New Innovations in Diode Laser Cladding

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Abstract

The Fraunhofer Center for Surface and Laser Processing developed a new cladding process, utilizing a 3 kW direct diode laser and a coaxial powder-feeding nozzle. Porosity free and near crack free nickel based coatings with a high content of globular tungsten carbide (WC) are applied to metal surfaces. The process reduces the operational cost of conventional CO_2-systems by at least a factor of three and lowers investment costs by utilizing smaller laser systems. The process found its first application in the oil industry where it is applied to down-hole drilling equipment. In collaboration with a partner, new superior wear protective hard coatings were developed, tested and applied to a number of oilfield tools.

In future developments the Center for Surface and Laser Processing will apply the technology for the repair of tools and dies and increase cladding efficiency further by using special plasma and induction based hybrid technologies.

Introduction

For the current laser cladding applications in the field of surface protection, remanufacturing and rapid prototyping CO_2 and Nd:YAG lasers are typically used. So far direct diode lasers are not very common for these types of applications, since they are comparably new, have a lower beam quality and usually a rectangular or line shaped spot with a short working distance. However, their extreme compact size, ease to operate, high wall plug efficiency and lower investment and running costs makes them very interesting for laser cladding, especially in an industrial environment.

The Fraunhofer Center for Surface and Laser Processing has overcome the limitations and developed a new cladding process, utilizing a 3 kW Rofin-Sinar direct diode laser and a coaxial powder-feeding nozzle. The goal was, to apply wear and corrosion resistant layers with a high content on Tungsten-Carbide (WC) on metal surfaces. These layers have the same quality as if applied with CO_2-systems but at lower investment and operational costs.

Process development diode laser cladding

Laser cladding is a technology, were metallic or ceramic layers are welded to a surface utilizing a laser beam as the heat source. Figure 1 shows the cladding principle and Figure 2 a process picture of diode laser cladding.

For the described application and process development the following equipment has been used:

- Rofin DL 030 S direct diode laser
- Fraunhofer IWS coaxial cladding nozzle
- GTV powder feeder
- 4-axis motion system

The powder materials for the layers are globular tungsten carbide (WC) and a Ni-based alloy as the matrix. Substrates are Inconell alloys and austenitic stainless steels.

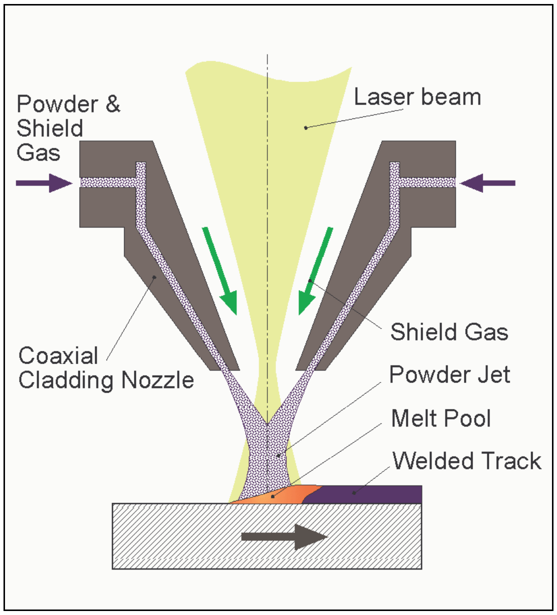

Figure 1a: Principle of laser cladding with coaxial powder delivery.

Diode Laser modifications

Typical non-fiber coupled high power diode lasers have a rectangular spot and a lower beam quality than CO_2 or Nd:YAG lasers. Furthermore the standard laser focus of the used Rofin DL 030 S was too small for the targeted application, where larger surfaces are coated. To ensure a good and economical material deposit, bead widths of approximately 6 mm (0.235 inch) are necessary. The used laser had a standard minimal focus size of 0.8 x 1.3 mm^2 (0.030 x 0.050 $inch^2$) at a working distance of 42 mm (1.654 inch).

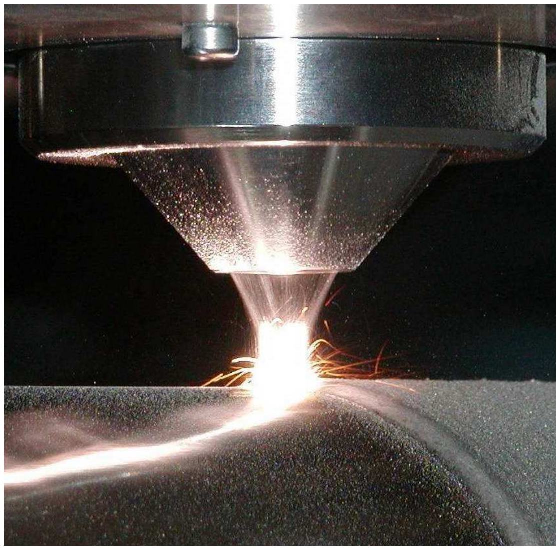

Figure 2: Diode laser cladding

One option to solve the problem described above is the utilization of a fiber coupled diode laser system. Its circular, top hat beam profile makes it ideal for laser cladding. The laser beam can be defocused the to the needed spot size. However, through losses at the fiber in- and out-coupling up to 20% less power is available on the surface of the work piece. Furthermore the investment costs are noticeably higher than for a direct diode laser system.

In order to develop a simple and cost efficient system for laser cladding, a direct diode laser was modified to match the required beam profile.

First attempt to increase the working distance and to scale the focus size was to remove one lens of the focusing optics. To further increase the spot size, the laser beam was defocused below its focal plane. Due to the nature of diode lasers an undefined spot geometry with a random intensity distribution and hot spots was the result. Even though laser cladding does not require a high beam quality, it makes the process very instable and sensitive to environmental influences. The hot spots reduced the parameter window for high quality claddings significantly. For example already slightly higher substrate temperatures caused local overheating of the melt pool and thereby porosity and increased dilution. In addition the still short working distance of about 100 mm (4 inch) resulted an increased contaminations on the laser optics.

In a second step the laser spot was made square in the focal plane by readjusting the diode stacks inside the laser head. Thereby it was also possible to achieve a relatively smooth intensity distribution. To obtain the needed spot size of approximately 6 x 6 mm^2 (0.235 x 0.235 inch^2), a lens with 300 mm focal length was used. Thus the process could be run in the focal plane of the laser, which has a determined spot geometry. The result is an increased stability of the cladding process with a large parameter window. Figure 3 shows the setup.

Figure 3: Diode laser cladding

Powder feed rates of up to 50 g/min (0.11 lb/min) or cladding rates of approximately 5 cm^3/min (0.3 cui/min) are possible at 2.5 - 3 kW on preheated parts. Figure 4 shows the cross sections of two sample claddings. Abrasion tests proved, that the diode laser claddings had the same wear resistance as the competing CO_2 claddings.

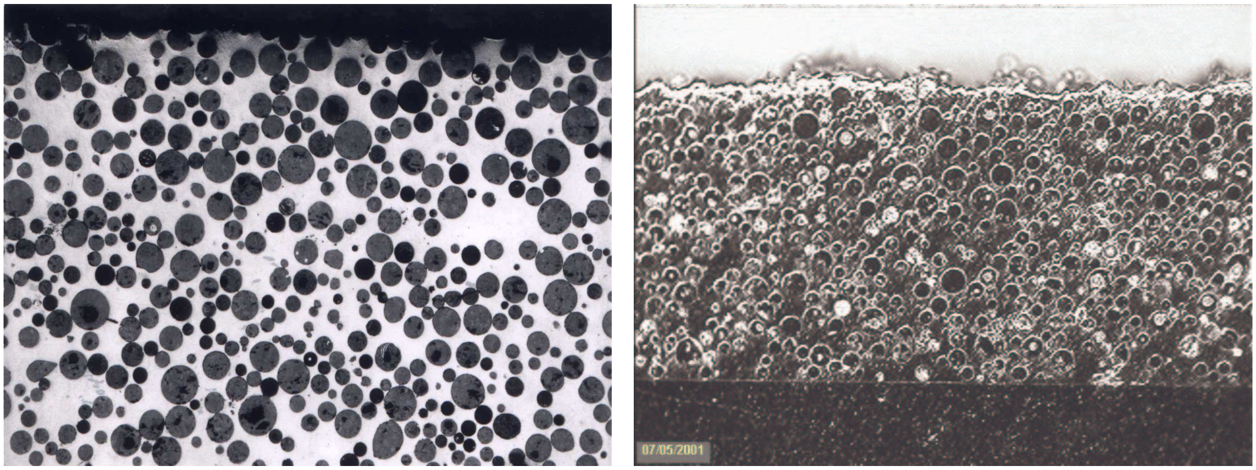

Figure 4: Cross section of two sample layers, made by diode laser cladding (65 mass-% tungsten carbide in a Ni-base matrix).

Economical aspects

In Table 1 an approximate comparison of the electrical energy costs can be seen. The used laser powers are needed to run the described application. CO_2 lasers require higher power for the same cladding application due to their lower absorption on metal surfaces. As it can be seen, the laser power costs for a diode laser are noticeable lower than for CO_2 or Nd:YAG laser. In addition to the electrical power there are costs for preventive maintenance, cooling and consumables like laser-gases for the CO_2 or water filters and cover slides for the diode and YAG.

Table 1: Comparison electrical energy costs (cooling not included)

Approximate Running costs	CO_2	Nd:YAG (diode pumped)	Diode
Required laser power	5 kW	3 kW	3 kW
Average wall-plug efficiency	10 %	10 %	30 %
Approximate electrical power consumption of the lasers	50 kW	30 kW	10 kW
Electrical power cost per hour @ 0.09 $ / kWhr	4.50 $/hr	2.70 $/hr	0.90 $/hr

Conclusions and outlook

Porosity free and near crack free nickel based coatings with a high content of globular tungsten carbide are deposited onto metal surfaces with a diode laser. The process reduces the operational cost of conventional CO_2 or Nd:YAG laser systems by at least a factor of three and lowers investment costs by utilizing smaller laser systems. The process found its first application in the oil industry where it is applied to down-hole drilling equipment. This industrial application runs in production since October 2001.

Currently the Fraunhofer CSLP in Plymouth, Michigan and the Fraunhofer IWS in Dresden, Germany is developing hybrid technologies, were laser cladding is combined with induction preheating or plasma welding technologies to increase the process speed and quality.

With the combination of laser cladding and induction preheating up to 8 times higher cladding speeds have already been achieved with CO_2 lasers. It furthermore reduces auxiliary time by eliminating the preheating with a torch and it provides better process stability especially on large parts, which cool down locally after long process times. The combination of plasma welding and laser cladding is used were large surfaces need to be coated but precise deposition is required in some functional areas. This guaranties high process efficiency without sacrificing quality.

These cladding technologies can be used to effectively apply wear and corrosion resistant layers on surfaces, remanufacture tools and dies and for rapid prototyping.

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Meet the Authors

Alexander Groth graduated in November 2000 with a degree in Manufacturing and Engineering at the University of Applied Sciences in Dresden, Germany. In March 2000, he joined the Fraunhofer Institute for Material and Beam Technology (IWS) in Dresden, Germany with a work focus on laser rapid prototyping. Since May 2001, Alexander works for the Fraunhofer Center for Surface and Laser Processing (CSLP) in Plymouth, Michigan as a Project Manager, specialized in the development of new cladding technologies with high power diode lasers.