Deposition rates between 0.9 and 5 kg/h are possible (Davis, 1993; Fahrenwaldt & Schuler, 2006; Nouri & Malek, 2007; Shahi & Pandey, 2007). This was raised by a more recent development, the GMA tandem weld-cladding. Here a specialized tandem torch and two welding power sources are used. This technology allows very high deposition rates of up to 20 kg/h and is able to achieve dilutions that are under 3 % if applied at smaller deposition rates. At high deposition rates of 20 kg/h the dilution rises to about 11 % (Cramer, 2001).

PTA weld-cladding is a more advanced technique with a plasma arc that is constricted by the use of surrounding shielding gas which is fed through a special nozzle. The deposition rates of the standard process is up to 7 kg/h with dilutions that range between 5 and 20 %, varying in respect to the used material (Davis, 1993; Deuis, Yellupb, & Subramanian, 1998; Kim, Yoon, & Lee, 2002). Dilutions of less than 1 % are possible with low deposition rate of under 2 kg/h (Lakshminarayanan, Balasubramanian, Varahamoorthy, & Babu, 2008).

The SAW process is a high deposition rate cladding technique, but has the disadvantage of high dilutions. This technique can be applied with different forms of deposition material. If powder is used, deposition rates of up to 9 kg/h can be achieved (Davis, 1993). Similar deposition rate are possible with a single wire as deposition material. Tarng et al. used a Taguchi method to optimize parameters and found an optimum of 12,8 % dilution for this case (Tarng, Juang, & Chang, 2002). A significant raise in deposition rate is possible by using a multi-wire technique. This enables deposition rates of up to 27 kg/h, but also raises the dilution to a value between 15 and 25 % (Davis, 1993).

Laser cladding processes show the best quality for cladding with dilutions between 1-10 % (Davis, 1993). The techniques has been developed that far, that there is no substantial dilution of the coating with the substrate, yet a very strong bond is achieved (Lepski & Brückner, 2009). High power laser cladding is able to deposit up to 9 kg/h. The disadvantage is that 10 kW of comparable expensive laser radiation is needed (Brückner, Nowotny, & Leyens, 2012).

The novel approach described here is a process combination of an arc and a laser process which synergistically utilizes the advantages of each technology. The none-transferred arc is established between two consumable wire electrodes (Fig. 1). Therefore the plasma is used more efficiently for melting the wires whereby more deposition material is provided. Also the heat input into the workpiece is reduced significantly. This heat input from the molten material and the plasma radiation is not uniform, what means that a deeper penetration is expected in the middle of the seam compared to the sides, where no metallurgical bond is expected. To gain a uniform, low penetration metallurgical bond, parameters for the arc process need to be found that reduce the penetration in the middle to nearly zero. A laser scanner system is used to create a tailored temperature profile on the work piece surface. The heat distribution of the temperature profile should compensate the smaller heat on the sides of the seams which the arc based melting process provides.

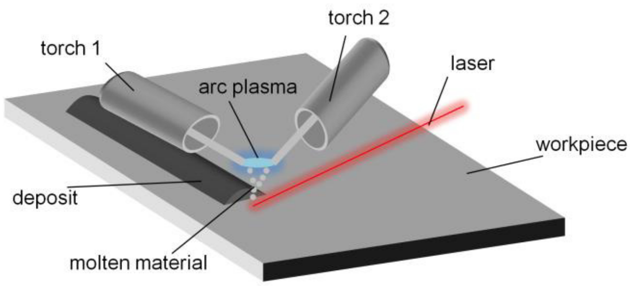

Fig. 1. experimental setup

2. Experimental

To be able to achieve a successful process combination both processes, plasma melting and laser heating, have to be investigated separately. The plasma process needs to melt high amounts of deposition material and place it on the substrate without penetrating it. This alone would lead to a none or only partly welded coating. By using a laser to apply a locally fitted heat distribution on the substrate right in front of the impinging melt, it should be possible to achieve a minimal but sound bond of the coating to the substrate in the entire seam.

2.1. Plasma melting tests

The first step was to learn about the behavior of the plasma arc between the two wire electrodes. For a repeatable process, a steadily burning arc is mandatory and to know about the flow of the melt will help to optimize the process. Also the determination of a proper height of the plasma-melting process above the workpiece is the fundament of further process development steps. Since greater heights mean more time to fall for the melt and further distance to the hot plasma process the presumption is, that greater heights lead to smaller penetrations of the weld bead into the work piece. To verify this, plasma melting tests at different heights have been performed using 1.4430 wires as deposition material and S355 mild steel as substrate. The wires had a diameter of 1.2 mm and substrate material with a thickness of 20 mm. A gas mix of 92% Ar and 8% CO_2 had been used at a flow-rate of 13 l/min per torch through standart nozzles. The welding speed was set to 20 cm/min. Most important parameters for the process are the arc current (222 A) and the voltage (32 V) along with the wire feed rate – 8.6 m/min for the positive and 9.1 m/min for the negative wire.

2.2. Laser induced heat distribution

Initial tests have shown that the welds exhibit penetration maxima in the seams. These come from greater heat-input in these regions. To be able to achieve an even penetration depth a tailored heat distribution is needed. The tailored heat distribution tests have been performed with a 500 W diode laser and a single axis scanner. A velocity perpendicular to the scanner movement, of 20 cm/min has been used to match the speed of the melting tests. The presumption was that the plasma melting tests show a centered penetration maximum. Therefore the scanner mirror was moved sinusoidal. The frequency was chosen to 15 Hz, which is easily achieved by the scanner and should suffice due to the low thermal conduction of steel.

3. Results and Discussion

Fig. 2 shows a picture sequence of the process taken with a high speed camera. From the top there are two wire electrodes coming together at an angle of about 80°. The left electrode (A) is negative and the right electrode (B) is positive charged. The plasma plume between the electrodes is pressed downwards by the shielding gas. Also the direction of the wire leads to a downward direction of the plume. This behavior results in heating of the melt on the work piece surface and should be reduced by an adequate nozzle design which allows smaller shielding gas flow rates.

The experiments prove that it is possible to ignite a steadily burning electrical arc between two consumable electrodes and have the molten material drop on the surface of the substrate (Fig. 2). With a deposition rate of 10 kg/h the process has shown its potential as a high deposition rate cladding technique. As these were the first experiments for this setup, it can be reasonably assumed that the deposition rate can at least be doubled.

Other interesting details can be seen in the picture sequence regarding the melt behavior. The melt stream from the right electrode is very constant. On the left, the melt stream is thinner. Sometimes the stream is not disturbed (D) and sometime it forms droplets (C). Droplet forming is determined by a variety of forces acting on the molten metal such as gravity, effective inertia, surface tension, magnetic force, arc pressure and viscous drag of the shielding gas flow (Haidar, 1998). To oppose these forces a higher viscosity of the meld is desirable. This can be achieved by reducing the temperature of the melt (Echendu & Anusionwu, 2011). By raising the wire-feed of the left electrode without changing the current, the additional material should result in cooling the melt and therefore less droplet formation.

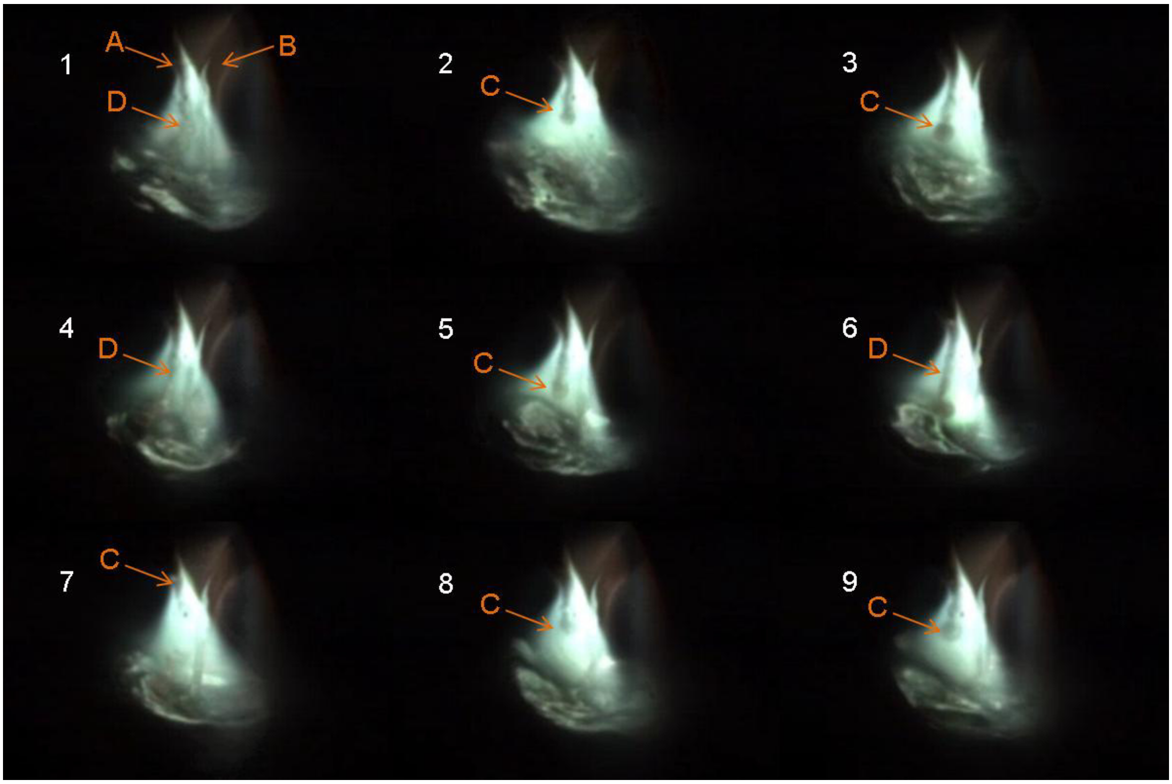

Fig. 2. high speed camera picture sequence of the plasma process at 1000 Hz that shows a steadily arc and droplet forming on the left electrode; A: left electrode(-) B: right electrode(+) C: droplet D: constant melt stream

Experiments with different heights of the process above the work piece have shown an unexpected behavior. The presumption that with increasing heights the penetration depth is lowered could not be validated by the cross-sections shown in Fig. 3. Unexpectedly it was found, that with the increase of the height the penetration into the work piece moves further away from the middle to the side. This is due to the unsymmetrical arc process. The negative electrode on the left is molten more efficiently than the positive one on the right. Also, the standard shielding gas nozzles are disadvantageous, due to the combination of single gas streams in the process region. A combined nozzle, reducing gas turbulence and enable lower shielding gas flow rates, would be beneficial to the process.

If by means of adjusting the wire feed rate to current ratio, constructing a combined nozzle and geometric adaption the unsymmetrical behavior of the process can be compensated, the height test should be redone. In order to achieve the low dilutions aimed for, the penetration, shown in Fig. 3 must be reduced to nearly zero.

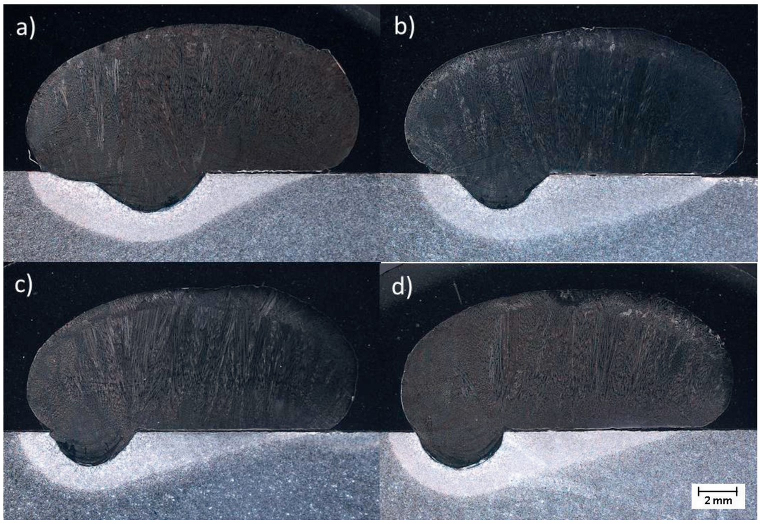

Fig. 3. four cross sections with different arc heights a) 8 mm b) 12 mm c) 14 mm d) 16 mm

First tests regarding the temperature distribution show, that wobbling the laser focus with a sinusoidal signal leads to a bone shaped heat profile in the hottest area which is the red colored region in Fig. 4. Due to the work piece movement a heat trail is established. The heat distribution in the trail is changed due to heat flow. Together with the information from the cross section in Fig. 3 it will be possible to tailor a heat profile and apply it in the right distance to the impinging melt in order to achieve an equalized welded bond.

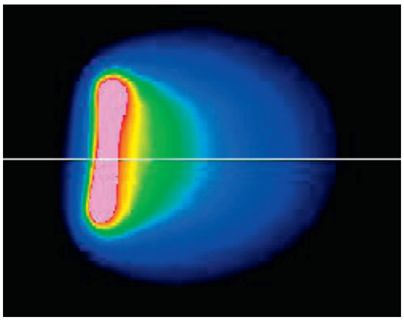

Fig. 4. temperature distribution on work piece

4. Summary and Outlook

The work shows, that it is possible to establish a steadily burning arc between two consumable electrodes and reach a deposition rate of 10 kg/h. A constant melt stream from the positive charged electrode was observed and a thinner, droplets forming melt stream from the negative charged. This behavior is due to overheating of the melt. The tests regarding the heights of the process above the workpiece have shown the unexpected results. A sideward shift of the weld penetration in respect to the heights was noticed.

Regarding the laser heating, a sinusoidal wobbling function was applied to the scanner which deflects the laser beam. This resulted in the desired heat profile with more heat on the sides.

The further steps in the development will be experiments with different torch angles to compensate the sideward drift of the weld penetration. Also the construction of a combined nozzle which will hold the torches and is able to work with a reduced shielding gas flow is planned. After these steps, the height test will be redone, expanding the height range in order to reduce the penetration into the work piece to zero. Furthermore, the deposition rate will be raise to a minimum of 20 kg/h and the melting and the heating process will be combined.

Acknowledgement

This research and development is partly funded by the German Federal Ministry of Education and Research (BMBF) (fund number 02PK2263) and managed by the Project Management Agency Forschungszentrum Karlsruhe, Production and Manufacturing Technologies Division (PTKA-PFT).

References

Brückner, F., Nowotny, S., & Leyens, C. (2012). Innovations in laser cladding and direct metal deposition. *Proceedings of SPIE* (Vol. 8239, pp. 823904–823904–6). doi:10.1117/12.906706

Cramer, H. (2001). Tandemauftragschweißen SLV München MSG Auftragschweißen Cramer.pdf.

Davis, J. R. (1993). Hardfacing, weld cladding, and dissimilar metal joining. *ASM International, ASM Handbook.*, *6*, 789–829.

Deuis, R. L., Yellupb, J. M., & Subramanian, C. (1998). METAL-MATRIX COMPOSITE COATINGS BY PTA SURFACING. *Composites Science an Technology*, *3538*(97), 299–309.

Echendu, O. K., & Anusionwu, B. C. (2011). An Investigation of the Viscosities of Various Groups of Liquid Metals. *The African Review of Physics*, *6*, 35–40.

Fahrenwaldt, H. J., & Schuler, V. (2006). *Praxiswissen Schweißtechnik* (3. ed.). Wiesbaden: Vieweg. doi:10.1007/978-3-8348-9192-1

Haidar, J. (1998). Predictions of metal droplet formation in gas metal arc welding. II. *Journal of Applied Physics*, *84*(Journal of Applied Physics), 3530. doi:10.1063/1.368528

Kim, H., Yoon, B., & Lee, C. (2002). Wear performance of the Fe-based alloy coatings produced by plasma transferred arc weld-surfacing process. *Wear*, *249*, 846–852.

Lakshminarayanan, A. K., Balasubramanian, V., Varahamoorthy, R., & Babu, S. (2008). Predicting the dilution of plasma transferred arc hardfacing of stellite on carbon steel using response surface methodology. *Metals and Materials International*, *14*(6), 779–789. doi:10.3365/met.mat.2008.12.779

Lepski, D., & Brückner, F. (2009). Laser Cladding. In J. Dowden (Ed.), *The Theory of Laser Materials Processing* (Vol. 119, pp. 235–279). Springer Netherlands.

Nouri, M., & Malek, F. (2007). Effect of Welding Parameters on Dilution and Weld Bead Geometry in Cladding, *23*(6), 817–822.

Shahi, A. S., & Pandey, S. (2007). Effect of Auxiliary Preheating of the Filler Wire on Quality of Gas Metal Arc Stainless Steel Claddings. *Journal of Materials Engineering and Performance*, *17*(1), 30–36. doi:10.1007/s11665-007-9132-1

Tarng, Y. S., Juang, S. C., & Chang, C. H. (2002). The use of grey-based Taguchi methods to determine submerged arc welding process parameters in hardfacing. *Journal of Materials Processing Technology*, *128*, 1–6.