Cladding with High Power Diode Lasers

High power diode lasers offer significant quality and cost advantages for many cladding applications over both traditional techniques and other laser-based methods.

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 resurface a component that has become worn through use. Cladding specifically 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 limited due to both cost and practical factors.

Over the past several years, a new type of cladding tool based on high power diode lasers has become available. In many instances, this technology offers superior overall quality, reduced heat input, virtually no part distortion and better thickness 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. Sample cladding results for steel 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 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, mixing of the base material into the clad layer). Heat input into the part can cause mechanical distortion, which may create the need for further processing after cladding. It may also cause volatile alloying elements to evaporate, and 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.

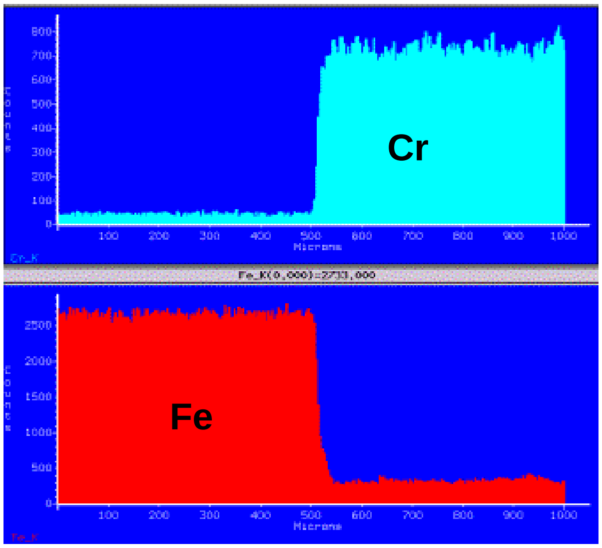
In thermal spraying, the clad material, in powder form, is melted by a flame or electricity, and then sprayed on to the work-piece, which is heated to $<200°C$. The four most common embodiments of this approach are flame spraying, arc spraying, plasma spraying and high-velocity oxyfuel (HVOF).

A primary advantage of all thermal spraying techniques is the low heat input into the part, which means there is no heat affected zone. It also enables the process to be utilized with a wide variety of substrate materials, including metals, ceramics and even plastics, and produces virtually no dilution. 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. Typically, thermal spraying is relatively simple and inexpensive to implement.

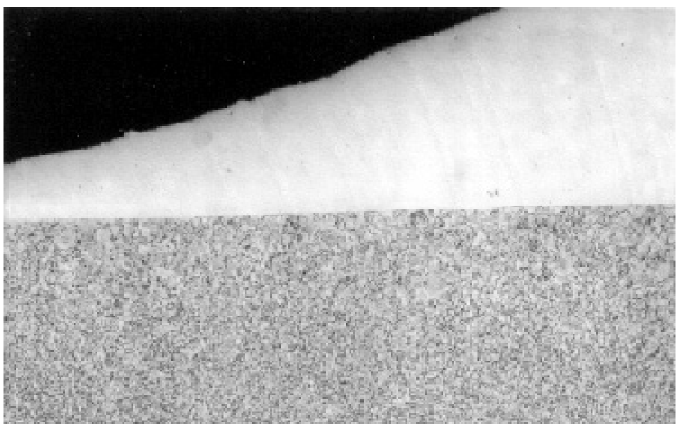
The biggest drawback of thermal spraying is that the bond between the clad layer and the substrate material is primarily mechanical, and not metallurgical. This can lead to problems with adhesion and poor wear resistance, especially to pinpoint loading. Also, thermal spray claddings are typically much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

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 commonly performed with CO_2, various types of Nd:YAG, and more recently, fiber lasers.

Laser cladding typically produces a high quality clad. That is, a clad having extremely low dilution, low porosity and good surface uniformity, as demonstrated in the graph and photo. Moreover, laser cladding produces minimal heat input on the part, which largely eliminates distortion and the need for post processing, and 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. And except when using CO_2 lasers, the laser power can be fiber delivered, which provides substantial flexibility in terms of how the process is implemented.



SEM line trace of C22 clad with a high power diode laser at 4 kW and 0.5 m/min.



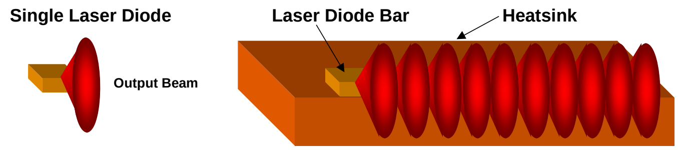
SEM photo of the clad cross section shows essentially no dilution of the substrate material

The limitations of 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. This can be particularly true of CO_2 lasers, whose infrared light cannot be fiber delivered, thus necessitating that the laser be brought into proximity with the workpiece. Also, most metals are more reflective at the infrared output wavelengths of CO_2 (10.6 µm) which results in lower process efficiency for this type of laser. 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 - at least theoretically - provide 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 Coherent has developed the HighLight™ series of products, based on high power diode laser technology.

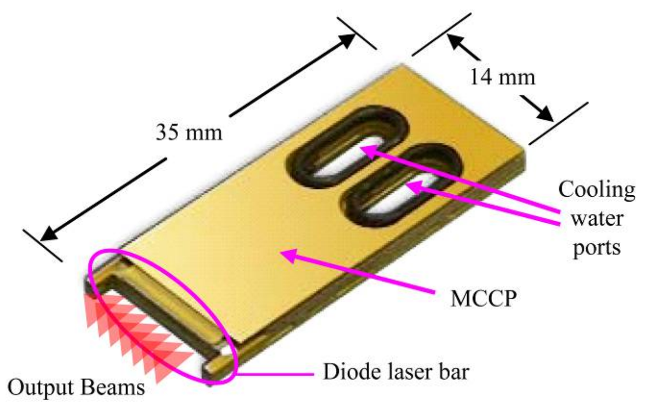
The diode laser is a semiconductor device that directly converts electrical energy into laser light. Typically, higher power diode lasers output in the near infrared, most commonly at either 808 nm or 975 nm. A typical, individual diode laser emitter might produce at most a few Watts of output power. 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, in turn, be combined in horizontal and vertical stacks to produce high power direct diode laser systems with total output power in the multi-kilowatt range.



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

The small size of diode lasers makes them easier to integrate into workstations. It also means that 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.

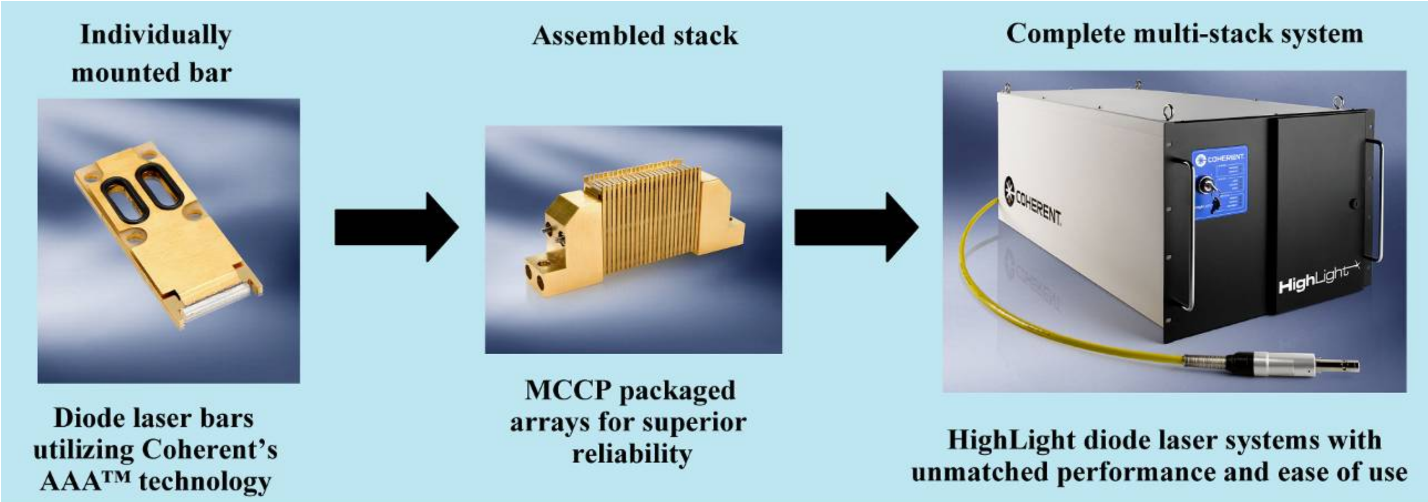
The photo shows a mounting configuration for diode laser bars called a Micro Channel Cooled Package (MCCP). Here, the diode laser bar is mounted on to a plate that contains internal channels for water circulation. The MCCP contains two large water ports, one for input and one for output, which each have 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 next photo 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 4 kW of power.



A single diode laser bar mounted on a MCCP

Coherent HighLight Diode Laser Systems

Coherent HighLight diode laser systems were specifically designed for industrial processing applications, such as welding, heat treating and cladding. The Coherent HighLight diode laser product line

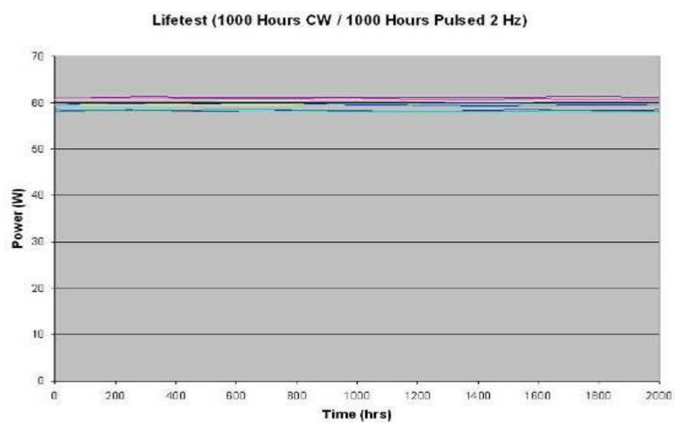


Coherent is the only vertically integrated supplier of high power diode lasers, producing everything from the wafer level through to finished systems

currently consists of two models. The first is the HighLight 4000L which offers 4 kW of output at 808 nm. The nominal beam size from this laser is 1 mm x 12 mm at a 90 mm working distance. A variety of optical accessories are available so that the output can be well matched to the needs of specific applications. The second model is the HighLight 1000F which is a high brightness, fiber-coupled system that delivers 1 kW at 975 nm from a 600 µm core optical fiber. The combination of small size and fiber delivery (fiber lengths from 10 m to 50 m) make the 1000F particularly easy to deploy in industrial environments where space and access to electrical and water service are an issue.

Coherent HighLight 4000L 4 kW diode laser system

Coherent HighLight systems deliver an ideal combination of reliability and ease of use thanks to the use of advanced technology in diode construction, process control and packaging, as well as practical systems convenience factors. We've also carefully engineered our MCCP technology to make it exceptionally robust and reliable as confirmed by both field data and on-going life-testing. For example, the next 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 materials 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, we've seen no diode array failures due to corrosion or erosion in our MCCP architecture in 10 years of actual industrial operation.

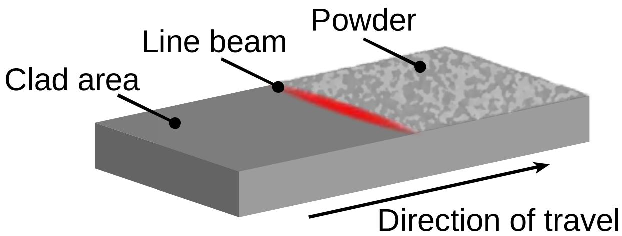


Testing indicates 20,000 hours MTBF for Coherent MCCP diode lasers with on/off cycling

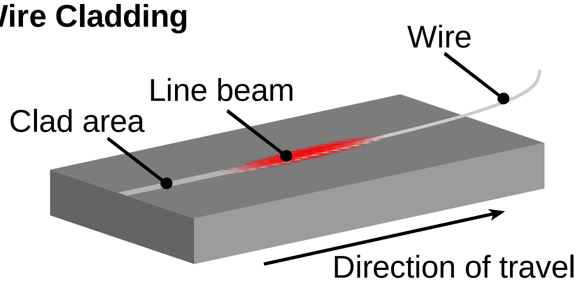
The output from both the HighLight 4000L and HighLight 1000F are particularly well suited to the needs of laser cladding. Since the area illuminated by the laser beam on the work surface is typically smaller than the area to be clad, the beam is usually manipulated across the part. In the case of powder-based cladding with the HighLight 4000L, the long axis of the line beam (12 mm) is oriented perpendicular to the scan direction, enabling large areas to be processed rapidly. 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.

The HighLight 1000F offers all the benefits of flexibility and remote access inherent to fiber delivery. The small beam size it produces makes it most suited to either selective cladding of small areas or processing of small parts.

Powder Cladding



Wire Cladding



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

HighLight Cladding Advantages

Coherent's HighLight high power diode laser systems offer unique advantages for cladding over any other currently available technology. When compared to arc welding methods, HighLight offers lower heat distortion, reduced dilution (typically < 4%), lower porosity (< 1%) and better surface uniformity. Together, these properties largely eliminate the need for post processing and its associated cost and time. The high quench rate of the HighLight laser produces a finer grain structure in the clad. Furthermore, these benefits apply at any power level, and hence, deposition rate; this is unlike arc welding, in which clad quality suffers with increasing power and deposition rate. Finally, the Highlight line beam can process large areas rapidly and its shape can be easily modified to match the needs of a specific application, thus resulting in versatile control of clad width and thickness. The option of fiber delivery also offers the possibility of remotely locating the laser from the process.

Both the HighLight laser and thermal spraying techniques avoid significant heat input into the part and minimize dilution. However, unlike thermal spraying, HighLight laser cladding forms a true metallurgical bond with the base material. The result is better adhesion and wear resistance. Furthermore, clads produced with the HighLight can withstand compression and tension without cracking or delamination.

When compared to other lasers, HighLight systems offer superior output characteristics and also a number of practical advantages. One reason for this is that the shorter wavelength output of the HighLight is better absorbed by cladding materials than the light of the Nd:YAG and especially the mid-infrared CO_2 laser. This means that a HighLight laser can melt a given clad material using substantially less output power than a CO_2 laser.

In addition, HighLight lasers offer a substantial 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 fiber lasers. When combined with the higher absorption due to its short wavelength, this translates into lower operating costs, a smaller carbon footprint, and increased deposition efficiency. Power costs are further reduced because the HighLight has instant "on" capability, so there is no standby power consumption. And, even larger savings results from reduced maintenance costs, which are orders of magnitude smaller for the HighLight as compared to other lasers. Maintenance downtime is also minimized because the physically compact HighLight laser can be more rapidly replaced than bulkier laser types, and replacements can even be shipped via expedited courier services.

Cladding Process	Power (kW)	Deposition Rate (lb/hr)	Efficiency (lb/kW*hr)	Heat Input/ Distortion	Notes
HighLight	4	8	2	1	Powder Cladding Rate, Expect Greater Efficiency & Higher Deposition With "Hot Wire" And "Hot Wire" x 2
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-

*Because light from the CO_2 laser is not absorbed as well as the HighLight, more power is required for processing. Even at 5W, the deposition rate is lower than for a HightLight laser at 4W.

In terms of the process, the line beam output of the HighLight 4000L offers an advantage over the output of other laser types when processing large areas. In particular, it enables the production of wide, flat clads having low dilution. Furthermore, overlapping passes wet together well to produce a flat surface profile requiring a minimal amount of post machining.

From a practical standpoint, the compact HighLight laser has a substantially smaller footprint than other laser types, thus allowing greater flexibility in its mounting and placement. Plus, it offers the option of fiber delivery for remote location.

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

Typical Results

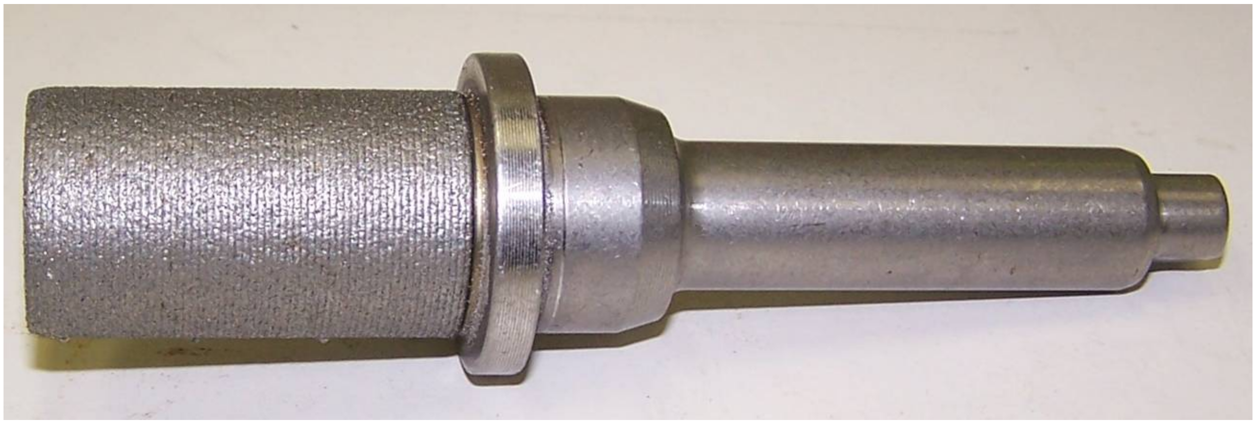
The following gallery presents some typical cladding results obtained with HighLight lasers, and should indicate the quality, capabilities and flexibility that can be obtained with this process.

Print Roller Shaft

Substrate material	Mild Carbon Steel
Cladding material	Hoganas C22 Hastelloy
Laser type	Coherent Highlight 4000L
Laser power	4 kW
Spot size	0.5 x 12 mm
Travel Speed	0.6 m/min
Powder Feed Rate	25 g/min
Step Size	8 mm
Clad Thickness	0.5 mm
Process notes	Helium cover gas

Circumferential Laser Cladding of Shaft Journal

Substrate material	High Alloy Steel
Cladding material	Inconel 625
Laser type	Coherent Highlight 1000F
Laser power	1 kW
Spot Size	2 mm
Process Speed	0.75 m/min

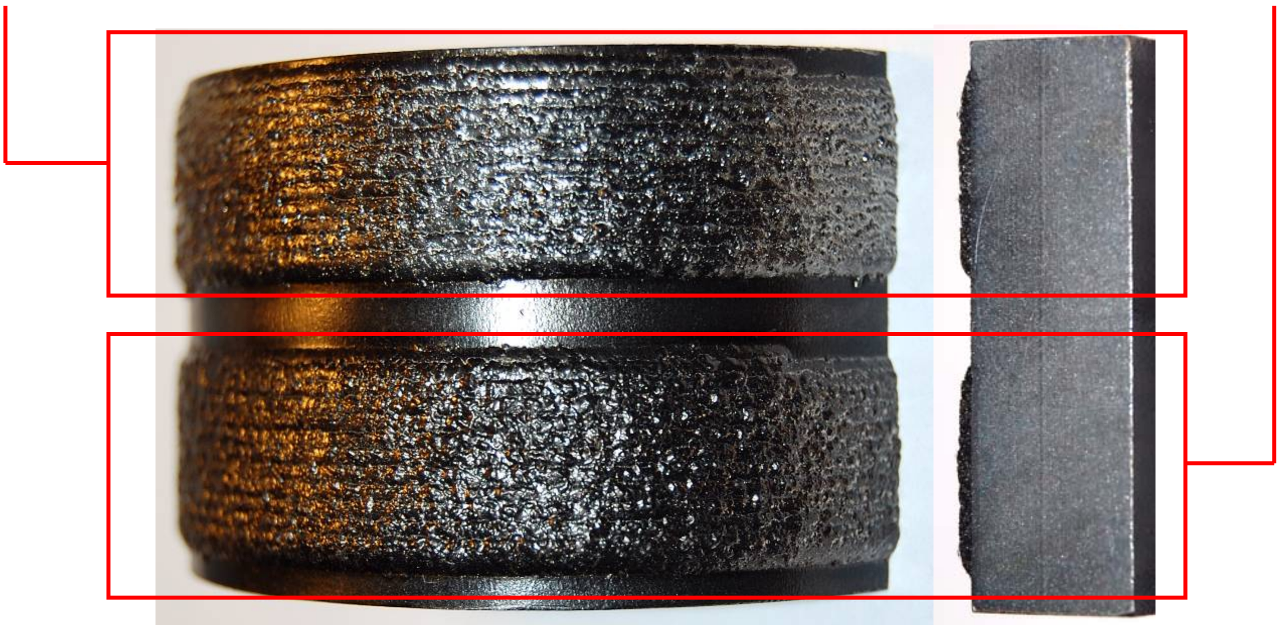


2” diameter, 0.40” wall thickness pipe

Substrate material	1018 Steel
Cladding material	Hoganas 2537-02
Laser type	Coherent Highlight 1000F
Laser power	1 kW
Spot size	~ 3 mm
Step over (index) distance	1.0 mm
Process Speed	1.2 m/min
Deposition Rate	20 g/min
Clad Thickness	0.8 mm
Process notes	Argon delivery and cover gas

2” diameter, 0.40” wall thickness pipe

Substrate material	1018 Steel
Cladding material	3550 Super Stainless
Laser type	Coherent Highlight 1000F
Laser power	1 kW
Spot size	~ 3 mm
Step over (index) distance	1.0 mm
Process Speed	1.2 m/min
Deposition Rate	20 g/min
Clad Thickness	0.8 mm
Process notes	Argon delivery and cover gas



Roller Teeth Mock Up

Substrate material	Mild carbon steel
Cladding material	Deloro 60 clad powder
Laser type	Coherent Highlight 1000F
Laser Power	1 kW
Spot Size	2 mm
Process Speed	0.35 m/min
Clad Thickness	1.2 mm

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