Technology development for manual laser cladding of high-alloy tool steels with simultaneous inductive preheating for crack prevention

Jonas Kimme
Institute for Machine Tools and Production Processes (IWP)
Chemnitz Univerity of Technology
Chemnitz, Germany
jonas.kimme@mb.tu-chemnitz.de

Josephine Zeisig
Leibniz-IFW Dresden
Institute for Complex Materials
Dresden, Germany
j.zeisig@ifw-dresden.de

Alexander Fröhlich
Institute for Machine Tools and Production Processes (IWP)
Chemnitz Univerity of Technology
Chemnitz, Germany
alexander.froehlich@mb.tu-chemnitz.de

Verena Kräusel
Institute for Machine Tools and Production Processes (IWP)
Chemnitz Univerity of Technology
Chemnitz, Germany
verena.kraeusel@mb.tu-chemnitz.de

***Abstract*—The paper presents the development and successful application of simultaneous inductive preheating during manual laser cladding for repair purposes of weld-critical materials. The design and optimization of a suitable inductor as well as the analysis of the welding process was carried out by means of FE-simulation in order to generate material deposition without imperfections. Based on suitable parameter variation studies, crack and pore-free deposition layers could be produced with the tailor-made process, which shows a high potential for the repair of high-performance tools.**

***Index Terms*—repair welding, laser cladding, tool steels, powder metallurgy, inductive preheating**

I. Introduction

Laser deposition welding occupies a key position in modern toolmaking [1]. The increasing processing of high-strength alloys and composite materials in areas such as the automotive industry or mechanical engineering leads to reduced tool life. In order to extend the service life and develop high-performance tool components, deposition and repair welding represents a cost and resource-saving alternative to the continuous purchase of new tools [2]. The process of repair welding is performed by first removing the damaged or worn material by grinding and then polishing the part to obtain a bright and clean surface. Afterwards, an operator uses a welding process to manually apply additional material in form of a filler wire. Fig. 1b shows the principle of laser cladding. Finally, the original shape of the tool is restored by cutting processing or spark erosion. By using a suitable welding process and a suitable filler material, hard and wear-resistant edge layers with sufficient toughness can be produced so that both worn areas and chipped edges can be rebuilt. However, the repair of tools made of selected special tool steels poses a great challenge, as these are considered to have limited weldability.

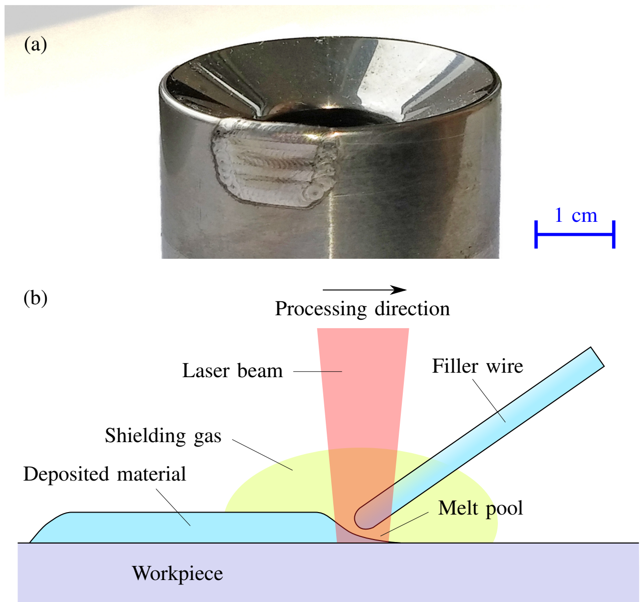

Fig. 1. Laser repaired tool before machining (a) and principle of manual laser deposition welding (b).

II. Technical Background

During the welding process of high-alloy tool steels e.g. produced by powder metallurgy, there is a high susceptibility to cracking due to the special alloy compositions. High residual stresses result from the high temperature gradients during cooling or from phase transformations, which can ultimately lead to failure of the weld seam and to tearing out all of the applied material.

One way to counteract this behaviour of the material is to preheat the substrate to temperatures above 200 °C [3], [4]. This measure extends the cooling time of both the weld metal as well as the heat-affected zone (HAZ) and reduces the risk of cold cracks. The aim of the presented work is to achieve this by means of a suitable simultaneous inductive preheating of the base material.

III. Preparation and Experiments

In the first step, a suitable inductor geometry was determined using the FEA software COMSOL Multiphysics 5.4. For one thing, the inductor must preheat respectively postheat the area of the weld seam. Furthermore, the inductor must not hamper the operator in his work, so that good accessibility to the welding point is guaranteed during the process. The developed C-shaped inductor that was used is shown in Fig. 2a.

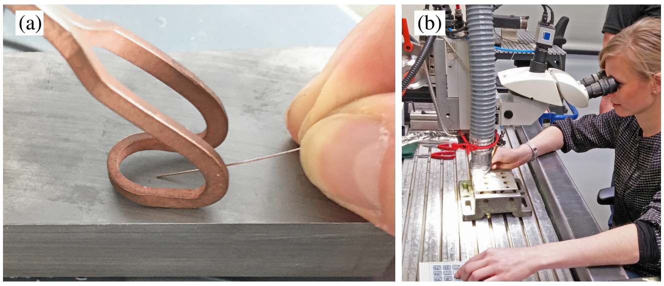

Fig. 2. Inductor for preheating (a) and experimental setup for manual laser cladding (b).

The welding tests were carried out on an experimental setup for manual laser cladding (Fig. 2b). This includes a Nd:YAG laser, which was operated in pulse mode (rectangular) with a power of 2800 W, a pulse frequency of 8.9 Hz and a pulse duration of 8 ms. That equals a pulse energy of 22.4 J and an average power of about 200 W. The welding speed was 340 mm/min. For preheating an induction generator MFG 10 from EMAG Eldec with an output of 10 kW was chosen. A conventional high-performance wire QuFe60 (1.3348, quada V+F) with a diameter of 0.4 mm was used as filler material. The high chrome tool steel Elmax (Uddeholm) hardened to 62 HRC served as the base material. The shielding gas was argon.

By means of preheating tests without laser welding, a Micro-Epsilon thermoMETER CTLaser pyrometer was used to determine the maximum preheating temperature that can be achieved when moving at welding speed at the focal point of the laser on the substrate surface. These tests showed that a stable preheating temperature of 210 °C was reached about 6 s after switching on the induction generator.

IV. Results

During the welding tests without preheating, the applied material tore out of the substrate already after the first layer (Fig. 3a). As a result, multilayer cladding welds were not possible. With the addition of the inductor, the material had significantly better weldability. By means of preheating, cladding welds with ten layers exhibiting no cracks could be achieved (Fig. 3b), which is already sufficient for common repair welds. In addition, larger areas could be welded without failure compared to no preheating (see Fig. 3a and b). In the comparison regarding the achieved hardness of the layers no considerable deviations could be detected. This means that consistently high hardnesses can be achieved despite preheating. Microsections show cladded layers without cracks or pores and a good bond to the base material (Fig. 3c).

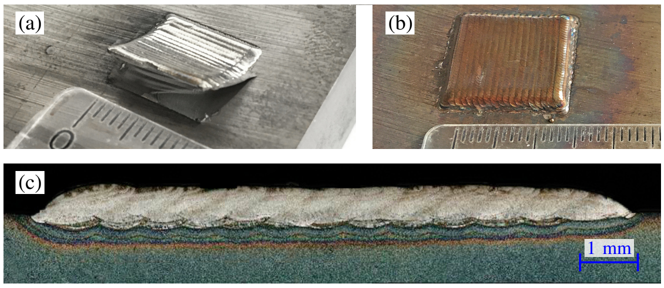

Fig. 3. Torn out single-layer cladding without preheating (a), preheated ten-layer cladding without cracks (b) and microsection of a three-layer cladding.

This behaviour is due to the significantly reduced cooling rates of the weld metal and the HAZ. The findings generated from the tests validate the results of a simulation model created with the FEA software simufact.welding 8.0. A weld bead consisting of 26 single spots was analyzed once without and once with the preheating used in the tests showing a strongly reduced cooling rate when preheating (Fig. 4).

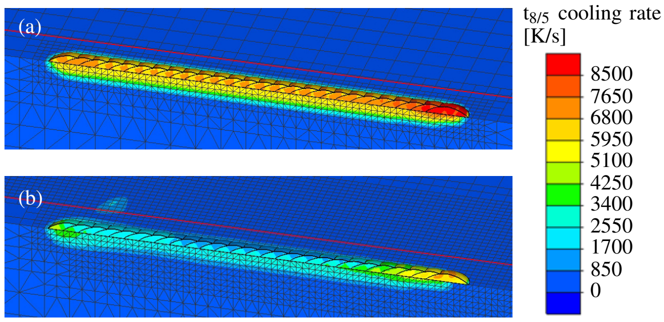

Fig. 4. Sectional view of the weld seam and FE calculated $t_{8/5}$ cooling rate without (a) and with preheating (b).

V. Conclusion

The results of the investigations show that by means of inductive preheating crack-free cladding of high-alloy tool steels, which tend to crack strongly during welding, is possible. As a result, tools repaired by the used prcedure can be expected to have a longer service life before they fail again. Simultaneous heating with the developed C-shaped inductor eliminates the need for upstream complete heating of large workpieces, reduces the process time and energy consumption.

References

[1] Jhavar, S., Paul, C. P., Jain, N. K. (2013). “Causes of failure and repairing options for dies and molds: A review,“ Engineering Failure Analysis, 34, 519–535, September 2013.

[2] Toyserkani, E., Khajepour, A., Corbin S. (2004). “Laser Cladding,“ CRC Press, July 2004.

[3] Šturm, R., Štefanikova, M., Steiner Petrovič, D. (2015). “Influence of pre-heating on the surface modification of powder-metallurgy processed cold-work tool steel during laser surface melting,“ Applied Surface Science, Volume 325, 203–210, January 2015.

[4] W. T. Preciado, C. E. N. Bohorquez (2006). “Repair welding of polymer injection molds manufactured in AISI P20 and VP50IM steels,“ Journal of Materials Processing Technology, 179, 244–250, October 2006.