Cladding with High Power Diode Lasers

Cladding is a well established process used in a variety of industries for improving the surface and near surface properties (e.g. wear, corrosion or heat resistance) of a part or to re-surface a component that has become worn through use. Cladding typically involves the creation of a new surface layer having different composition than the base material as opposed to hardening, which simply entails changing the properties of the substrate itself in a thin surface layer. There are currently quite a number of different techniques for performing cladding, each with its own specific characteristics in terms of the materials employed, the quality of the clad layer and various practical issues including throughput speed, process compatibility, and cost. Laser-based processes are amongst these techniques, however, their implementation has been somewhat limited due to both cost and various implementation factors.

New cladding technology based on continued advances in high-power diode arrays and product packaging has now become available. In many instances, this technology offers improved process throughput, superior overall clad quality, reduced heat input, minimal part distortion and better clad deposition control than traditional technology, while also delivering lower operating cost and easier implementation than other laser-based methods. This article provides an introduction to high-power diode laser technology and its use in cladding. In particular, it compares the capabilities and characteristics of diode lasers with traditional cladding methods as well as alternative laser technologies. Various sample cladding results are also presented.

Traditional Cladding Processes

Current cladding technologies can be broadly classified into three categories; these are arc welding, thermal spraying and laser-based methods. Each of these methods has its own advantages and limitations and as a result, there are certain types of applications for which each is best suited.

There are a number of different arc welding techniques such as gas tungsten arc welding (GTAW), plasma arc welding (PAW), plasma transferred arc (PTA), gas metal arc welding (GMAW), submerged arc welding (SAW) and several others. In all these processes, an arc is established to melt the surface of the base material, usually in the presence of a shield gas. The clad material is then introduced in either wire or powder form and is also melted by the arc, thereby forming the clad layer. The various embodiments of this basic approach differ in the details such as using the filler metal as the electrode, the use of flux, or the ability to use a hot (pre-heated) or cold filler wire.

In the most general terms, all arc welding techniques deliver a fully welded, metallurgical bond having high strength, good impact properties and low porosity. Arc welding methods also offer high deposition rates (which translates into high throughput) and relatively low capital cost for the equipment.

The major negatives of arc welding cladding are high heat input into the part and depending upon the particulars, relatively high dilution of the clad material (that is, unwanted migration of the base material into the clad layer). Heat input into the part can cause mechanical distortion which may create the need for further post-processing after cladding. It may also cause volatile alloying elements to evaporate which can result in surface hardening of some materials. In addition, it is not always possible to realize in practice the high deposition rates of which arc welding processes are theoretically capable. This is because dilution, heat input, distortion, hardness and other metallurgical properties are sometimes negatively affected when the arc energy is increased beyond an optimum level that is generally at the lower end of deposition rate range.

In thermal spraying, the clad material, in powder form, is melted by a flame or electricity and then sprayed on to the work-piece. In most cases, this is a low-heat process, typically < 200°C. The four most common embodiments of this approach are flame spraying, arc spraying, plasma spraying and high-velocity oxyfuel (HVOF).

The primary advantage of all thermal spraying techniques is the low heat input into the part which means there is no heat-affected zone and minimal dilution. It also enables the process to be utilized with a wide variety of substrate materials including metals, ceramics and even plastics. Thermal spraying also supports a very broad process window in terms of the range of coating thicknesses that can be achieved and the deposition rates supported, although these coating tend to be thinner than arc or laser based coatings. Typically, thermal spraying is relatively simple and inexpensive to implement.

One of the significant drawbacks of thermal spray process is that the bond between the clad layer and the substrate material is mechanical, not metallurgical in nature. This can lead to problems with adhesion and poor wear resistance, especially with pinpoint loading. Also, thermal spray claddings are typically much stronger in compression than in tension and often exhibit some level of porosity.

Laser cladding typically produces a high quality clad having extremely low dilution, low porosity and good surface uniformity as demonstrated in the photo below. Moreover, laser cladding transfers minimal heat input into the part which minimizes distortion and the need for post processing. It also typically avoids the loss of alloying elements or hardening of the base material. In addition, the rapid natural quench experienced with laser cladding results in a fine grain structure in the clad layer which tends to improve the corrosion resistance.

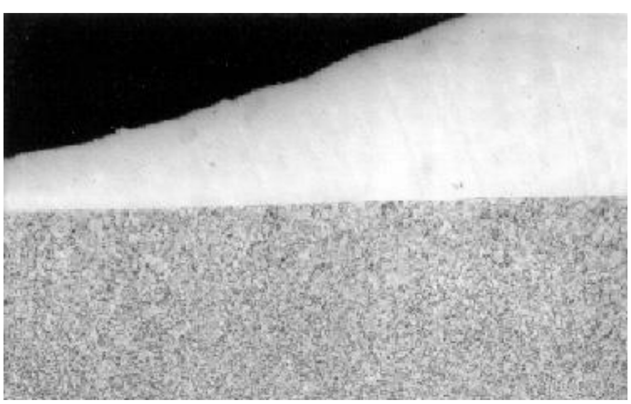


Figure 1. *Photo of the clad cross section shows essentially no dilution of the substrate material.*

Laser cladding is conceptually similar to arc welding methods, but in this case, the laser is used to melt the surface of the substrate and the clad material which can be in wire, strip or powder form. Laser cladding is often performed with CO_2, various types of Nd:YAG, and more recently, fiber-coupled or fiber lasers.

The limitations of traditional laser cladding are mainly practical in nature. Specifically, the capital cost is higher than other cladding techniques and the physical size of the equipment can make it difficult to integrate into some production settings. For CO_2 lasers, in particular, the high reflectivity of most metals at the infrared output wavelength (10.6 µm) results in lower process efficiency. Finally, in many cases, laser cladding doesn't support the deposition rates achievable with arc welding (albeit usually with a sacrifice in clad quality for fast arc welding).

High-Power Diode Lasers

Laser-based cladding techniques provide (at least theoretically) several quality and process related advantages over both arc welding and thermal spray methods. However, traditional laser types have not always delivered on this promise and have also displayed significant drawbacks in terms of output characteristics, operating costs and ease of implementation. In response to the need for a more optimal source for this application, cladding systems based on high-power direct diode laser technology have been recently expanded to include higher power levels and a more flexible, highly capable solutions.

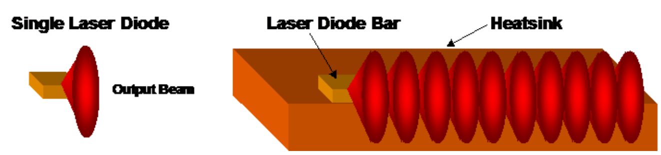


Figure 2 *Diode laser bars consist of multiple individual emitters on a single, monolithic substrate, each producing a divergent cone of light.*

The diode laser is a semiconductor device that directly converts electrical energy into laser light. Typically, higher power diode lasers output in the near infrared, most commonly at 975 nm. A typical, individual diode laser emitter might produce at most a few Watts of output power. However, numerous emitters can be fabricated on a single monolithic semiconductor substrate or "bar" with a total output as high as 100 W. These linear bars can be combined in horizontal and vertical stacks to produce high-power direct diode laser systems with total output power in the multi-kilowatt range.

The small size of diode lasers makes them easier to integrate into workstations. It also means they produce their waste heat in a relatively small physical area. As a result, they can be effectively cooled with a small volume of circulating water and a chiller.

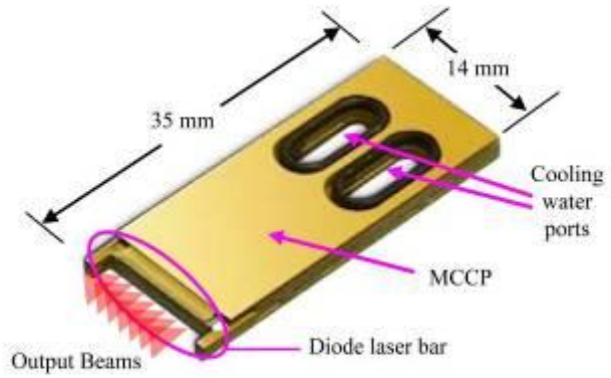


Figure 3. *A single diode laser bar mounted on a MCCP.*

The photo shows a mounting configuration for diode laser bars called a Micro-Channel Cooled Package (MCCP). Here, the diode laser bar is mounted on to a plate that contains internal channels for water circulation. The MCCP contains two large water ports, one for input and one for output, which each have an o-ring at their edge. These o-rings provide a water tight seal when two MCCPs are placed against each other face to face. This enables multiple MCCPs to be stacked together and water circulated through the entire assembly. The photo below shows the power scaling progression from individual MCCP mounted diode laser through assembled stack to an integrated, multi-stack assembly that can deliver as much as 8kW of laser power.

Commercial Diode Laser Systems

Currently available high-power diode laser systems offer output power and beam characteristics that are well matched to the needs of cladding and which enable a high degree of flexibility in terms of their implementation. For example, Coherent HighLight D-Series lasers are planned to be offered with output powers of 2.8 kW, 4 kW, 6 kW, 8 kW and 10 kW (all at 975 nm wavelength). The 6 kW and 8 kW models are designed with line beam dimensions of 1 mm width, and either 6 mm, 12 mm or 24 mm length. Lower power systems have additional beam lengths of 3 mm, 4 mm, or 5 mm. Furthermore, an optional beam shaping accessory can expand the 1 mm beam width dimension to 3 mm, 4 mm, 5mm, 6 mm, 8 mm or 12 mm. Thus, the output can easily be optimized to match a wide range of process requirements.

Figures 5a,b & c. *Current high-power direct diode laser systems are exemplified by the Coherent HighLight 8000D which provides 8kW of output with a variable beam profile which can be specifically optimized for large area and high deposition rate cladding.*

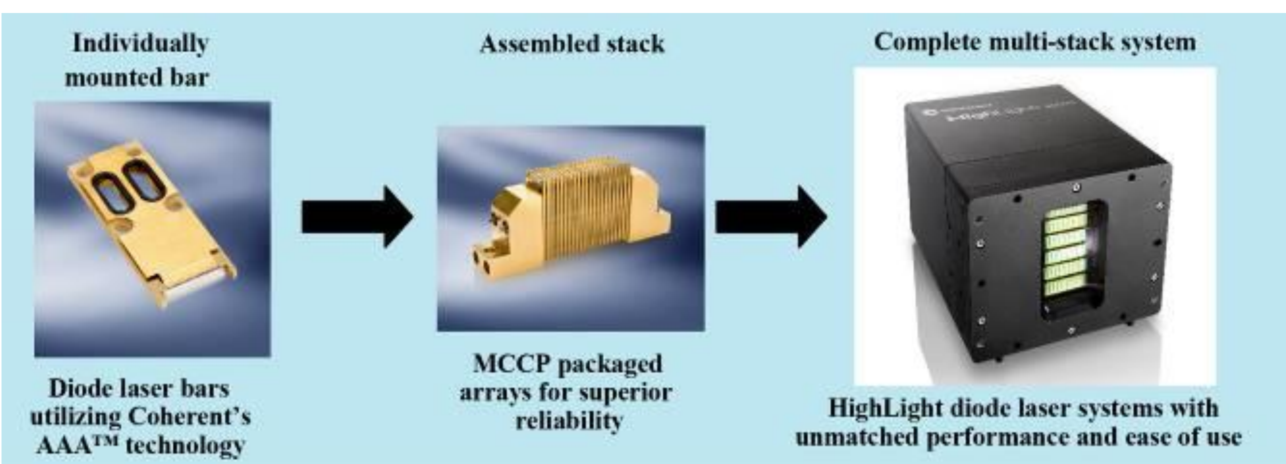


Figure 4. *Individual diode laser bars are combined into stacks, and multiple stacks are assembled into systems.*

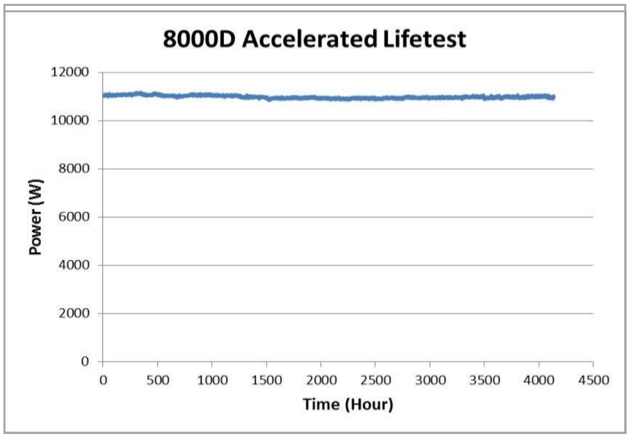


Figure 6. *Coherent HighLight 8000D (8 kW) laser life test data which extrapolates to an anticipated diode array lifetime (MTTF) exceeding 20,000 hours*

High-power diode laser systems also offer advantages in terms of reliability and ease of integration over most other laser types. For example, the graph shows output power from 10 different laser bars as they are on/off cycled over 20,000,000 times at a cycling frequency of 2 Hz. These particular testing conditions were chosen to mirror the on/off cycle demands of many real world material processing applications. Note that there is no significant drop off in output power over the 2,000 hour test period in any of the devices, and these results can be extrapolated mathematically to indicate a projected array lifetime of at least 20,000 hours. Furthermore, at Coherent we've seen no diode array failures due to corrosion or erosion in our MCCP architecture in 10 years of actual industrial operation.

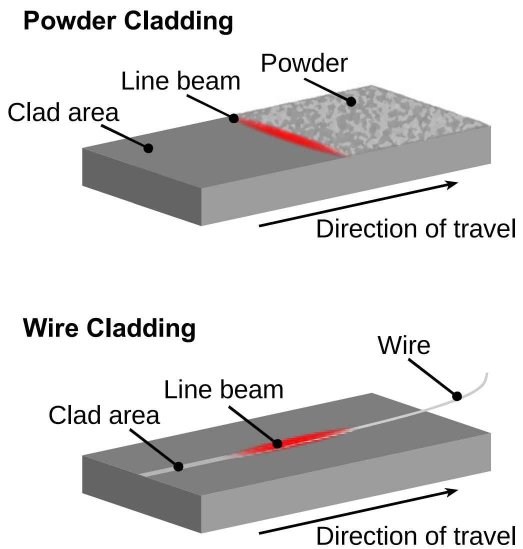


Figure 7. *Typical configurations for powder and wire cladding using the line beam output from a high power diode laser system.*

Since the area to be clad is typically larger than the beam, the beam is moved across the part via automation thereby permitting large areas to be processed rapidly. In the case of powder-based cladding, the long axis of the line beam is oriented perpendicular to the scan direction thereby enabling large areas to be processed. For example, a single pass "effective" clad width of 20 mm can be achieved when using the 24 mm line beam option. Alternately, in the case of wire feed cladding it is usually advantageous to orient the beam such that the short axis is in the direction of travel. In addition to process efficiency, this configuration allows the back of the line to smooth out the weld bead similar to a "follower" torch used in the GTAW or PAW processes.

Diode Laser Cladding Advantages

High-power diode laser systems offer unique advantages for cladding compared to other currently available technology. When compared to arc welding methods, diode laser systems offer lower heat related distortion, reduced dilution (typically 4-7%), lower porosity (< 1%) and better surface uniformity. Together, these properties potentially eliminate the need for post-processing and its associated time and monetary expense. The high quench rate of the diode laser produces a finer grain structure in the clad leading to better corrosion resistance. These benefits are generally not significantly negatively affected as laser power and deposition rate increase. In contrast, for most arc welding processes, clad quality suffers with increasing power and deposition rate. Finally, the line beam shape can process large areas rapidly with a high degree of control over clad width, thickness and deposition rate.

Both the diode laser and thermal spray techniques avoid significant heat input into the part and minimize dilution. However, unlike thermal spray, diode laser cladding forms a true metallurgical bond with the base material. The result is better adhesion and wear resistance. Furthermore, metallurgically bonded clads produced with the diode laser limit the cracking and de-lamination most often associated with mechanical coatings.

When compared to other laser solutions, diode laser systems offer more ideal output characteristics and also a number of practical advantages. One reason for this is that the shorter wavelength output of the diode laser is better absorbed by the underlying base material and clad alloy than the light of the Nd:YAG laser and especially the mid-infrared CO_2 laser. This means that a diode laser can deposit a given clad material using substantially less output power than a CO_2 laser, typically on a 1: 2.5 power ratio.

Cladding Process	Power (kW)	Deposition Rate (lb/hr)	Efficiency (lb/kW*hr)	Heat Input/ Distortion	Notes
High Power Diode Laser	7	20	2.9	1	Powder Cladding Rate, Expect Greater Efficiency & Higher Deposition With "Dual Hot Wire"
CO_2	5*	5	0.95	1	Coaxial Cladding nozzle
Plasma Arc Welding (PAW)	10	15	1.5	3	500 amps x 15 volts, + "Hot Wire" Power
Gas Tungsten Arc Welding (GTAW)	10	15	1.5	6	500 amps x 15 volts, + "Hot Wire" Power
Gas Metal Arc Welding (GMAW)	17	15	0.9	10	500 amps x 30 volts, 3/32" Wire
FCAW	17	20	0.9	10	500 amps x 32 volts, 3/32" Wire
Submerged Arc Welding (SAW)	32	50	1.6	20	1000 amps x 32 volts, 7/32" Wire, DC-

In addition, diode lasers offer a significant cost advantage over other laser types. One reason for this is that their electrical efficiency (conversion of input electrical energy to useful light output) is four times higher than for CO_2 lasers, about three times higher than diode-pumped Nd:YAG lasers and nearly twice that of currently available fiber lasers. When combined with the higher absorption rate this translates into lower operating costs, a smaller carbon footprint and increased deposition efficiency. Power costs are further reduced because the diode laser has instant "on" capability, meaning there is no standby power consumption. Even larger savings results from reduced maintenance costs which are orders of magnitude less for the diode as compared to other lasers. Maintenance downtime is also minimized because the physically compact diode laser can be more rapidly replaced than bulkier laser type, and replacements can even be shipped via expedited courier services.

In terms of the process, the line beam output of the free-space delivered diode laser offers an advantage over the output of other laser types when processing large areas. In particular, it enables the production of wide, flat clad deposits up to 23 mm in width having low dilution. Furthermore, overlapping passes wet together well to produce a flat surface profile requiring a minimal amount of post-machining. The direct-diode large area/high deposition rate cladding solution is able to cover the area to be clad at a rate of 3-5 times that of most competitive laser and non-laser cladding technology. From a practical standpoint, the compact diode laser has a smaller footprint than many laser types, thus allowing greater flexibility in its mounting and placement.

The table above summarizes the main benefits of the diode laser as compared to other cladding technologies. Here it is clearly seen that diode technology offers an unmatched combination of low heat input and high operational efficiency.

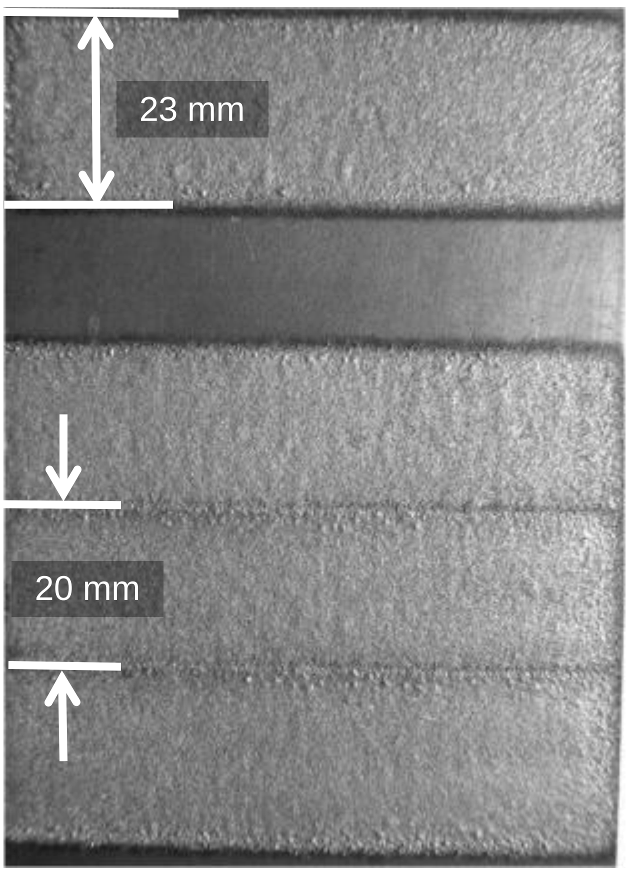
Typical Results

The gallery on the following pages presents some typical cladding results obtained with Coherent HighLight direct diode laser systems and should indicate the quality, capabilities and flexibility that can be readily obtained with this process technology.

In conclusion, high-power direct diode lasers are a unique source for cladding that deliver a number of advantages over traditional technology as well as other laser sources. In particular, diode lasers produce a high quality clad with excellent physical characteristics and a true metallurgical bond, yet without the heat input into the part associated with non-laser technology. In addition, they are more economical to operate than other cladding laser sources and their small physical size and optional fiber delivery simplify their integration and use.

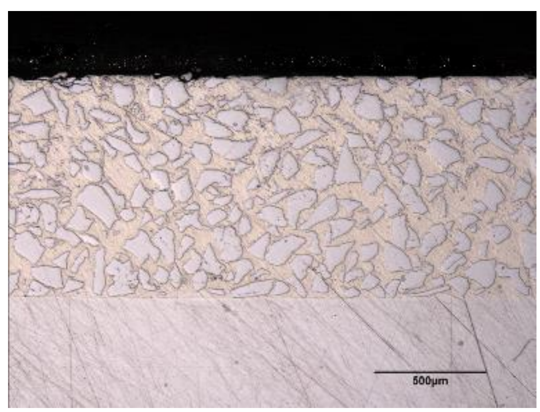
Large Area Cladding of Steel Plate with new HighLight D-Series Laser System

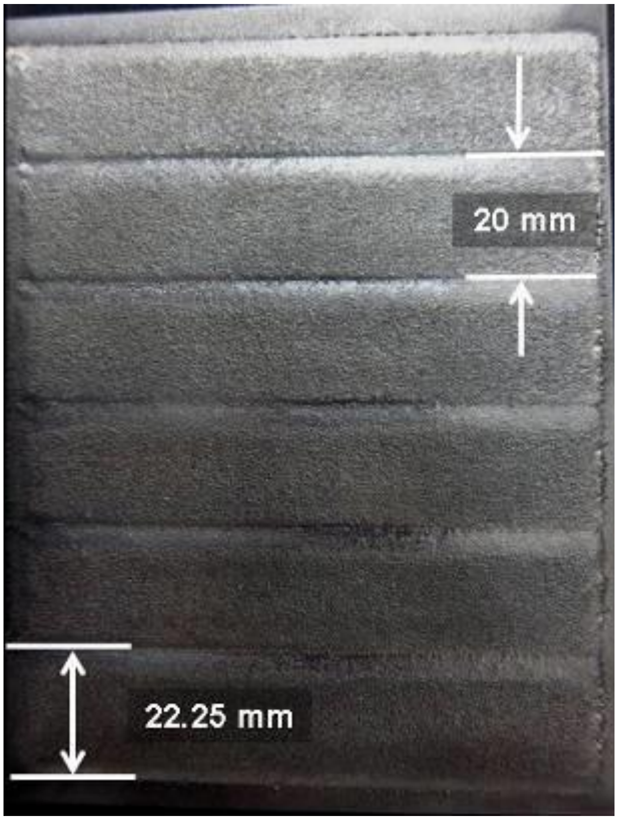
Substrate material.................... 1018 Steel (12mm thick)
Cladding material...... Hoganas 1559-40-60% (60%WC)
Laser type .... Coherent Highlight 8000D
Laser power .... 7 kW
Beam Shape .... 3 x 24 mm
Clad Width 23mm
Overlap 3mm
Effective Clad Width 20mm
Clad Thickness .... 2 mm (single pass)
Process Speed .... 0.39 m/min
Deposition Rate .... 20.37 lb/hr
Nozzle Capture Efficiency..................................... 83.8%
Cover/Delivery Gas.. Argon
Preheat .... None



Thin Layer Ni-WC Clad (60%) Deposit

Substrate Material:1018 Low Carbon Steel (12mm thick)
Cladding Powder ..... Hoganas 1559-40-60% (60% WC)
Laser type .... Coherent Highlight 8000D
Laser Power... 7kW
Beam Shape .... 3 mm x 24 mm
Clad Width .... 23 mm
Clad Overlap .... 3 mm
Effective Clad Width .... 20 mm
Clad Thickness .... 0.4mm (single cladding pass)
Cladding Speed .... 1.08 m/min
Cover/Delivery Gas... Agon
Preheat .... None

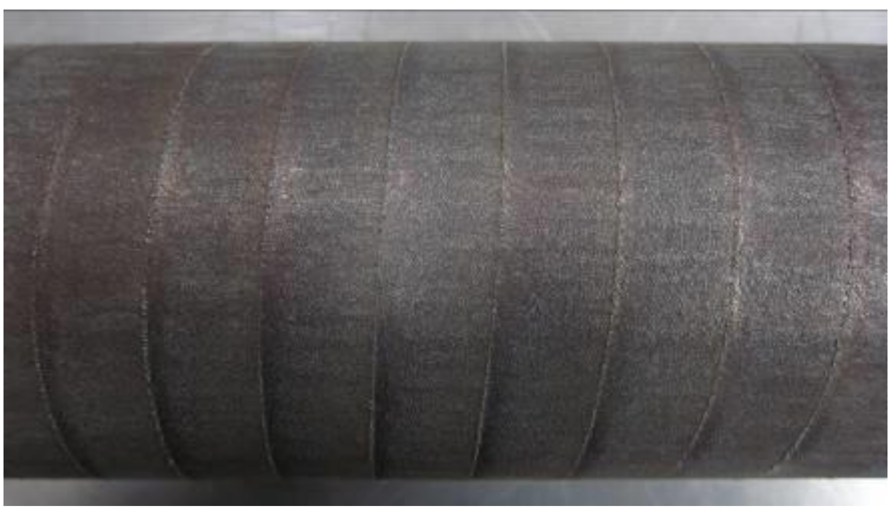




HighLight 8000D (8kW) Cladding Example

Substrate Material.................... 1018 Low Carbon Steel
Base Material Thickness...................... 100x125x12 mm
Cladding Powder .... Hoganas 2537 (comparable to Stellite 6)
Laser type .... Coherent Highlight 8000D
Laser Power..8kW
Beam Shape ....3 mm x 24 mm
Clad Width ....22.25 mm
Overlap ....2.25 mm
Effective Clad Width ....20 mm
Clad Thickness .... 1.25mm (single pass)
Cladding Speed ....0.6 m/min
Deposition Rate ....~ 12 lb/hr
Nozzle Capture Efficiency..........................est. 85 - 90%
Cover/Delivery Gas... Argon
Preheat .... None

Large Area Cladding of Stainless Steel Shaft
Substrate material............ SU316L stainless steel shaft
Cladding material.................... NiWC powder (30% WC)
Laser type .... Coherent Highlight 8000D
Laser power ....8 kW
Beam Shape .... 3 mm x 24 mm
Clad Width ....20 mm
Clad Thickness ....1.5 mm
Process Speed .... 0.4 m/min



Large Area Cladding of Stainless Steel Shaft
Substrate material............ SU316L stainless steel shaft
Cladding material...... Hoganas 3.33 Iron-based powder
Laser type .... Coherent Highlight 8000D
Laser power .... 8 kW
Beam Shape .... 3 mm x 24mm
Clad Width ....20 mm
Clad Thickness ....0.5 mm
Process Speed .... 0.5 m/min

Coherent HighLight D-Series Large Area/High Deposition Rate Laser Cladding Solution