HARDFACING: TRADITIONAL VERSUS LASER

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Greener Industrial Components
Cork-based start-up, LaserAge has perfected 'hardfacing' technology, extending the life of metal components and providing a cost saving proposition for every engineering sector.

INTRODUCTION

Laser cladding (hardfacing) is a **welding**-related technique that **restores** worn surfaces of used implements by depositing a welded **overlay**, providing hardness, abrasion, erosion, galling, impact, corrosion or heat resistance to cover the original or the worn out surface so that it **performs** better in a harsh environment, for longer time and with less maintenance. When applied to new parts, it protects the substrate material with a layer of a complex alloy coating by enhancing its chemical, physical and mechanical **properties**. This technology can be applied for the repair of Industrial Wear Parts in Aerospace and Power Generation Industries, i.e., gas & steam turbine components, Mining, Transportation, Aggregate/Cement, Recycling, Agricultural, Chemical and Injection Mould Industries. Examples of wear parts suitable for laser cladding (hardfacing) are listed in Figure 2.

Laser Surface Treatment Technology (LSTT) is a term used for hardening, cladding, alloying, heat-treatment and surface modification. Laser hardfacing (most cladding is a hardfaced coating so the two terms mean the same thing) is also included in this list and it used mainly to describe build-up/repair/re-manufacture of new/worn components due to excessive wear from erosion or corrosion.

HARDFACING

The economic importance of hardfacing derives from the feasibility of selectively applying expensive materials, chosen for their properties, and depositing them onto a common inexpensive base metal where they are required for best performing their specialized **function**. The base material provides the bulk of the structure and saves the end-user 95% in superalloy material costs.

Category	Process
Arc welding	Flux core arc welding (FCAW)
	Gas metal arc welding (GMAW) (MIG)
	Gas tungsten arc welding (GTAW) (TIG)
	Plasma arc welding (PAW) (PTA)
	Shielded metal arc welding (SMAW)
	Submerged arc welding (SAW)
Torch welding	Oxy/fuel gas welding (OFW)
Other welding	Electron beam welding (EBW)
	Electroslag welding (ESW)
	Furnace braze (FB)
	Laser beam welding (LBW)

Table 1; Common hardfacing techniques include arc, torch, and other processes.

In case of large bulky, difficult to transport components, the repair process will preferably be **manual**, and will be performed by a skilled welder using portable equipment. Mechanized setups are implemented, when applicable, if long stretches of weld deposit are needed, using either Gas Metal Arc Welding (GMAW also known as MIG) or Submerged Arc Welding (SAW), because of their higher deposition rate when compared to manual Shielded Metal Arc Welding (SMAW or Stick).

Conversely, small parts to be processed in large quantities are more economically repaired using an automated hardfacing **machine** in a properly set up industrial environment. The laser is excellent for processing high volume parts. A laser cladding (hardfacing) workstation can replace a conventional hardfacing machining system, produce quality components and with high productivity rates. The initial capital investment is high, but this is offset in the medium to long-term by the benefits gained.

Laser hardfacing uses a high power laser beam to fuse hardfacing coatings onto substrates where excessive wear or corrosion has occurred, see Figure 3. This process deposits hard material onto low grade, engineering components, extending the life of those components. It is complementary to or even substitutional to the manual GMAW, GTAW, PAW and other welding processes.

Laser hardfacing is a subject of considerable interest at present because it offers the chance to save strategic materials by coating the surface properties of bulk materials with enhanced hardfacing wear (or corrosion) resistant superalloy coatings. The coating enhances the surface properties of the bulk material by improving wear (or corrosion) properties on its surface in the same way as conventional coating processes. However it does so it with more precision and with less thermal load on the bulk material.

Figure 1(a) shows a schematic of the blown powder **cladding** technique (hardfacing) with a side feed powder nozzle injecting alloy powder into a laser generated melt pool. By simultaneously rotating the component (shaft), a welded coating was deposited as shown in Figure 1(b). The figure shows a shaft, with a coating of a wear resistance hard-facing matensite stainless steel deposited onto the surface of mild steel, C45. By overlapping laser weld beads, a hard coating was produced. This enhanced the life of the component several times over and only the part of the shaft that came in contact with the bearing needed to be coated.

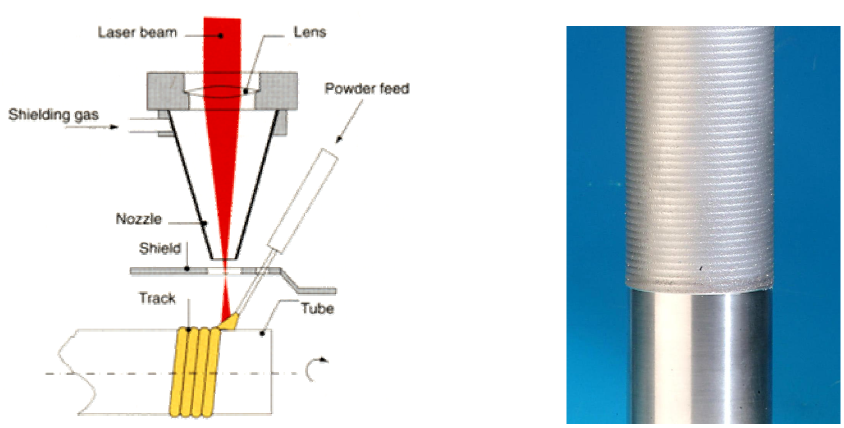


Fig. 1(a) Schematic of the Interaction Zone (b) Shaft Cladding

The thickness range of hardfacing coating is from 1 mm up to several cm. For layers <1mm, one should investigate the applicability of a thermal spray process, a method of depositing materials with designated properties, without welding the base material or even heating it much.

<u>**The technical benefits**</u> of laser hardfacing (over other non-laser welding techniques) include: low dilution rates (<3%), uses less filler material, higher hardness and small Heat Affected Zone (HAZ). These are listed in more detail in Table 2. The business benefits include extra protection to components

thus longer life, up to a factor of five. The process is fast, accurate and easy to automate. This increases production and reduces TRT (Turn Around Times). Once the process is validated it is readily adopted because of the proven benefits.

<u>The benefits to the customer</u> are

- Building new parts with assured longer life of elements subjected to wear and abrasion.
- Rebuilding worn parts at a fraction of replacement cost.
- Savings in maintenance costs when rebuilding on site and in situ.
- Hardfacing alloy only needs to be deposited where it is needed and not have to cover the whole component
- Breakdown time or scheduled maintenance shutdown is reduced thus increasing work efficiency.

The most common hardfacing materials are nickel alloys and iron/chromium alloys used in wear resistance and high stress abrasion.

Metal Alloy	**Purpose**
Cobalt-base alloys	wear and corrosion resistance
Copper-base alloys	rebuilding worn machinery parts
Iron chromium alloys	high stress abrasion
Manganese steel	wear application
Nickel-base alloys	metal-to-metal wear resistance
Tool steel	tooling, wear application
Tungsten carbide	high stress abrasion

Table 2; Common Materials for Hardfacing

Low alloy steel for hardfacing containing chromium, molybdenum and manganese (total alloy content of **6 to 12%**) can be used as a support for more abrasion resistant layers: moderate in price and machinable,. They offer higher impact resistance but only offer moderate improvement over the base metal abrasion resistance.

Higher iron base alloys (alloy content of **12 to 25%**) of chromium and molybdenum, with manganese and Silicon. Alloys with high carbon content are essentially cast irons. Austenitic manganese steel, including also nickel and molybdenum, are impact resistant. They develop higher hardness and abrasion resistance through mechanical deformation or work hardening, usually in operation. However the application is more difficult because one must avoid overheating which tends to embrittle the overlay. Alloy content can reach almost 40%.

More expensive high carbon and higher alloy content (**25 to 50%**) alloys have chromium and molybdenum, which form massive carbides. Hardness depends on the substrate but it is usually so high that the deposit is non machinable. Cobalt base alloys with high proportions of chromium and tungsten are often described as the most versatile alloys, capable of resisting abrasion, corrosion, heat, oxidation, impact and wear. Nickel base hardfacing alloys are selected for heat and corrosion resistance when metal-to-metal contact wear is present.

The last group of hardfacing alloys presents tungsten carbide (WC) particles embedded in one of any kind of matrix metal like iron, steel, bronze, nickel or cobalt. These alloys have the highest abrasion resistance when impact is low or moderate.

In general hardfacing selection is more based on the **application** than strictly on composition. See Figure 2 for an extensive list of applications suitable for the laser cladding (hardfacing) process. For laser hardfacing, the above materials must be provided in either powder or wire form.

Advantages of using lasers over non-laser hardfacing methods:

- A laser system can be **readily automated**, **easily monitored** and **time-shared.**
- **Low wear** and tear of the machine hence low running costs.
- **Less after-machining**, if any, is required on the processed part.
- **Complex component** shapes can be treated.
- Remote **non-contact** processing is usually possible.
- Treatment can be **localised** to a small area unlike plasma spraying.
- Suitable for production line rather than batch processing.
- Treatments are rapid.
- A laser can also be used as a **high precision machine tool** for cutting, welding, surface treatment and other material processing applications.

Table 3 shows the merits of laser hardfacing versus TIG welding. Laser hardfacing puts a lower thermal load on the substrate as compared to TIG welding. Thus cooling rates are rapid, and the microstructure is finer leading to enhanced mechanical properties, i.e. higher hardness. Also the Heat Affected Zone (HAZ)[♦] is smaller, implying more heat sensitive components can be treated in this way.

	TIG	Laser
Dilution Rate	10 – 40%	< 5%
User of filler material	More & Non-uniform deposition	Less and uniform deposition
Hardness Value	Relatively low	Relatively high
Heat Affected Zone	Large & wide	Small & narrow
Finish	Rough surface, less durable	Good surface, long life
Pre and post Treatment	Many	Few
Dendritic Structure	Coarse	Fine
Automation	Difficult	Easy
Portability	Available	In progress

Table 3: TIG versus Laser Hardfacing

If too much heat were applied during the repair process, the weld bead or clad would have been “alloyed” into the substrate resulting in a new alloy being generated, which can be detrimental to the physical and mechanical properties of the component’s surface being repaired. Laser hardfacing avoids this by having low dilutions rates of the order of <5% of the substrate material, as compared to 10-40% if other methods,

In conclusion laser hardfacing can be applied to many high value industrial components, as shown in Figure 2. Usually only large corporations can afford such laser hardfacing machines. An 8-axis coaxial CO_2 laser cladding system costs approximately €500,000+. Currently LaserAge is reviewing this market and would like to be in a position to offer this service, both nationally in beyond in 2005.

[♦] The HAZ is the area in the substrate that has been heat affected by the laser beam but not melted by it. It alters the structure of this area and not always to the benefit of the materials mechanical properties.

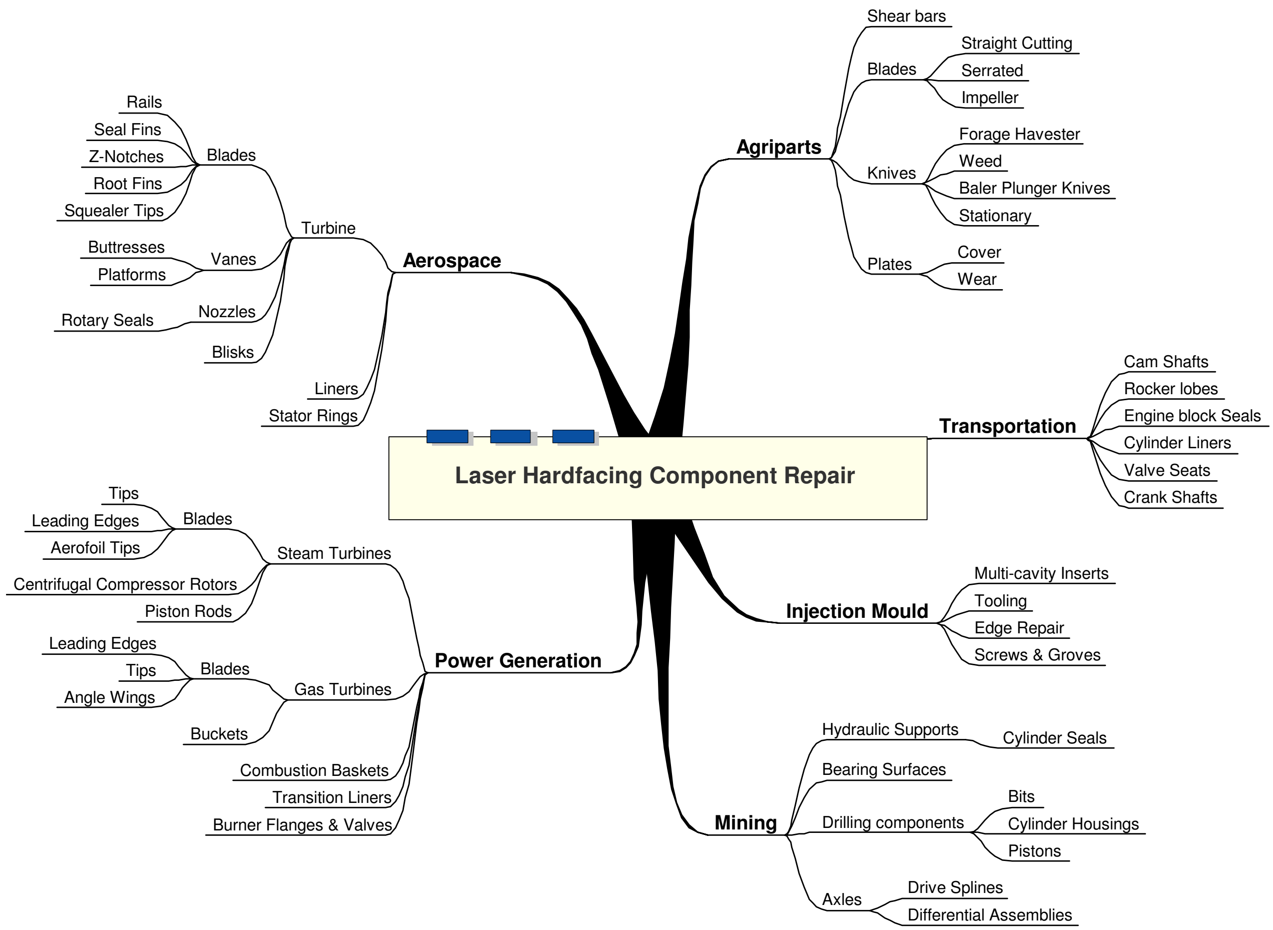


Figure 2; an extensive list of component wear parts that are suitable to the laser cladding (hardfacing) process.

Examples

1. Injection Mould Repair

Laser cladding or hardfacing was used to repair a multi-mould tooth brush holder by depositing a hard, high-temperature erosion-resistant material. Figure 3(a) shows the worn and quite heavily eroded mould, which would be scraped and replaced with a new one. By using laser hardfacing it was repaired and received a new lease of life. Fig 3(b) shows the mould milled back to reveal that the under surface is in good condition. TIG welding or plasma spraying would be inappropriate as too much heat would have distorted the component. Fig 3(c) shows the mould after it has been laser clad (hardfaced) and Fig 3(d) shows the finished product machined to its original shape. Cooling rates during the cladding process are generally high and this enhanced the hardness of the component even further.

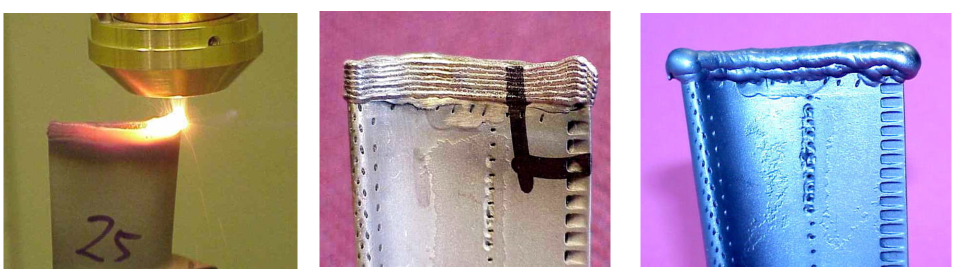
(a) (b) (c) (d)

Fig. 3 Injection mould tooling for toothbrush holder; (a) eroded, (b) ground back, (c) laser clad, (d) milled to original tolerances. Courtesy of ILT, Germany.

2. Turbine Blade

In the aerospace industry, erosion, thermal and hardfaced resistant coatings are paramount for the protection of turbine blades, which operate in very hostile conditions. The blades are generally cast from superalloy materials and traditionally these blades are repaired manually (TIG). Training a welder to deposit an aerofoil build-up of 4-5 mm in height and 1 mm thick of a superalloy material, without cracking and doing it all in a specially designed 1000°C inert gas shroud box can be demanding on the welder at times. In searching for a more user-friendly, repeatable, less labour intensive (cost reduction) and automated process laser hardfacing was used. By using a powder feed system and a specially designed powder nozzle adapted for this application, laser hardfacing was able to complement the welder.

Fig 4(a) shows the laser hardfacing process being applied to the tip of a High Pressure Turbine (HPT) blade. The laser beam formed a shallow melt pool on the surface of the aerofoil and simultaneously Ni-base powder was deposited into the laser generated melt pool (on the aerofoil) and weld beads were laid down, one on top of each other. By depositing weld beads in this fashion the tip was repaired in a matter of minutes. Figure 4(b) shows the finished blade ready for milling.



(a) (b) (c)

Fig. 4(a) Laser hardfacing of turbine blade, (b) laser clad blade (c) manually welded blade.
(Courtesy of SIFCO Turbine Components Ltd.)

By comparison additional post-processing work had to be carried out on the manually Tungsten Inert Gas (TIG) welded blade, Fig 4(c). The tip of the manually welded blade had to be EDM (Electro Discharge Machining) in order to expose the cooling holes (on top of the aerofoil), which are always filled in during the manual welding process. Laser hardfacing eliminated this and many other steps of the manual repair process and thus offered considerable cost and time savings.

3. Cutting (Agricultural) Blades

Tungsten carbide (WC) is a very hard substance and would be ideal for hardfacing applications. In its pure form its hardness is second only to diamond. As is the case with all hard substances, carbides are brittle, rendering them useless in their pure state for high impact applications. In order to capture the benefits of the high wear characteristics of WC, it is mixed with a filler metal (or matrix) up to a ratio of WC 50wt.%. When heated in a laser beam the WC particles and filler metal (Ni-base) are bombarded onto the inexpensive cast iron blade substrate. The matrix melts thus giving the carbide a liquidified bed in which to settle, the melting point of the matrix being lower than the carbide particles.

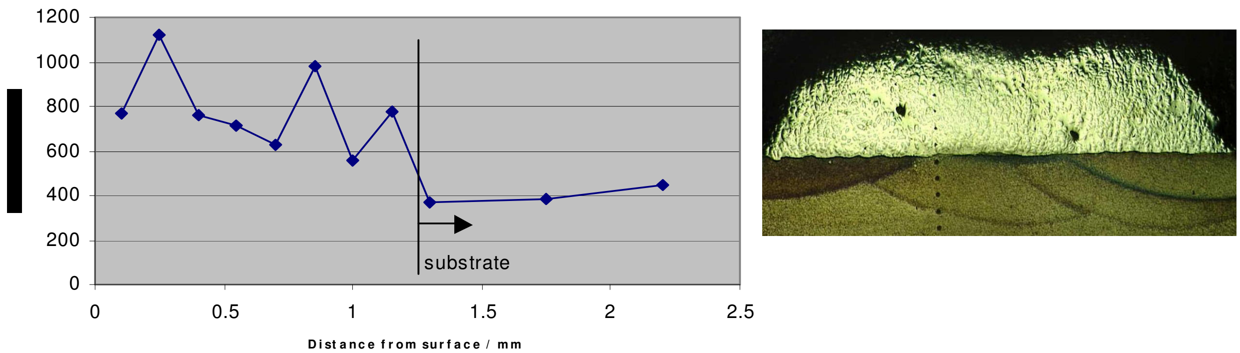


Figure 5; Graph of Hardness of WC + Ni base binder material laser hardfaced onto a cast Fe substrate.

The Figure 5 shows a layer of Ni-alloy cladding material impregnated with WC Particles. The laser beam does not melt the WC thus they retain their properties. Applications such as agricultural foraging systems, i.e., cutting blades and shear bars benefit from this technology. The present method of hardfacing some of these components is Plasma Transferred Arc (PTA). With this process distortion and cracking are common.

CONCLUSIONS

Lasers are increasingly finding successful industrial applications in many aspects of re-manufacturing engineering wear part components

Laser hardfacing presents clear advantages for the repair of Ni, Co, and Fe-base substrates over GMAW, GTAW, PAW and other welding processes. It produces little distortion and results in high quality coatings. Because the process is an additive one, repairs and modifications to industrial engineering wear components are now achievable where before such components would have been made redundant because there was not a weld repair service available.

Reduced post-processing requirements and increased TRT (turn around times), increased quality part, and increased component lifetimes, are all benefits of the laser hardfacing process.

Cork-based LaserAge is currently developing a transportable Laser hardfacing unit for *on site* and *in situ* repair service. “Laser hardfacing is a cost cutting, strategic material saver and consequently, a green technology,” says LaserAge MD, Leo Sexton Laser. “Hardfacing has found its rightful place in the manufacturing/repair sector, bringing huge cost benefits to any number of sectors by extending the life of components and slashing repair costs. The technology has evolved into being a very versatile and complementary manufacturing tool which we can provide for businesses in every sector.”

LaserAge offers extra protection and longer life to engineering components in the Aerospace, Injection Mould, Transportation, Mining, Agriparts and Power Generation Industries by **Laser Hardfacing** (Laser Cladding). If you want to know more about this subject then please go to www.laserage.ie or contact LaserAge on 00 353 (0) 21 4899 723.