Laser Cladding Basics

Drivers for the laser cladding process include laser beam characteristics, filler material, base material, and thermal properties of the part

BY WAYNE PENN

The unique capability of laser cladding enables part processing with reduced heat and smaller grain structure compared to conventional welding. Applications for laser cladding include depositing a robust surface treatment to salvage and repair used parts. Laser cladding basics include an understanding of the laser light and the interaction of the laser beam with the material. In this article you will be introduced to several of the major components affecting the cladding process. The key components are integrated to form the laser cladding system.

Process Description

Laser cladding uses the high energy density generated by a laser beam to form a molten pool in a base material for metallurgically bonding with a filler material using a diffusion type of weld. The interaction between the laser beam and the base material is primarily a function of the following properties:

1. Laser beam absorption
   - Absorption of the beam generates the molten zone.
   - A shorter wavelength laser generally absorbs better in metals.
2. Laser beam reflection
   - Back reflection from the surface of the metal is high.
3. Laser beam transmission
   - For metals, penetration of the laser beam (photons) is low.

Absorption of the laser beam results in the heating of the base material. Very high energy densities are possible with a laser. Different material processing results can be achieved with increasing the energy density. The following examples are processes that follow a trend of increasing energy density:

1. Surface heating (low energy density)
2. Soldering
3. Brazing
4. Heat treating (surface hardening for appropriate alloys)
5. Diffusion welding (low penetration)
6. Cladding (diffusion welding plus extra energy for additive mass)
7. Keyhole welding (greater penetration)
8. Cutting (similar or greater keyhole welding energy density plus coaxial assist cutting nozzle)
9. Drilling (generally pulsed beam)
10. Ablative material removal (very high energy density)

Generally the power, pulse length, and beam quality of the laser determines what material processing techniques are possible. Typical energy densities for cladding or metal deposition range from 10^4 to 10^5 watts per square centimeter (W/cm^2). Energy densities above 10^5 W/cm^2 result in a keyhole welding process producing larger penetrations than the diffusion process. Diffusion welding of the clad deposit produces a narrow dilution zone between the clad and the base material. A portion of the filler material may be preheated by the laser beam just before wetting into the molten pool. The high energy density enables rapid heating and rapid self-quench times.

One of the key advantages of the laser cladding process over conventional welding metal deposition (gas metal arc welding (GMAW) or gas tungsten arc welding (GTAW)) is the smaller dilution zone resulting in a smaller heat-affected zone (HAZ). Figure 1 shows a 200-× magnified view through a metallurgical microscope of a laser deposit of 420 stainless powder deposited on 4140 steel. The microhardness diamond squares show a greater hardness in the deposit (HRC 60+ in the stainless deposit possible). For an example of the reduced heat possible with pulsed laser welding see Fig. 2. Laser cladding is similar to laser welding with filler material added to the weld pool. The rapid heating and cooling of a laser welded deposition can result in high hardness being achieved in the deposition.

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Fig. 1 — Laser clad deposit of 420 stainless steel on 4140 (200 ×).

Fig. 2 — Laser beam welding and GTAW visual heat effects.

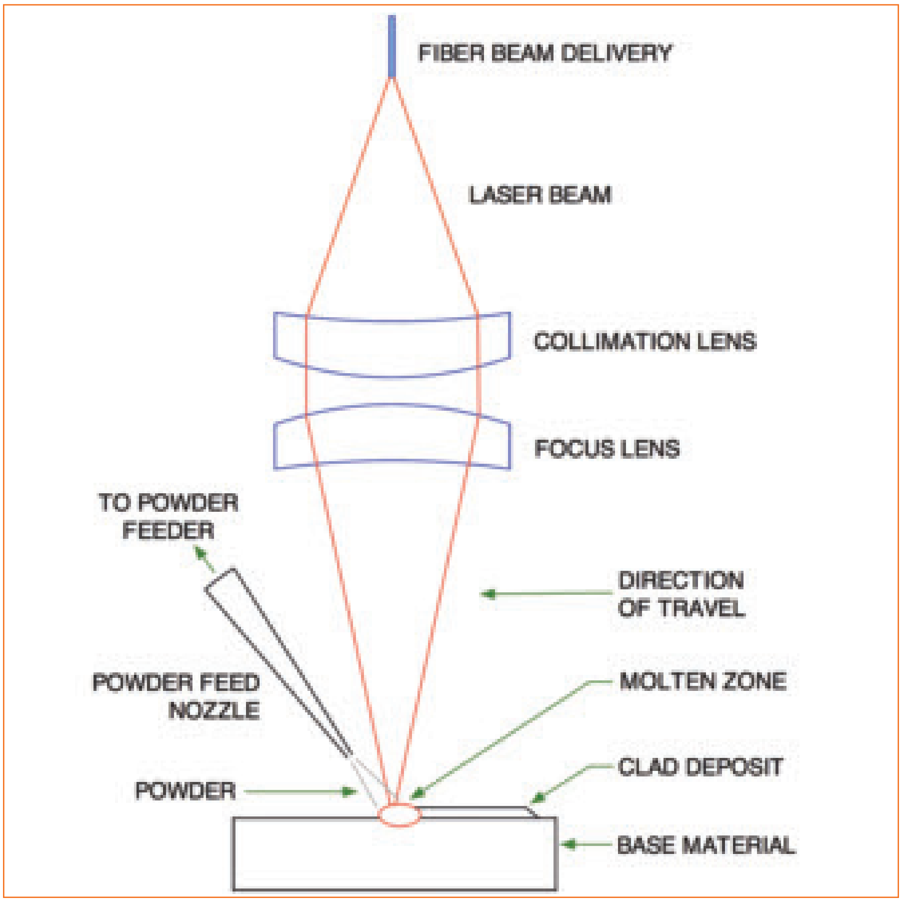

Fig. 3 — Diagram of laser cladding beam delivery head.

Table 1 — Types of Lasers Used for Cladding

Laser	Wavelength	Beam Quality	Beam Delivery
CO_2	10.6 microns	high	free space (mirrors)
Nd:YAG	1.06 microns	low	large fiber (typ. 0.4–0.6 mm)
Fiber	1.07 microns	high	small fiber (typ. 0.05–0.1mm)
Direct diode	0.8–1 microns typ.	low	free space (typ. rectangular beam)

The Molten Pool

The shape of the molten pool is primarily controlled by the laser spot shape and energy distribution, the incoming direction of new material plus effects from the filler material. Part geometry, mass, and the heat sinking properties of the material have an impact on how the part is processed. Powder scatters the laser beam and wire may distort the shape of the pool due to the heat sinking of the wire. The distribution of the laser energy can be modified with time or spatial techniques for shaping the thermal profile. Cooling of the part is also affected by the cover gas type and flow along with the fume removal flow rate.

The Laser Energy Source

The laser provides the energy to the molten pool. Cladding is generally done with a continuous beam laser. Pulsing the beam on and off is used to control the location and possible shape of the deposit. Several different types of lasers in the kilowatt class can be used. Table 1 shows the lasers used for cladding.

The beam quality of the laser determines what can be achieved with spot size, working distance, and depth of field (processing window size around the focal point). Higher beam quality gives greater flexibility in the optical system design. Diffusion welding spot shape for metal deposition covers a broad range including circles, squares, rectangles, and ellipses. Different sizes and shapes can be achieved as long as the energy density requirements are met for the molten pool. Often the shape is limited by the properties of the laser type and beam quality. For example, fiber-delivered lasers generally produce a round spot, elliptical spot, or scanned to a 2D shape. Direct diode lasers that are not fiber delivered are often configured to a rectangular shape.

Beam Delivery

To generate the required energy density, the beam out of the laser is focused onto the part to clad the surface — Fig. 3. The processing environment for the laser cladding head needs care, protection, and maintenance. Provisions for robust clad processing includes management in high back reflection environment, optics protection and cooling, shield gas provisions, feed material handling, head protection, fume removal, and maintenance.

A wire feed beam delivery in progress is shown in Fig. 4. The head is connected to a laser by an optical fiber. The spot size for this head is generally adjusted between 1 and 2 mm in diameter and used with a 1.6-kW, 100-micron fiber-delivered fiber laser.

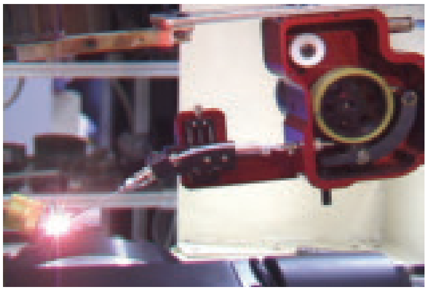

Fig. 4 — Precision wire feeder with laser metal deposition from a 1.6-kW fiber laser.

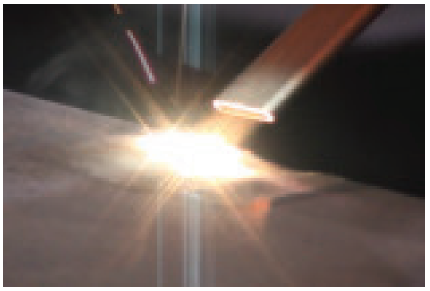

Fig. 5 — Laser cladding using a 4-kW diode laser with powder.

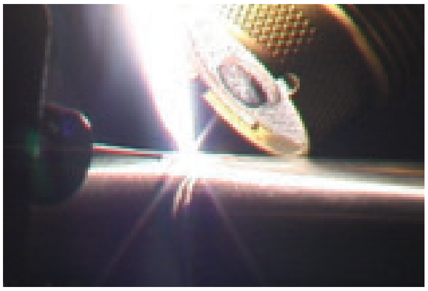

Fig. 6 — Precision laser metal deposition with 0.01-in. wire using a 1.6-kW fiber laser.

Fig. 7 — Multipass laser metal deposition with precision wire feeder.

The spot size and shape is controlled by the capabilities of the laser power and beam quality and the optical design of the beam delivery head. The requirements of the application drives the choices. To cover larger areas, rectangular-shaped spots may be used. A typical rectangular spot for a direct diode laser may be 1 × 12 mm with 4 kW of laser power. A deposit then would be made with the wide orientation of the beam producing bands of cladding that can be laid down side by side.

Filler Material

The filler method is generally integrated into the focusing head. Choice between coaxial and side powder feeder depends on the availability, application, and objective. Wire feeder systems generally come into the molten pool through a carefully oriented and aligned mechanical wire feeder. The laser cladding of a surface with a 4-kW direct diode laser with diffusion coupling using powder feed is shown in Fig. 5. Here the powder is brought into the side through a flattened copper tube. Long deposition times would require the powder nozzle to be water cooled. The thickness of the deposit may range from 0.25 to 0.75 mm depending on variables that include speed, power, powder rate, and feeding method.

Processing with keyhole beam coupling (ejected plasma is observed) with a precision wire feeder is shown in Fig. 6. The wire feeder is feeding a 0.01-in. wire into a molten spot created by a fiber laser. The wire is melted as it is fed into the molten zone. This process requires careful alignment and runs cleaner than the powder. Figure 7 shows a multipass example with the wire feeder using a fiber laser.

The Laser Cladding System

The operational environment for a CDRH certified Class 1 laser system includes an enclosure protection system that meets the Maximum Permissible Exposure (MPE) requirements for the laser beam; additional requirements according to ANSI Z136.1 (2007), *Safe Use of Lasers*; and information for the Laser Safety Officer (LSO), which can be obtained from the Laser Institute of America (*www.laserinstitute.org*).

The major components for a laser cladding system include the laser, beam delivery system, processing head, motion system, system control, enclosure, and material handling and automation as required. Process development including the metallurgy is a prerequisite for establishing a successful application.

Procedure

Laser cladding produces metallurgical bonds with the base material. The resulting process results can be considered as having the following zones.

1. Deposited material
2. Dilution zone
3. Heat-affected zone
4. Original base material.

Establishing a laser cladding process is similar to laser diffusion welding. First, the laser power and processing speed are adjusted for a smooth weld bead profile. Next, the filler material is added, usually along with a power increase to melt the additional metal. The process results then need evaluation with metallurgical analysis and processing parameters are adjusted for optimization.

Operator experience plus the system's specifications and controls will determine the laser cladding capabilities. Process development includes defining the processing variables at the production rates desired. It is important to evaluate the capabilities and robustness of the process at production rates.

Conclusions

Laser cladding offers new capabilities for part repair. Additionally, laser cladding for new parts may offer improved capabilities for wear surfaces.

Most likely, the applications for laser cladding and precision metal deposition will increase in the future with education on the capabilities of laser metal additive processes. The increase in applications can be further enabled by lower cost lasers and new capabilities that will offer precision control of laser spot geometry and heat distribution. This will provide even greater flexibility with laser cladding.◆