LANE 2010

Laser reconditioning of crankshafts: From lab to application

Koehler, H.[a]*, Partes, K.[a], Seefeld, T.[a], Vollertsen, F.[a]

aBIAS – Bremer Institut für angewandte Strahltechnik, Klagenfurter Str. 2, D-28359 Bremen

Abstract

In marine diesel engines, damaged crankshafts are common and expensive defects. Worn surfaces of main bearings and crankpin journals often require a complete replacement of these components. This paper presents the development of a repair procedure on its way to application. As an alternative to the method of grinding the accordant surfaces and using matched bearing shells, a rebuild to the original diameter is the goal of this investigation.

This paper describes the development of a controlled diode laser cladding process in the lab and the characterization of flat specimens particularly by metallographic analysis and hardness testing.

In preparation of the industrial application, previously ground crankpin journals of crankshafts could successfully be cladded with identical parameters as found on flat specimens in the lab. The claddings show a high quality in terms of connection to the base material and dilution. In hardness tests steep gradients from heat affected zone to unaffected base material could be measured. ⓒ 2010 Published by Elsevier B.V. Open access under CC BY-NC-ND license.

Keywords: process sensing and controlling, surface treatment, laser cladding, robotics, high power diode lasers, marine diesel engines, crankshaft

1. Introduction

The reconditioning of worn crankshaft main bearings and crankpin journals of ship diesel engines is commonly realized by mechanically grinding to a reduced diameter. This procedure has some drawbacks. According to elastostatics as described in [1], the bending stiffness of a cylindrical geometry which is pivot-mounted on two edges has a proportional dependence on the diameter d by d^4. It follows that decreasing a crankshaft's diameter causes a strongly decreasing stiffness. Another drawback is that tailored bearing shells with matched diameters need to be produced which is a costly procedure.

A much more convenient approach to repair worn bearing journals is to apply a method which builds up the original contour. Laser cladding is a suitable process that has been qualified for many other applications where a local heat input and low distortion is demanded [2, 3]. Moreover, the process has advanced to state of the art in surface treatment technologies during the past decade [4, 5]. Especially high power diode lasers have proved for this process [6, 7]. The achievable coating qualities are well suited for bearing journal surfaces. Required mechanical properties like hardness and friction behavior can be adjusted and improved in comparison to the original material

---

* Corresponding author. Tel.: +49-421218-5090; fax: +49-421218-5095.
E-mail address: koehler@bias.de.

by choosing tailored materials.

In the following the development of a laser cladding process in preparation for the industrial application of crankshaft reconditioning is described. In a first development step the cladding system was assembled in the lab in order to qualify the process and the machinery on flat specimens. Secondly, the setup was transferred to a production site where complete crankshafts could be handled. After the process was again applied on flat specimens, the laser cladding of round specimens and finally of crankpin journals of crankshaft segments was investigated.

In marine engineering it is essential to prove the mechanical properties of machine components after applying new processes. Approvals can solely be accomplished by the classification societies. Therefore the presented research steps were performed in close consultation with the German Lloyd.

2. Experiments

2.1 Materials and Geometries

A very common material for forged crankshafts of marine medium-speed diesel engines is 42CrMo4 [8]. This material was chosen as base material for the investigations. Flat specimens which were cut out of a complete crankshaft as well as crankshaft segments were prepared for processing. Figure 1 shows both geometries. On specimens which were to be cladded the grey marked regions were mechanically removed. The radii of the flat specimen with R = 60 mm were machined subsequently to the cladding process. Another type of specimen was cylindrical ship building steel with a diameter of 80 mm. Typical widths of the crankpin journals were about 80 mm. The groove to be cladded was 50 mm in width. The depth from top edge of the crank web to journal surface in bottom dead center position was about 200 mm.
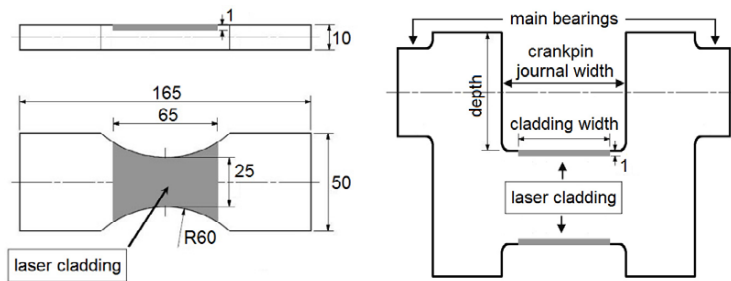

Fig. 1. Top and side view on flat specimen (left) and cross-sectional view on crankshaft segment (right)

To rebuild the original contour the Co-based alloy Deloro Stellite 21 was selected as it has a high temperature strength and toughness, a good resistance to cavitation corrosion and mechanical wear [9, 10]. Furthermore it is very well processable in powder form due to its spherical grain shape and diameter. Stellite 21 has shown to be highly compatible to steels as could be shown for example in [11].

2.2 Setup

A Rofin-Sinar DL 035Q high power diode laser with a maximum output power of 3.5 kW at a wavelength of 808 and 940 nm has been selected as heat source. These wavelengths show a higher absorption in steel than other solid state lasers [12]. A laser beam shaping with a focal length of 300 mm was selected. The laser beam had a slightly deflected part as can be seen in the beam profile in figure 2.
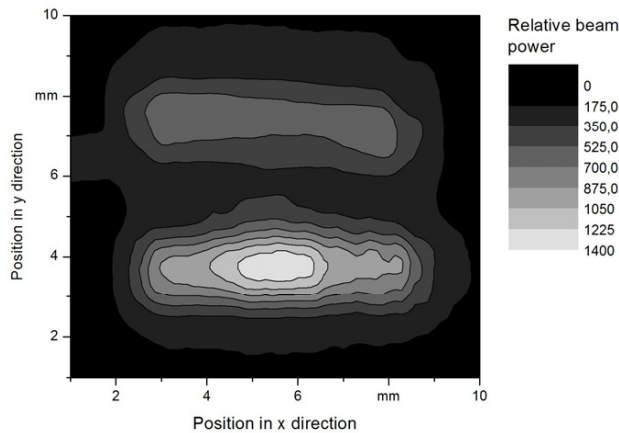
Fig. 2. Beam profile of applied high power diode laser in focal position, focused by an optic with f = 300 mm

The laser cladding process was controlled by a fast control loop which measured the temperature and the melt pool size by a camera-chip with adequate IR-filtering. To keep a desired melt pool size the laser output power was adjusted accordingly to the actual size. Different systems which work on this principle have been developed [13, 14]. In these investigations a commercially available camera-based control-system which was developed at the IWS-Dresden was utilized.

The applied laser had very compact dimensions so that it could be mounted directly on a CNC-based machine or a robot. The radiation is directly coupled into the process zone. The process development in the research lab had to meet the boundary conditions given by the crankshaft geometries. Due to the restrictions in width and depth of the process zone the powder material was injected by an off-axis powder nozzle. The nozzle and the process control camera were directly attached to the laser housing. An additional positioning laser was attached to the cladding system to enable an accurate adjustment. The flat specimens were clamped to a water cooled steel block.

For cladding the crankshaft segments the cladding system was attached to a robot. To process crankpin journal surfaces the main shaft axis was fixed to a rotational axis on one side and on the other side was supported by a stand. A constant feed velocity and orientation of the cladding head towards the crankpin journal was obtained by a coordinated movement of shaft and robot. In the area of the centered oil bore the process was not turned off and had to be ground to a manufacturer-specified geometry. Figure 3 shows the cladding head attached to the robot manipulation system.
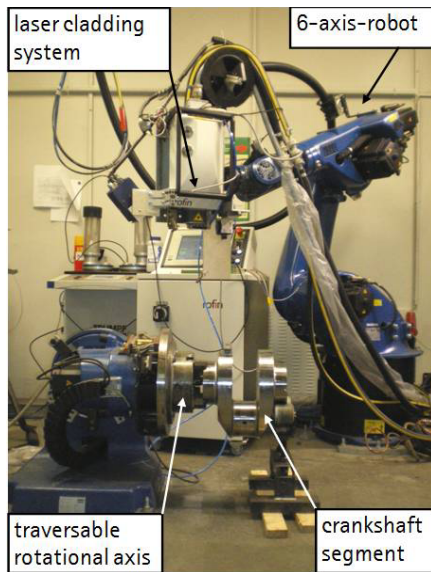
Fig. 3. Laser cladding head attached to robot manipulation system, parameters of cladding process

Parameter investigations under variation of the following parameters were executed:
- melt pool size
- set temperature
- track offset
- feed velocity
- distance workpiece to camera
- angle between workpiece and camera
- distance workpiece to powder nozzle
- angle between workpiece and powder nozzle
- distance edge of optics to workpiece
- flow rate powder feed gas
- powder feed rate
- flow rate shielding gas

Firstly single tracks were cladded overlappingly on flat specimens to fill up the previously machined grooves. In order to clad the complete area the starting and end points were taught offside the specimens' surfaces. Hence the laser cladding process started before pointing onto the specimen's starting edge and stopped behind it. Secondly the cladding of round specimens with resulting process parameters was tested. After a sufficient clad quality could be ensured by metallographic investigations crankpin journals were processed.

2.3 Analysis

The quality of cladded flat and round specimen was investigated by inspection of metallographic cross-sections by optical microscopy. Hardness measurements were carried out with a Vickers Hardness tester LECO MHT series 210.

3. Results

3.1. Flat specimen

The aimed clad height of at least 1 mm could be achieved as can be seen in figure 4. A height difference of 0.2 mm remained between cladding and surrounding specimen surface after grinding. The lower clad height around the edges could be neglected as these were machined afterwards for getting the test shape. The single tracks can be identified very clearly. The first track's starting point was at the top left edge. All tracks were cladded into the same direction. The last track was made on the very right so that the last heated area on the specimen was on the lower right.
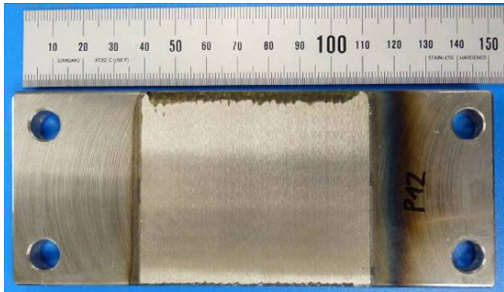

Fig. 4. Grooved and subsequently laser cladded flat specimen after flat grinding (top: mm-scale ruler)

The process worked very stable when the positioning between powder nozzle, laser beam spot and workpiece was within a narrow window. Table 1 shows the resulting set of parameters which could be found during the investigations.

Table 1. Resulting process parameters for controlled laser cladding of flat specimen

Process parameter	Value
melt pool size (relative units)	3500
set temperature	1450°C
track width	5 mm
track offset	2.5 mm
feed velocity	0.6 m/min
distance workpiece to camera	430 mm
angle between workpiece and camera	48°
distance workpiece to powder nozzle	6.5 mm
angle between workpiece and powder nozzle	52°
distance edge of optics to workpiece	278 mm
flow rate powder feed gas (Ar)	8 l/min
powder feed rate (Stellite 21)	19.8 g/min
flow rate shielding gas (Ar)	17.5 l/min

The process data recording of a single track is shown on the left in figure 5. It shows that the starting point at 1 s and the end point at 6.5 s offside the specimen lead to a strongly increasing power compared to the rest of the track.

The melt pool size was very stable at 3500 relative units. The absolute melt pool size can be approximated by the beam area determined by weld penetration tests. The size was about 6x6 mm². Along the track the power to reach the desired melt pool size decreased slightly.

On the right side the temperature distribution is shown. The set temperature is 1450°C and it is colored in white. The upper part of the picture points into the feed direction. The lower part is dominated by the injected powder stream which cools this area down to about 1250°C.
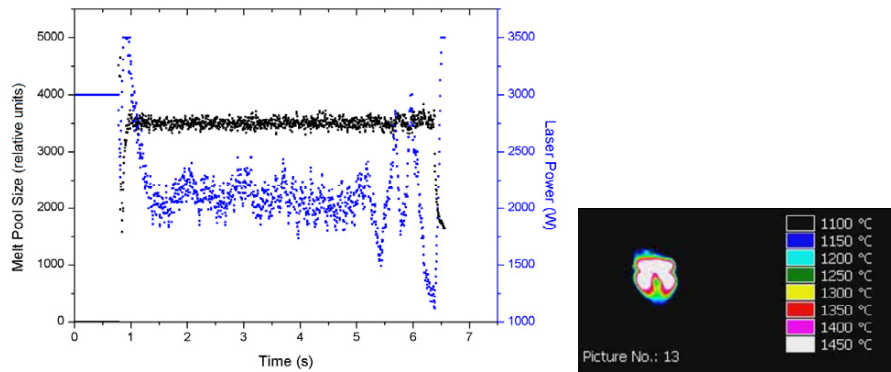

Fig. 5. Process data recording of single track welding on flat specimen with constant melt pool area and varying laser power (left) and resulting characteristic temperature distribution (right)

Metallographic investigations on the left in figure 6 showed a very good connection between cladding and base material. Furthermore only a small amount of dilution could be realized. The distinction between heat affected zone (HAZ) and unaffected base material could clearly be identified by the etched cross-section. The Vickers hardness test showed that there is a drop from about 500 HV0.1 to 300 HV0.1 in the transition of HAZ to unaffected base material.
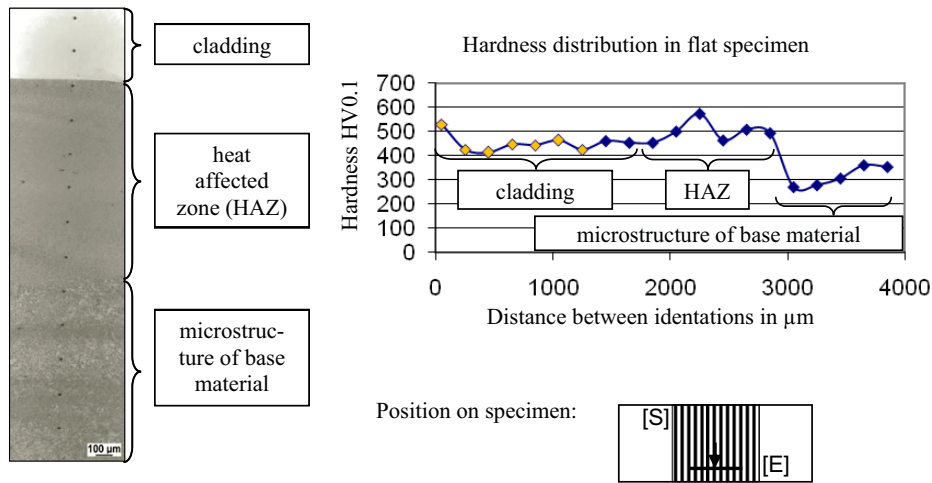
Fig. 6. Microstructure (left), hardness-distribution (top, yellow: hardness indentations which are not shown in left cross section) and position of both in cladded flat specimen (bottom, S: starting point, E: end point)

To prove the hardness distribution in the transition of HAZ and unaffected base material a matrix of indentations was measured. The measurements were made centered on the specimen. Figure 7 shows the indentations on the left side and the resulting distribution on the right side. It can be seen that the hardness in the HAZ is around 430 HV0.1 and has certain areas where it increases to 580 HV0.1. In single points values above 760 HV0.1 can be measured. The unaffected base material shows a fluctuation in hardness from about 250 to 370 HV0.1.
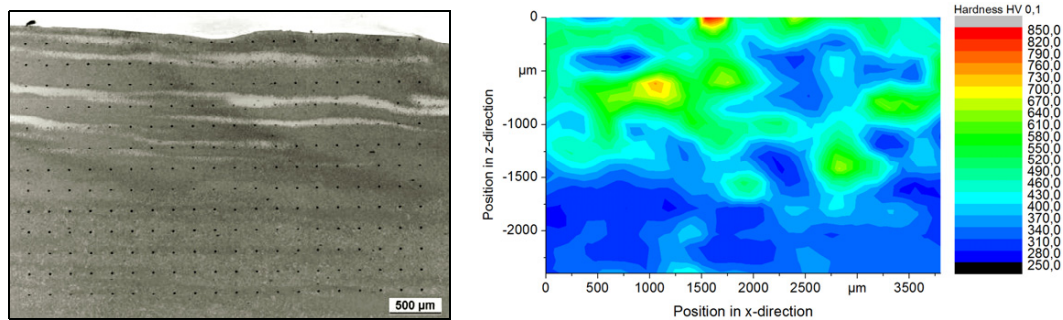

Fig. 7. Hardness distribution in HAZ and unaffected base material (left) and according cross-section (right)

3.2. Round specimen

To adjust and test the production-lab setup a round specimen was cladded. During the first revolution the laser power to reach the desired relative melt pool size of 3500 was controlled to the maximum available power of 3.5 kW as it can be seen in figure 8. After the first revolution at about 35 s the deviation of the melt pool size decreased and the laser power dropped to around 2 kW. The specimen was not clamped in center position as can be seen from

the periodic power curve. Despite of this, the melt pool size and the cladding quality remained homogenously. The characteristic power level and temperature distribution could be achieved analogously to the flat specimen.
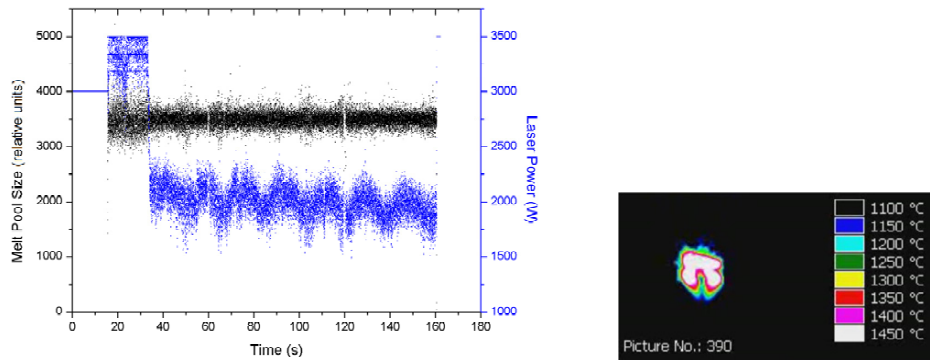

Fig. 8. Process data recording of constant melt pool area and varying laser power (left) and characteristic temperature distribution (right) on round specimen

The resulting clad quality is shown in figure 9. The connection between base material and coating is very good. The appearance of the cladding on the round specimen was identical to that of the flat ones processed in the research-lab. Furthermore an identical clad height could be maintained.
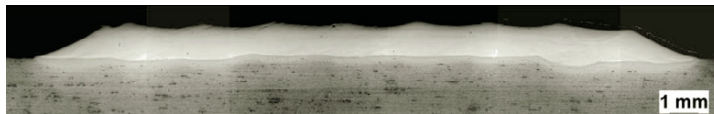

Fig. 9. Cross-section of laser cladded round specimen, base material: shipbuilding steel, coating: Stellite 21

3.3. Crankshaft

After the process could successfully be recommissioned on round specimens the system was prepared for cladding crankpin journals. The cladding process on a crankpin journal is shown in figure 10.

Similarly to the characteristic on the round specimen the power during the first revolution was controlled to the maximum of 3.5 kW as can be seen in figure 11. After the first revolution a mean power level of about 2.75 kW can be observed. The power for the same melt pool size had to be controlled 750 W higher than on flat and round specimens. Contrary to the heat accumulation effect on smaller geometries this could not be observed on complete crankshafts neither on segments. The resulting temperature distribution is identical to the ones observed on flat and round specimens.
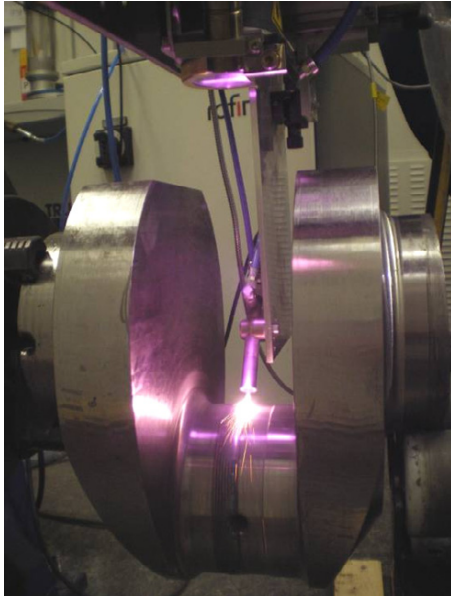
Fig. 10. Laser cladding of a crankshaft segment

Again periodic deviations from the mean power level can be observed. This can basically be traced back to three effects. Firstly the centered bore which can be seen in figure 10 and 12 was processed without turning off the process. Secondly the coordinated movement of robot and rotational axis was based on previously taught points. If these differ slightly the ideal orientation of the process was not maintained and the melt pool size reacts sensitively. In consequence the laser power had to be increased to remain a constant melt pool size. A third influence was misalignment in clamping, as it could be observed on round specimens.
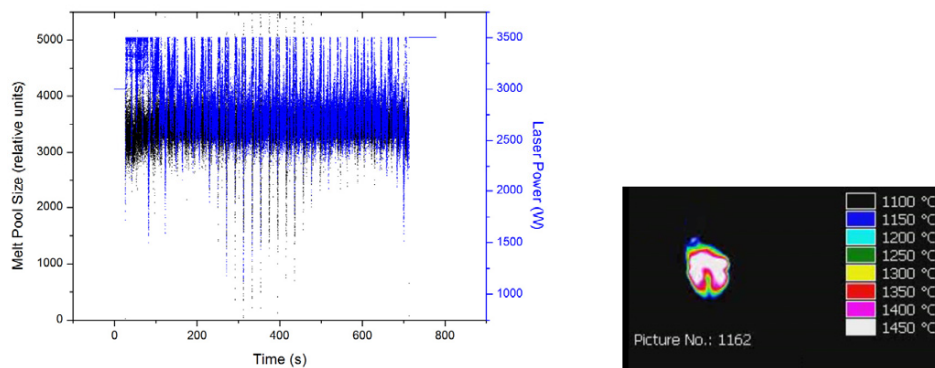

Fig. 11. Process data recording of constant melt pool area and varying laser power (left) and temperature distribution (right) of crankpin journal

Fig. 12 shows a cladded crankpin journal from two perspectives. The width of the cladding was about 50 mm. The left picture shows that the oil bore is not closed by the cladding. On the right the cladded surface of the lower

dead center area is shown. Both pictures show areas where the light green color of the coating goes to blue in consequence of a slightly different gas shielding due to positioning deviations.
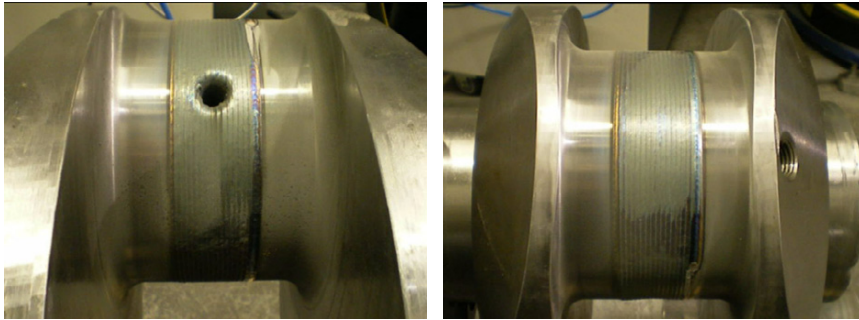

Fig. 12. Laser cladded crankshaft segment around oil bore (left) and on bottom side at lower dead center position (right)

4. Discussion

On flat and round specimens the first tracks were processed with a higher power than subsequent tracks. This was due to a certain amount of heat that had to be placed into the component before it stabilized. The heat induced by the laser beam could not be conducted out of the flat specimen geometry despite clamping and water cooling. Comparing the surrounding of the last cladded track of the flat specimen in figure 4 and the crankpin journal in figure 12 it can be observed that annealing colors only appear on the smaller flat specimen geometries. On the other hand the heat conduction in the crankshaft was very efficient. This was due to the much bigger heat sink provided by the surrounding material. As can be seen by comparing figure 5 and 11 the necessary laser power to obtain an equal melt pool size was much higher.

The stability of the process was strongly depending on a correct alignment of powder nozzle, laser spot and workpiece. For ensuring a stable process with good clad quality the powder had to be injected into the feed velocity direction and under a flat angle. This characteristic could be traced back to the beam profile of the high power diode laser. The process worked stable because the controlling kept a certain melt pool size and geometry.

5. Conclusion

In the development of a process for repairing crankshafts the following results have successfully been achieved:
- development of a process setup which is adapted to crankpin journal geometries
- research on flat specimen to identify process parameters for cladding Stellite 21 on steel 42CrMo4
- transfer results on round specimen geometries
- apply cladding process on crankpin journals

The resulting components showed the following properties:
- high clad quality in terms of connection and dilution
- inhomogeneous hardness distribution in HAZ
- steep hardness profiles from HAZ to unaffected base material

The process proved to have a very good reproducibility when it was aligned within a narrow window. In order to improve the process stability an online-detection and controlling of the orientation of cladding head and workpiece would be beneficial.

Acknowledgements

References

1. W. Schnell, D. Gross, W. Hauger, Technische Mechanik 2 – Elastostatik, 7. Auflage, Springer Verlag (2002), S. 100
2. W. M. Steen, Laser Surface Cladding, Proceedings of the Indo US- Workshop on Principles of Solidification and Materials Processing, SOLPROS, 1988, p. 163 - 178
3. K. Partes, G. Sepold, Modulation of power density distribution in time and space for high speed laser cladding, Journal of Materials Processing Technology, 2008, 195, 27 - 33
4. F. Vollertsen, K. Partes, J. Meijer, State of the art of Laser Hardening and Cladding, Proc. of the Third Int. WLT-Conf. on Lasers in Manufacturing 2005, Munich, AT-Verlag
5. E. Beyer, K. Wissenbach, Oberflächenbehandlung mit Laserstrahlung, Springer Verlag (1998), S. 50
6. A. Groth, C. Walz, S. Nägeler E. Beyer (ed.) New innovations in diode laser cladding, Proc. of ICALEO 2002
7. J. Tuominen, P. Hayhurst, V. Eronen, P. Vuoristo, T. Mäntylä, Comparison of multifeed and off-axis high-power diode laser cladding High-Power Diode Laser Technology and Applications, Proceedings of the SPIE, 2003, 4973, p. 116 - 127
8. D. Woodyard (ed.), Pounder's Marine Diesel Engines and Gas Turbines, 9th Edition, Butterworth Heinemann (2009)
9. D.H.E. Persson, S. Jacobsen, S. Hogmark, Effect of temperature on friction and galling of laser processed Norem 02 and Stellite 21, 14th int. conf. on Wear of Materials 2003, Volume 255, Issues 1-6, p. 498-503
10. D. H. E. Persson, S. Jacobson, S. Hogmark, The influence of phase transformations and oxidation on the galling resistance and low friction behaviour of a laser processed Co-based alloy, 14th Int. Conf. on Wear of Materials 2003, Volume 255 (2003), p. 1134 - 1140
11. G. Habedank, C. Theiler, M. Grupp, H. Kohn, G. Sepold, F. Vollertsen, Laser beam cladding of steel with high power diode lasers, Proc. of the Third Int. WLT-Conf. on Lasers in Manufacturing 2003, Munich, AT-Verlag
12. F. Dausinger, Strahlwerkzeug Laser: Energieeinkopplung und Prozesseffektivität, B.G. Teubner Stuttgart, 1995, S. 59
13. E. Toyserkani, A. Khajepour, S. Corbin, Closed-Loop Control of Laser Cladding Process by Powder Injection, Proc. of ICALEO 2003, p. 122 - 130
14. J. T. Hofman, Development of an observation and control system for industrial laser cladding, Ph.D.-thesis, M2i, 2009