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# Laser-plasma-cladding as a hybrid metal deposition-technology applying a SLM-produced copper plasma nozzle

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## Abstract

Laser-Metal-Deposition (LMD) and Plasma-Transferred-Arc (PTA) are well known technologies which can be used for cladding purposes. The prime objective in combining LMD and PTA as a Hybrid Metal Deposition-Technology (HMD) is to achieve high deposition rates at low thermal impact. Possible applications are coatings for wear protection or repair welding for components made of steel. The two energy sources (laser and plasma arc) build a joint process zone and are configured to constitute a stable process at laser powers between 0.4-1 kW (defocused) and plasma currents between 75-200 A. Stainless steel 316L serves as filler material. For this HMD process, a plasma Cu-nozzle is designed and produced by powder bed based Selective Laser Melting. The potential of the HMD technology is investigated and discussed considering existing processes. This paper demonstrates how the interaction of the two energy sources effects the following application-relevant properties: deposition rate, powder efficiency and energy input.

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## 1. Introduction

In a wide variety of industries, modern components are constantly exposed to increasing corrosive, abrasive or thermal stress. These include, for example, the power and gas industry, mining as well as the agricultural sector. As these industries often involve large-area coatings, high deposition rates are required. Furthermore, a low energy input into the component is necessary to reduce distortion and to keep the thermal impairment of the substrate material as small as possible.

Laser metal deposition is a well-known technology for the deposition of wear resistant coatings or for repair applications [1]. Linking the complementary welding processes arc and laser beam in a common process zone to overcome the disadvantages of each individual process, is an idea that dates back to the 1970s. [2, 3] The so-called laser hybrid welding is

nowadays a state-of-the-art process, used, for example, in the shipbuilding industry to join ship panels [4].

In this paper, the described hybrid technology is designed as a metal deposition welding process rather than as joint welding and can therefore be termed Hybrid-Metal-Deposition (HMD) technology. In this context, a Cu-based plasma nozzle is developed and manufactured with additive methods and subsequently tested, to investigate the potential of additive production processes and thereby develop new deposition welding processes.

### 1.1. Laser-Plasma-Cladding as a Hybrid-Metal-Deposition Process

J.Wilden [5,6], Barroi and Hermsdorf [7–10], and also Som [11] have done significant work in using the hybrid approach for cladding purposes or additive manufacturing as a

deposition process. Barroi and Hermsdorf use wire-based gas-metal-arc (GMA) welding and take two different approaches:

The first approach's setup combines a 500 W diode laser at an angle of 90 degrees to the substrate with a GMA torch at 30 and 60 degrees to the laser beam in a pushing position. The two energy sources thereby form a joint process zone. By this approach a penetration depth of 0-0.17 mm and a dilution of around 10 % can be achieved.[7]

In the second approach by Barroi and Hermsdorf [8–10], a non-transferred arc between two consumable wire electrodes (tandem torch) provides already molten deposition material. An oscillating diode laser in front of the smelting line ensures a metallurgical bond between the substrate and the deposition material. By decoupling the deposition material melting process from the actual deposition of the material, dilutions of <5 % at deposition rates of 7.5 kg/h can be achieved.

In the hybrid design by Wilden [5, 6], a plasma torch runs at a distance of 1-2 mm in front of the laser spot and thus allows heating, cleaning and activating the substrate and the powder. The following defocused laser then melts the substrate to ensure a metallurgical bond. The two energy sources are aligned to each other in a V-shaped angle of 10-20°. The deposition material can be supplied as powder, with deposition rates of 1.6 kg/h, or by wire, with deposition rates of 1.38 kg/h.

In 2000, Som [11] presented a coaxial hybrid laser-plasma torch design for surfacing applications. In this torch design, the focused CO<sub>2</sub>-laser beam is coupled with a tubular cathode similar to designs for joining applications [12]. The study shows that the arc voltage decreases under the action of a laser beam. The feasible feed rates are around 0.83 m/min at deposition rates of 2.7 kg/h.

Challenging in all the above studies is, to build a compact processing head that combines the two energy sources in one process zone.

### 1.2. Additive manufactured Cu-based plasma nozzle

To develop a hybrid coating process as described above, it is investigated, how such a hybrid processing head can be manufactured in the most compact design possible. The freedom of design and the possibility of rapid prototyping qualify additive manufacturing as an ideal method for this purpose. In a first step, a plasma nozzle is produced following the additive process chain, to evaluate the possibility of using additive manufactured components in the highly stressed area of arc welding processes. This approach is pursued in the following.

A conventional plasma nozzle is a highly stressed Cu-based wear part that should not only be highly conductive but also withstand temperatures of up to 20000 K in the plasma stream [13]. Due to the high thermal conductivity (401 W/mK at 300 K), ductility and sensitivity to oxidation of pure copper, the additive processing of Cu-based alloys is challenging. High heat dissipation and the low absorption rate of the copper during melting require an adaptation of the standard SLM process. [14]

Popovich [15] present an investigation of SLM-produced Cu-Cr-Zr-Ti alloy specimens. With a laser power of 400 W and a scanning speed of 400 mm/s a density of about 97.9 % can be achieved.

As part of a multi-material analysis, Anstaett [16] processes the CuCr1Zr alloy with the SLM process at a laser power of 400 W, a scanning speed of 600 mm/s and a re-melting strategy. The investigation does not only achieve a relative density of approx. 99 %, it also shows that due to a high thermal conductivity the SLM-typical melting lines do not occur with this alloy and process parameters.

## 2. Experimental

### 2.1. Cu-Plasma Nozzle

The plasma nozzle is produced by using selective laser melting (SLM) on a SLM Solution 250HL machine in argon atmosphere. In order to achieve a good thermal and electrical conductivity of the plasma nozzle a CuCr1Zr-alloy (2.1293) was used as powder. The chemical composition of the applied powder is presented in Table 1, at a particle size distribution from 20 µm to 63 µm. The process parameters applied were developed in another study and can be found in [17]. The identified process parameters allow the production of CuCr1Zr components at a laser power of 350 W with a relative density of  $\rho_{rel} > 99 \%$ .

Table 1. Chemical compositions (in wt %) of the atomized powder

Cu	Cr	Zr
Balance	0.71	0.14

On the one hand, the design of the plasma nozzle takes account of construction rules that are determined by the additive manufacturing process. On the other hand, it takes advantage of the possibility of producing internal cavities.

### 2.2. Hybrid-Metal-Deposition (HMD) Process Design

The SLM-produced plasma nozzle is tested in a process, that combines laser and plasma deposition welding. Through the interaction of these two energy sources, the plasma process is meant to be stabilized at high speeds and the application rates are to be increased, as reported in the literature.

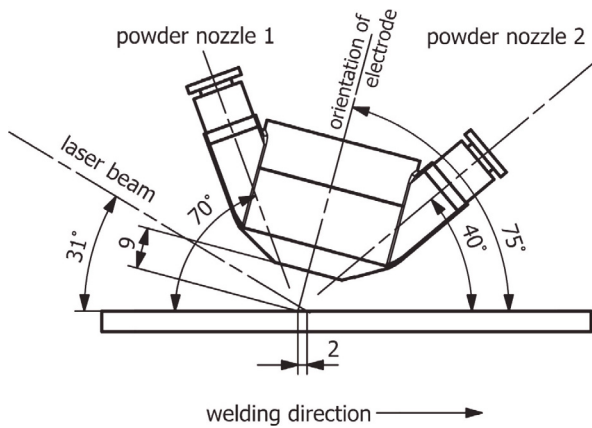


Fig. 1. Setup of the hybrid-process in mm

In order to achieve a joint process zone and good interaction between the two energy sources, the distance between the laser and plasma spot is set to 2 mm. The laser beam also crosses the extended perpendicularity of the electrode, hence it is located ahead in a pushing position, as shown in Fig. 1. A slight defocusing and the applied angle of the laser beam together create an oval laser spot with a width of approx. 4 mm.

The plasma torch is arranged in a dragging position at an angle of 75 degrees, so that the laser beam can reach into the process zone of the plasma arc. As indicated in Fig. 1 the powder flow is orientated at a 40° and 70° angle to the substrate, respectively. Stainless steel 316L was used as substrate material and in form of Metco 41C by Oerlikon as powder material.

For the introduced configuration of energy sources, two parameter sets are presented as examples, Table 2. Besides the energy input, they mainly differ in their choice of powder nozzles, at a constant powder mass flow. In set a) only powder nozzle 2 (Fig. 1) is used, providing powder, flowing in the opposite direction of the laser beam close to the substrate.

Table 2. Process parameter set a) and b)

	Unit	Set a)	Set b)
Laser power	kW	0.4	1.0
Plasma power	kW	5.38	1.66
Velocity	mm/min	1500	1000
Powder mass flow	g/min	52	52
Used powder nozzles	-	2	1 & 2

### 3. Results and Discussion

#### 3.1. Cu-Plasma Nozzle

To ensure efficient cooling of the SLM-produced plasma nozzle, the cooling channels are arranged spirally around the electrode shaft. For demonstration purposes, post-processing is kept as little as possible, leaving most surfaces - including water and powder channels - at a high roughness which is

characteristic of SLM components. Only the flange and the opposite nozzle outlet face were milled off, whereas the threads were cut, Fig. 2.

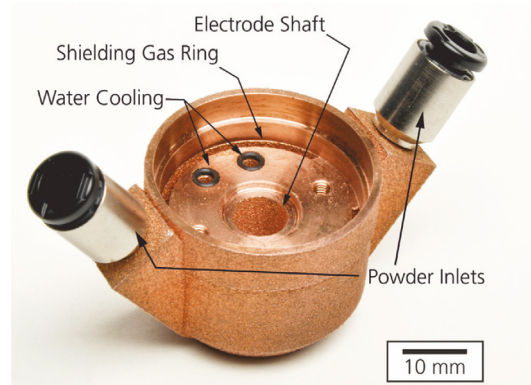


Fig. 2. SLM-produced plasma nozzle

The hardenable alloy is distinguished by its high strength characteristics even at elevated temperatures, its high tempering resistance and a high wear resistance [18]. Small additions of Zr to Cu-Cr alloys form zirconium sulfides, which can suppress embrittlement at intermediate temperatures and improve the material's hot ductility [15].

Unlike conventional plasma nozzles, in which the protective gas supply nozzle and plasma nozzle are two different components, the additive design combines both. This construction results in a coherent component with a shielding gas ring on the outer shell.

Both, pilot- and main arc, can smoothly be ignited by the SLM-produced plasma nozzle. The arc burns cleanly and constantly, no difference is observed compared to a conventionally manufactured nozzle. A possible impact of the increased roughness in the electrode shaft is not visible, cf. Fig. 3 right.

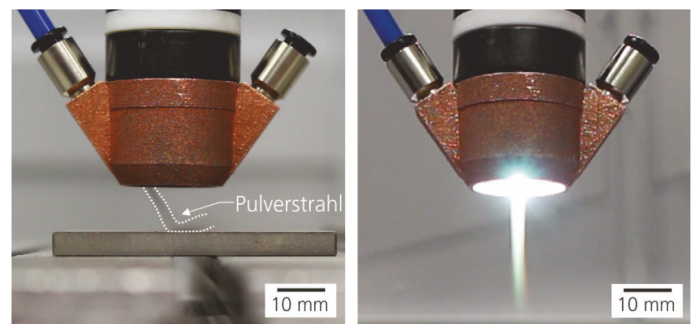


Fig. 3. Left: formation of the powder jet, right: pilot arc of the plasma nozzle at maximum plasma gas rate

The powder jet of the planned powder outlets is diffuse and unfocused, as can be seen in Fig. 3 left. The wide opening angle of the powder jet leads to a big powder spot with a modest powder concentration. A large amount of sprayers and welding beads of residual powder next to the seam are the

result, Fig. 4 right. This in turn results in a low powder efficiency of about 33 %, if only powder nozzle 1 is used.

### 3.2. Hybrid-Metal-Deposition (HMD) Process

The described arrangement simultaneously addresses three objectives: stabilize the plasma arc, preheat, clean and activate the substrate and thirdly hit the powder particles during flight in order to also preheat and activate them. Fig. 4 displays the track geometry generated by the parameters in Table 1.

As expected, the coating-ratio between width and height of the seams is high, due to the large laser and plasma spot. This is also the reason, why the plasma arc determines the shape of the dilution zone, especially at high currents, cf. seam a), Fig. 4 left. In comparison to the hybrid processes described in literature, the key figures of the exemplary parameter sets presented here are of a comparable order of magnitude.

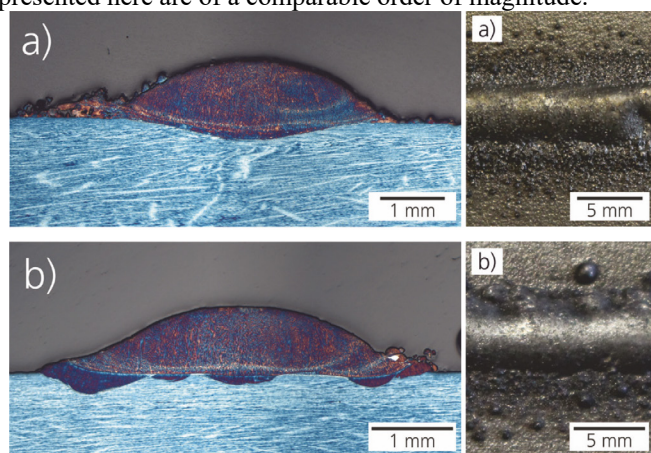


Fig. 4. Left: weld seam cross-section a) and b); right: top view on weld seam a) and b)

The high dilution of about 20% can presumably be further improved by means of an extended parameter study. The key characteristics of the seams are summarized in Table 3. Here too, it is seen that the powder jet must be more focused. The powder efficiency more than doubles when only the powder nozzle 2 is used. It is closer to the process zone where the powder jet is more collimated. An improved powder jet would also allow a higher deposition rate.

Table 3. Weld seam key figures

	Unit	Seam a)	Seam b)
Seam height	mm	0.91	0.82
Seam width	mm	4.58	4.83
Dilution	%	20.97	19.77
Deposition rate	kg/h	2.14	1.03
Powder efficiency	%	68.59	33.01

## 4. Conclusion and Outlook

In this paper, a new SLM-produced Cu plasma nozzle concept was presented by using a laser-plasma process combination for deposition welding, which is currently under development. The presented plasma nozzle operates at very high temperatures and currents. At first glance, the roughness of the nozzle surface does not have a noteworthy influence on the formation of the plasma arc. This significantly reduces any surface finishing post-processing steps that are usually necessary, when applying SLM. However, to achieve a better powder focusing and thereby increase powder efficiency, it is suggested to precisely drill the powder outlets in a post-processing step. The presented HMD process enables a stable cladding process. The parameters illustrated can be further improved e.g. by adjusting and repositioning the powder jet. However, they demonstrate that a configuration of the energy sources in this form is feasible.

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