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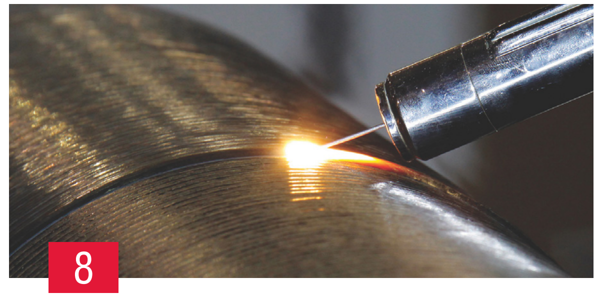

LASER CLADDING: THE FIRST LAYER OF ADDITIVE MANUFACTURING

By Wayne Penn

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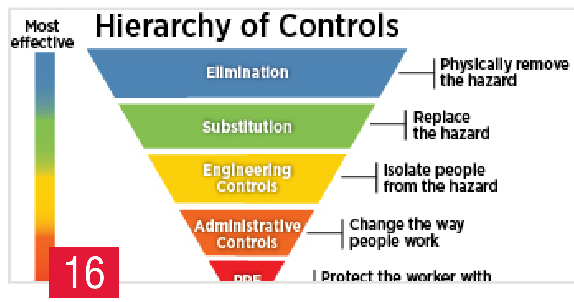

NON-BEAM TO THE EXTREME!

By Wesley Chase

Although laser beam hazards are better known, non-beam hazards (NBHs) pose an equal or possibly greater risk of injury or death. As laser technologies increase and new hazards are discovered, a greater number of ancillary or NBHs will need to be considered for a safe work environment. Wesley Chase of Lawrence Livermore National Laboratory briefly discusses the hazards, findings, and controls for silica, ozone, and nanomaterials in laser operations.

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Laser Cladding:

The First Layer of Additive Manufacturing

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Understanding the strengths and weaknesses of any process is important for good application results. Laser cladding is a welding process producing metallurgical bonds between the base material and the deposited clad surface. With the proper use of optics, one can focus a high power laser beam into a small spot and melt metal at a high speed. The ability to melt the metal at higher speeds lowers the heat input per unit length. For over 45 years I have worked with and built lasers. The first time adding metal to a part created a new level of excitement in working and playing with laser light. Over the past 20 years of my career, I have worked with laser cladding using both wire and powder deposition. In this article, I will elaborate on the laser cladding process, additive filler materials using powder and wire, a few cladding applications, plus some thoughts on cladding and additive manufacturing.

The Laser Cladding Process

The rapid heating and cool-down or quenching of the weld puddle and area affects the deposition material and the base material properties. Post-weld heat treatment (PWHT) is often needed for conventional welding and may also be necessary with laser cladding. Even though the heat input with laser cladding is less, it is still inducing stress and material property changes at some level. Laser cladding is not a magic wand, but with proper parameter development and application it can be a powerful tool for achieving results that otherwise may be difficult or impossible.

Benefits of Laser Cladding
Creation of a Small Heat Affected Zone (HAZ) in the base material
Production of a component with improved erosion properties
Production of a component with improved corrosion properties
Creation of a Metallurgical bond between the additive material and the base
Creation of a deposition material chemistry with low dilution of the base material
Lower heat input improves the ability to deposit matrix materials where one of the materials may otherwise melt and or evaporate into the deposit.
Ability to iterate and dial in the parameters for targeting material properties
Tailoring of the material performance properties of components; for example, internal ductility with a tough outer layer.

Challenges of Laser Cladding
High capital equipment cost
Many parameters to dial in, control and monitor
High grade and consistent quality required for the incoming materials
Precise integration of the optical, electronic, mechanical, and software control

Conventional Tungsten Inert Gas (TIG) Gas Tungsten Arc Welding (GTAW) or Metal Inert Gas (MIG) Gas Metal Arc Welding (GMAW) utilizes a plasma created by an electric arc to melt the metal. While the plasma temperature can be considerably higher than the melting point of the metal, it still takes time for the heat of the plasma to transfer and melt the metal. The heat of the plasma is transferred to the metal by some of the following mechanisms:

- Plasma surface contact
- Electrical resistance heating
- Convection carried with the shield gas
- Radiative energy from the plasma light

The plasma welding spot size or power density coupled with the heating mechanisms require additional time to melt the metal compared to laser welding. The additional time results in a slower weld speed and heating the base metal to a greater depth and increases the dilution of the additive filler material. While this can produce a good weld, the heat input to the base metal can be higher than a weld with a laser-produced filler.

The laser heating and melting of metal is a different mechanism. A laser beam is simply light. Light contains many packets of energy called photons. The laser beam itself is neither cold nor hot; rather, it is the interaction of the laser beam with a material that produces the heat.

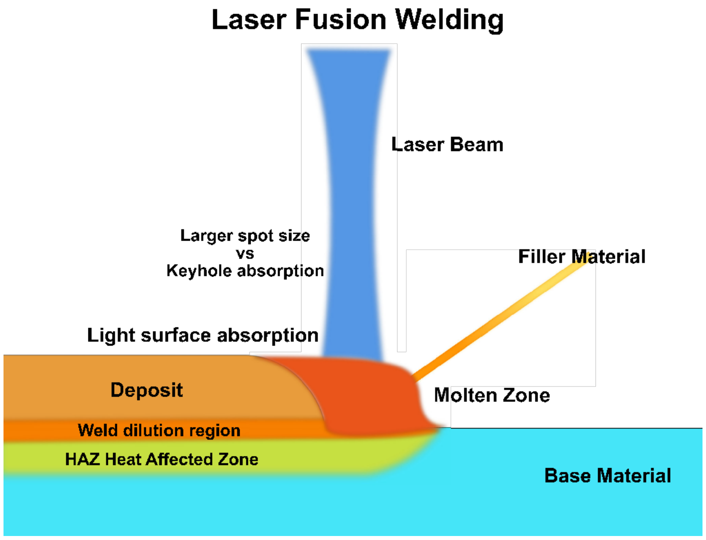


Fig. 1- Larger spot size- Laser conduction mode welding with filler or cladding

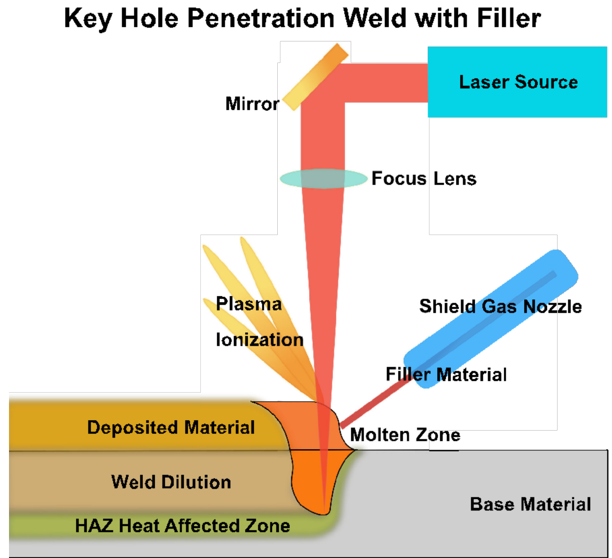


Fig. 2- Laser keyhole mode welding with filler or penetration welding

Laser Fusion Welding

Laser beam power densities on the order of 10,000 Watts/cm^2 can be absorbed by the surface of a metal; the material quickly melts under the power of the laser beam (see Fig. 1). The key here is surface melting. Melting below the surface is by heat conduction from the laser irradiated surface; hence, the term laser conduction welding or ***fusion welding.***

Key Hole Penetration Weld with Filler

Laser beam power densities above 100,000 Watts/cm^2 result in a different melting mechanism (see Fig. 2). The laser light no longer just interacts with the surface, but now the higher power density results in a propulsion mechanism that drives the laser beam down into the material resulting in even much greater absorption. The laser beam propelling down into the material causes metal vaporization and expansion that creates a keyhole or tunnel; hence, the term laser ***keyhole welding*** or penetration welding.

The beginning of my cladding journey started with some of the first industrial power diode lasers. A 1 kW diode laser offered a power density that was enough for welding metal. A high power diode laser wavelength of less than 1 micron offers improved absorption of the laser light for metals over the industrial CO_2 laser with a wavelength of 10.6 microns. Industrial laser power levels are now readily available to well over 10,000 Watts for the 1 micron to near-infrared (NIR) wavelength region.

Another Tool in the Welding Toolbox

The laser is just another tool in the welding toolbox. It still results in producing heat that can result in material transformations, material stress along with distortion and warping of the laser processed parts. Laser light is not a mystery, nor is it pixie dust; it is just basic welding with a new higher power density source that works with light for the heating mechanism.

Chart 1 on the next page shows many variables that begin to define the capabilities and features of the system. The system hardware I/O capabilities, controller, and software further define the cladding parameter matrix capabilities. For example, the starts and stops of cladding may need precise synchronous controls of laser power, surface speed, and feeder parameters for smooth controlled transitions.

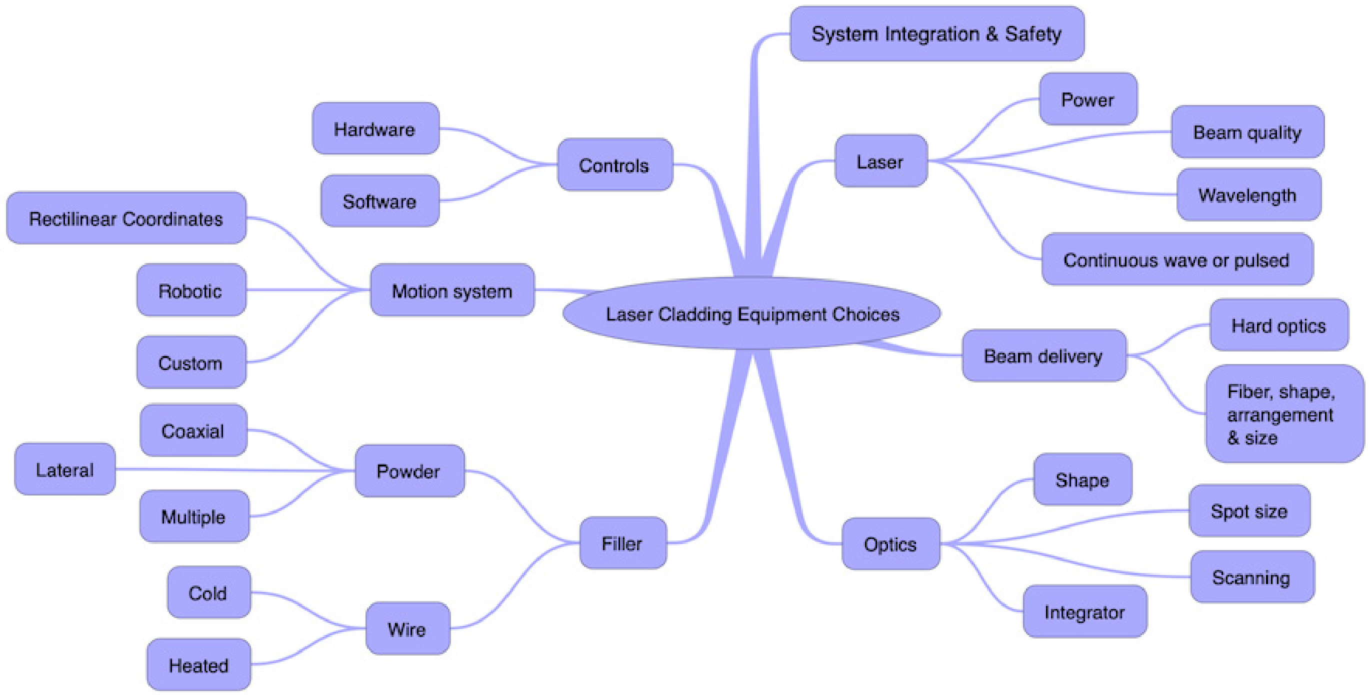


Chart 1-
Some of the laser cladding system configuration choices

The overall laser cladding system design, enclosure, safety interlocks and environmental control for safety and a consistent process are paramount.

Laser cladding needs, functions, and parameter choices include:

1. Laser
- 1.1. Power control including ramping
- 1.2. Spot size
- 1.3. Scanning
- 1.4. Beam pattern
- 1.5. Continuous wave (CW) and or pulsed

2. Optical head
- 2.1. Beam quality design
- 2.2. Optics
- 2.3. Cooling
- 2.4. Beam manipulation functions

3. Filler material delivery
- 3.1. Shield gases
- 3.2. Cooling
- 3.3. Geometrical configuration

4. Motion hardware
- 4.1. Geometry of part and beam motion
- 4.2. Axis of control
- 4.3. Surface speed control

5. Software
- 5.1. Input / Output (I/O) interfaces
- 5.2. Human Machine Interface (HMI)
- 5.3. Machine control algorithm
- 5.4. Ease of use
- 5.5. Compatibility with other software input
- 5.6. Vision
- 5.7. Quality and logging functions

6. System safety, enclosure, integration, HMI and environment

7. Control, interlocks, monitoring, logging, control functions, and I/O

From the list above you can get the idea that there is a wide spectrum of challenges and technologies for controlling and maintaining the process in an industrial environment.

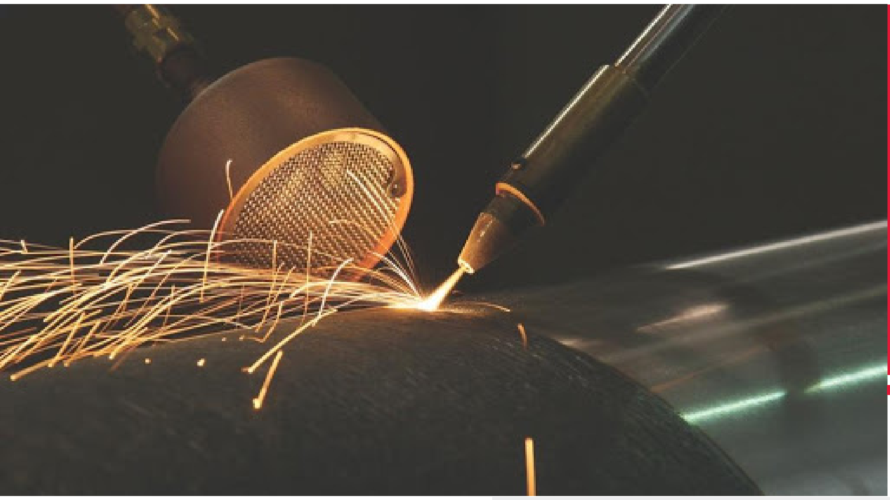
Additive Filler Material

Additive filler materials are generally metal alloys or pure metals. Powders and cored wires may have mixtures of alloys and elemental metals. Cladding is basic conduction welding with the addition of a filler.

Laser cladding is welding an overlay with less heat input (provided optimal parameters are dialed in). For laser cladding, the filler is added to the laser generated molten puddle, to build up the surface rather than burn the additive material down into the base. A small amount of dilution between the filler and the base is necessary to ensure good weld layer bonding.

Laser cladding and laser processing parameters provide the ability to iterate a matrix of experiments with the goal of improving material properties.

Powder Filler Material



Laser cladding with coaxially configured powder nozzles enables multi-axis motion systems where the head is steered to follow the contours; for example, cladding for part repair. Worn edges of the part can be built back up and then machined to finish dimensions.

Laser cladding with powder

Laser cladding with powder is also useful for materials that are made up of a mixture of powders. For example, in a wear resistant application, tungsten carbide (WC) particles are mixed with binder metals for fusing the WC particles into place without melting the WC.

Additionally, powders can be configured as mixtures of elements and alloys to achieve desired metallurgical properties. Optimizing particle size and shape distribution is essential for smooth powder flow. The nozzle geometry is important for controlled powder flow. If the nozzle is too close to the welding puddle, spatter can adhere to the nozzle surface and modify the powder spray pattern, thereby changing the cladding results.

Parameters affecting the cladding properties for powder include:

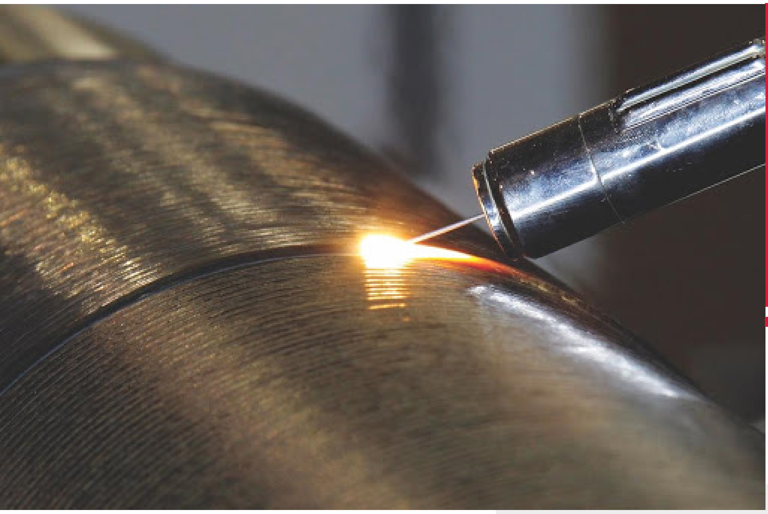
- **Distance from puddle**
- **Powder flow collimation**
- **Powder streams and beam orientations**
- **Keeping the powder evenly mixed and dry**
- **Weld orientation, vertical down, angled, side or upside down**
- **Transport gas velocity: quality of shield, cooling effects of the gas**
- **Powder intersection volume with the laser beam and weld puddle**
- **Nozzle location and geometry- coaxial, lateral, single nozzle or multiple.**

A proper maintenance schedule for cleaning the nozzle and maintaining the powder feed and lines is important for consistent results.

Powder Considerations

- **Spatter adhering which changes the spray pattern**
- **Parameter balance, bond at base not too much powder**
- **Surface finish powder grain texture**
- **Coaxial powder feed gives motion system freedom**
- **Additive material must be available in powder**
- **Resolution smaller laser spot size possible lending to smaller parts**
- **Deposition thickness, multiple passes**
- **Nozzles and pre-placed powder**
- **Material selection & properties**
- **Powder deposition efficiency, lost money, clean up**

Wire Filler Material



Wire as the filler material can be advantageous, especially for cylindrical part geometries. Wire feed can also be made into a hybrid process with the integration of a hot wire power supply for pre-heating the wire while being fed into the molten puddle.

Laser cladding with wire -
part restoration with multiple clad layers
NIR Laser beam coming in from the top

In general, laser welding with hot wire filler offers higher deposition rates with a smooth deposited finish. System integration plus optical, mechanical, and software control are important for good cladding capabilities. The purpose is to be able to add filler material to the weld puddle with minimal cooling to the molten volume, enabling the opportunity for improved deposition speeds. Iteration of a parameters matrix to optimize for the desired material properties is very important and requires validating with metallurgical analysis to insure base bonding and optimization of the heat input.

Wire Considerations

- **Clean wire**
- **Consistent processing performance**
- **Smooth surface finish from the melt pool**
- **Deposition speed increase with pre-heated wire**
- **Beam to wire orientation impacts motion direction**
- **Additive material must be available in wire**
- **Higher deposition rates for larger parts and less geometry resolution**
- **Range of deposition thicknesses possible**
- **Material selection & properties of solid wire and cored wire**

It is fundamental in any welding method, including laser welding with powder or wire, that the weldability of the base material with the addition of the filler is verified with welding trials. Typically, welding trials are made on metal coupons made of the same base material and using the same filler materials.

Considerations for both powder and wire:

- **The part must be clean, free of surface and ground in contamination**
- **Weld bond and satisfactory welding results from the base material and the additive material**
- **Process qualification**
- **Machine qualification**
- **Welding operator qualification**
- **Part qualification: Does the part meet the customers' requirements?**
- **Quality control, incoming material, processing results. Visual finish, special attention to starts, stops. Required testing**
- **Meets welding code standards as required**
- **Pre-machine and or surface finishing**
- **Post weld heat treat**
- **Post-machine**
- **QC and inspection**

Cladding Applications

The purpose of using lasers for cladding is the ability to produce a high enough power density for melting metal. The welded bond between the clad and the base results in a stronger bond than a mechanical bonding process. The benefits of laser cladding often focus on improving surface wear and corrosion performance. Application industries includes:

- **Power generation**
- **Oil and gas**
- **Pulp and paper**
- **Mold and die repair**
- **Engine component repair**
- **Electric motor component repair**
- **Turbine component repair**
- **Aerospace component repair**
- **Agriculture components**
- **Earth moving equipment repair**

In addition to part-repair and rebuild, cladding can be used in manufacturing new parts for realizing the benefits of the improved surface performance.

The upstream and downstream resources for a laser cladding operation include:

1. **Incoming materials inspection, qualification and metallurgy information.**
2. **Part pre-machining determination and operations.**
3. **Pre-machined part inspection**
4. **Part cleaning**
5. **Defining the laser cladding system need and parameters**
6. **Cladding operation**
7. **Cladding inspection and repair as needed.**
8. **Part post machining and finishing as needed**
9. **QC inspection and documentation as needed**

For new jobs and applications, one must develop the process. The development of the cladding process includes basic testing and parameters for the weldability of the incoming materials. Determining the success of the weld includes performing metallurgical micrographic investigations on the test parts bonding interface, clad chemistry, micro hardness across the bond region, and various bending and elongation tests and measurements.

Cladding and Additive Manufacturing Going Forward

Laser cladding is the first layer of additive manufacturing. What I am implying is that launching with the achievements of laser cladding can help to enable a larger scale production for direct energy deposition.

Laser cladding is all about welding with a filler material using a process that enables an improved component. By adding more layers, you can build a new component with features tailored for the application along with a potential for cost savings. Net shaping using basic laser cladding metal deposition technology can open the door to large component creation. The money being invested in research and industry with 3D printing bears witness to the growing enthusiasm and potential that laser additive metal deposition can have on our designs, capabilities, and our economy.