LASER HEAT- TREATMENT

Mohammed Naeem
mnaeem@gsig.com

SUMMARY

The high power heat source produced by a laser beam is ideal for surface modification. Laser heating produces local changes at the surface of the material whilst, leaving the properties of the bulk of a given component unaffected. The principle laser surface engineering applications can be divided into three broad areas (Figure 1). The following processes can also be divided into those relying on metallurgical changes in the surface of the bulk material i.e. transformation hardening, annealing, grain refining, glazing and shock hardening, and those involving a chemical modification to the surface by addition of new material i.e. alloying and cladding.

Heating without melting, commonly know as heat-treating. This involves solid-state transformation, so that surface of the metal is not melted. The fraction of the beam power absorbed by the material is controlled by the absorptivity of the material surface. Both mechanical (hardness, abrasion, resistance etc.) and chemical properties, (corrosion resistance etc.) can often be greatly enhanced through the metallurgical reactions produced during these heating and cooling cycles.

Heating with melting, i.e. laser glazing, surface homogenization, remelting. This method produces very rapid heating and melting and cooling to modify the surface properties.

Melting with addition of material, i.e. cladding, alloying impregnation, which involves melting of the surface plus material added to the surface to form a modified surface layer.

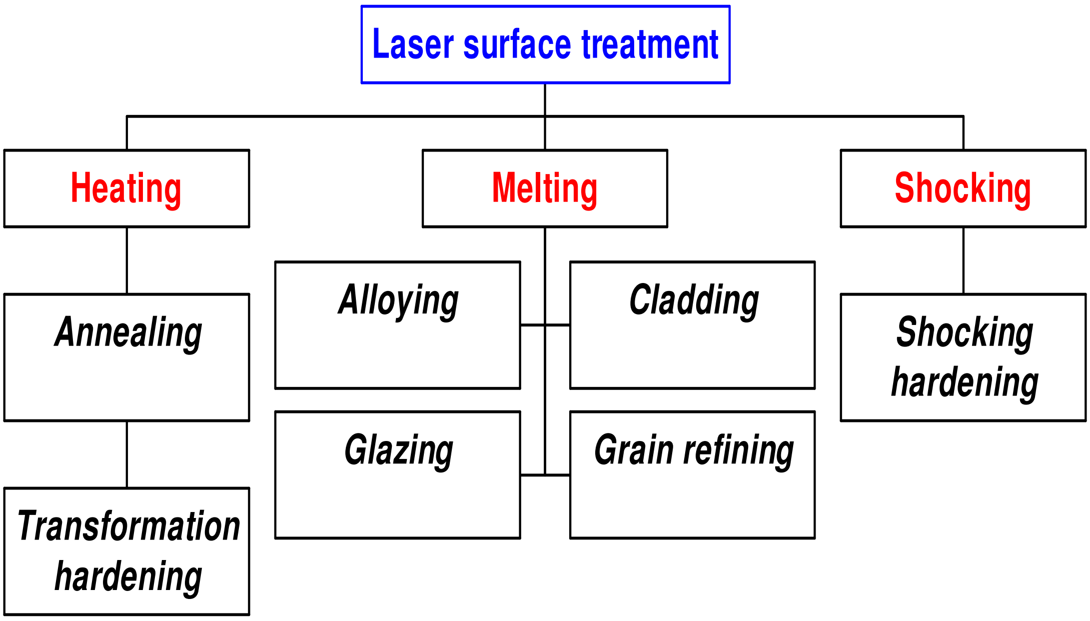


Figure 1: Methods of laser surface treatment of materials [1]

1. INTRODUCTION

The material of an engineering component has to exhibit properties that are often a compromise between those necessary for the bulk of the component, and those required at the surface. The modification of the surface of a component by heat treatment or surfacing techniques provides a solution to the compromise, allowing the specification of the bulk material to be dictated by strength or economic constraints, and the surface only to be tailored for wear, corrosion resistance or other properties desirable for its service use. Currently there are a wide range of techniques for surface modification are available [2] i.e.

- **Thermal treatments**
  - Induction hardening
  - Flame hardening
  - Laser hardening
  - Spark hardening
  - Electron hardening

- **Thermochemical diffusion treatments**
  - Carburising (gas, liquid, pack)
  - Carbonitriding (gas, liquid)
  - Nitrocarburising (gas, liquid)
  - Nitriding (gas)

- **Mechanical treatments**
  - Peening
  - Fillet rolling

Laser beam technology has led to the possibility of localized modifications to the microstructures of a range of materials. Such modifications can lead to improved service properties in the surface layers of a component, while leaving the bulk properties essentially unchanged. There are number of mechanisms by which these changes can be brought about, but all depend on the ability to manipulate the laser beam accurately, and on the high power density of the beam. The common advantages of laser surfacing compared to alternative processes are:

- Chemical cleanliness and cosmetic appearance
- Minimal heat input, since the source temperature is so high, transformation occurs so quickly and the heat input to the part is very low. This reduces the distortion and the heat-affected zone is very small.
- No post machining required
- Non-contact process
- Ease of integration

2. LASER HEAT TREATMENT PRINCIPLES

The principles of laser heating are similar to those of conventional through heating. The time scales involved in the former are, however, typically an order of magnitude shorter. Whereas heating is conventionally induced by a furnace, flame, arc or induction coil, the laser beam is focused or shaped into a suitable pattern and scanned over the component. The high energy density laser beam heats the surface much more rapidly, reducing the time for conduction into the bulk of the component. Laser heat treatment and surfacing techniques must complete directly with a wide range of comparatively low cost conventional processes and must therefore offer significant advantages.

The laser emits a beam of energy, in the form of either continuously or pulsed. The power of the beam and the diameter of the focused laser beam can be combined to give one laser parameter, the ***power density.*** The second and other parameter of laser treatment is the rate at which the power density is moved across a surface. This is often expressed as the interaction time, i.e. the length of time that the laser beam is focused on any one point on the surface. Figure 2 shows a range of laser material processes that can occur at different power densities and interaction time [3] and Figure 3 shows a modified version representing only the heat treatment processes [4].

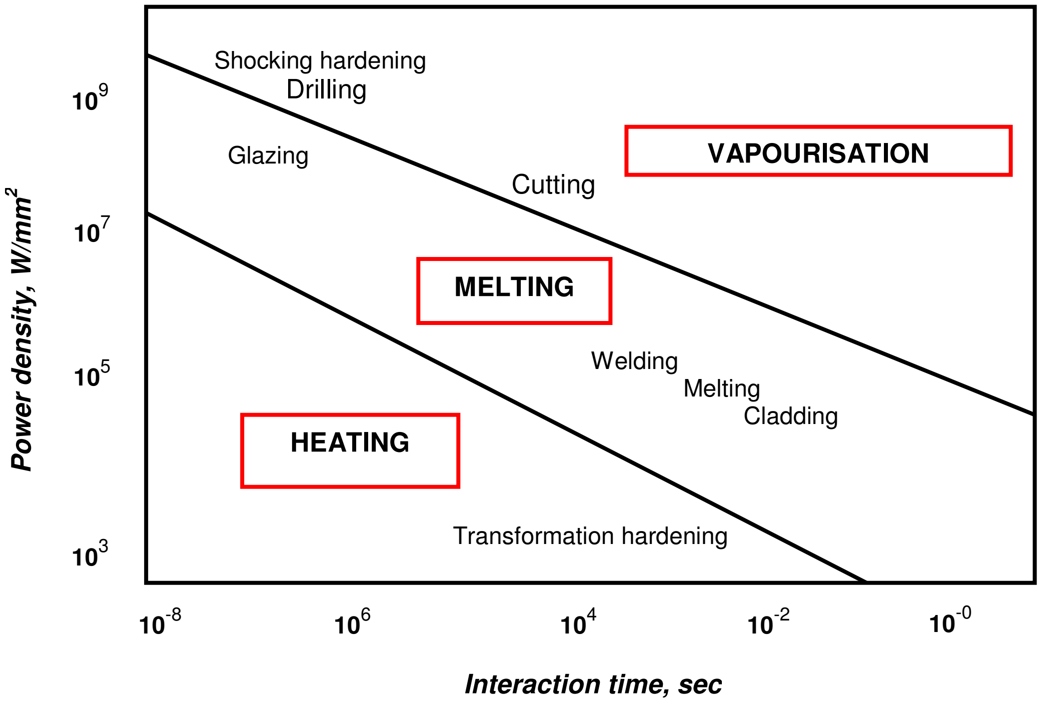


Figure 2: Range of laser processes mapped against power density and interaction tine

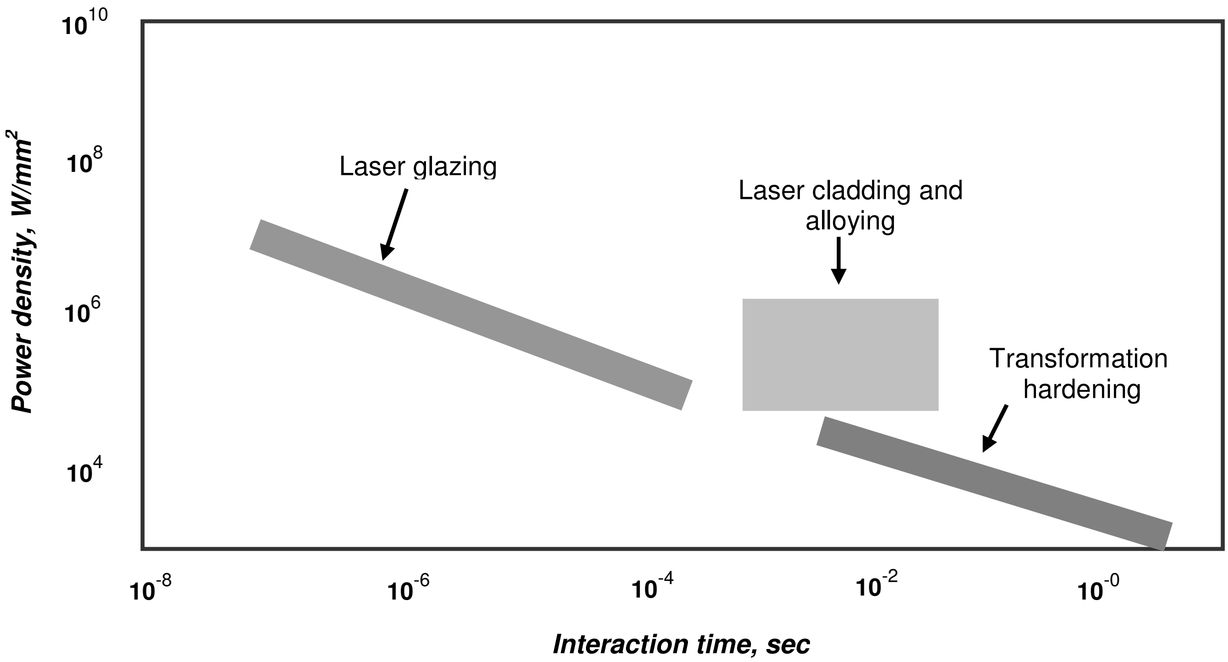


Figure 3: Laser heat-treating regimes

Materials of high hardenability may be processed with lower power density and a higher interaction time, in order to achieve a homogeneous case with significant depth. Materials with low hardenability are processed with higher power density and lower interaction times in order to generate the rapid cooling rates required for martensite formation at expense of a shallower case.

2.1 Laser sources

Currently four different type of laser sources i.e. CO_2, lamp and diode pumped Nd: YAG and high power diode lasers are being used for laser heat- treatment applications. Until about 10 years ago, only CO2 laser beams were able to deliver the combination of power density and interaction time necessary for laser heat treatment. The development of multikilowatt Nd: YAG lasers with both flashlamp and diode pumping provide an alternative source, with several advantages. One of the main advantage of the Nd: a YAG laser source is that the wavelength of the laser light (1.06µm) allows the beam to be delivered via an optical fiber with relatively small energy losses. This allows flexible delivery of the laser beam at the processing head. Consequently, Nd: YAG lasers providing high levels of laser power can be manipulated using robot (Figure 4), making them ideal for three- dimensional processing.

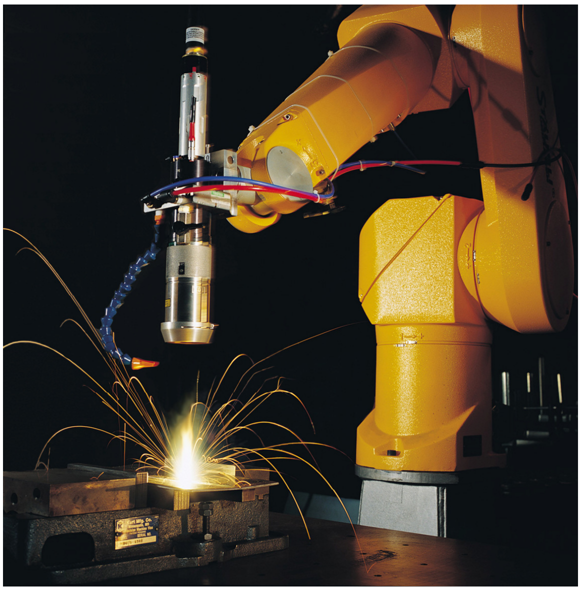


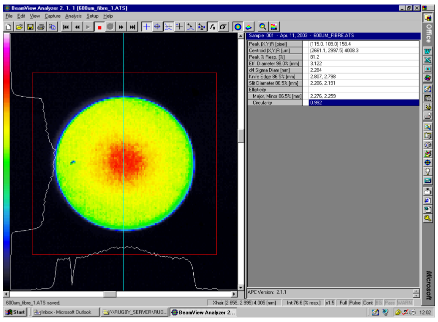
Figure 4: Fiber optic cable with output housing mounted on a robot.

As the beam wavelength decreases i.e. 1.06µm compared to 10.6µm for CO_2 laser, the absorptivity of metal surfaces increases, and so an absorptive coating is no longer necessary, thus simplifying the operation considerably. More recently, multikilowatt diode lasers have been developed with wavelength of 0.8µm, which are compact and can be mounted directly on a robot for hardening of complex geometry components.

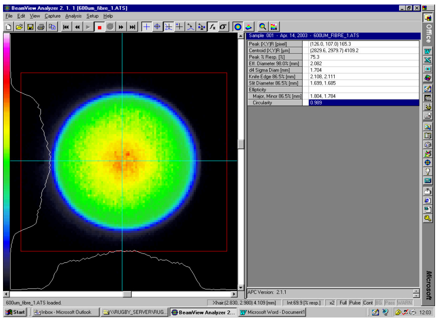
2.2 Beam shape

A round beam is often used for hardening with CO_2 and Nd: YAG laser beams. This is created by simply defocusing the beam, and is a satisfactory solution for many engineering applications. The depth profile of hardened region can be approximated as the mirror image of the beam intensity distribution, with reduced amplitude and some rounding of the edges resulting from lateral heat flow. Figure 5 shows beam profile of fiber delivered continuous wave (CW) Nd: YAG laser.

By using beam shaping optics, the shape of the hardened sections can be varied and may be possible to harden with higher coverage rates. If a uniform depth profile of constant width is needed, a kaleidoscope is the cheapest solution.



At end of fiber



At focus

Figure 5: Beam distributions

3. PROCESS PARAMETERS

Shield gas

Shield gas serves two functions in laser heat treatments. It shields the heated/melt zone from oxidation and also protects the focusing optics from the fumes. Argon and nitrogen shield gases are normally used and typical flow rates are around 20l/min. The flow rate will depend on the method of shielding and also diameter of nozzle that is being used to deliver the gas.

Feed rate

The length of the beam in the travel direction is fixed by the power density and track width requirements. A power level in the range 1-4kW is normally used. A high power enables high feed rate (Figure 6) to be used, with correspondingly high coverage rates. However, the practical range that can be used considerably as risk of both overheating, leading to surface melting or an insufficient peak temperature with no hardening. Feed rate is the variable that is normally changed when fine-tuning the process in order to achieve the required hardened depth and degree of homogenization.

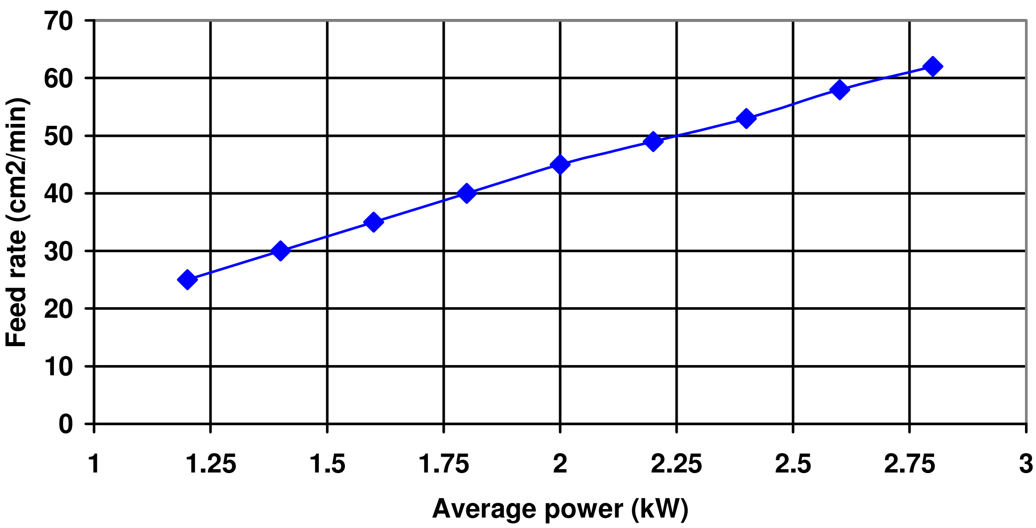


Figure 6: High power CW Nd: YAG laser transformation hardening (1045 steel, 0.5mm case depth)

4. MATERIALS

The range of alloys that can be transformation hardened by laser techniques covers all those than can be hardened by conventional methods. The response of steel to hardening increases with increasing carbon content, and hardness values have exceeded 700HV for steels containing 0.75% carbon content. In addition because of the high cooling rates plain carbon steel (0.2%C) will harden.

The hardenability of cast irons is controlled by the amount of pearlite present, and only martensitic stainless steels will respond to heat-treating.

In recent years, GSI Group has undertaken a number of projects with various customers to understand laser heat treatment with CW Nd: YAG laser. Work has centred on high average power (500W-2000W) continuous wave (CW) lasers and some of the results are presented in the following section.

A summary of the surface treatment conditions used and results achieved with different power levels and processing speeds on transformation hardening of low carbon steel is presented in Table 1. For low carbon steel using a 5mm spot diameter, the minimum speed at which transformation hardening without melting could be achieved was 0.5m/min. Transformation hardened sections displayed a primarily martensitic structure with some bainite and had a typical micro hardness of about 740 $HV_{0.2}$. The initial trials on transformation hardening using al 4kW CW laser have extended the processing capabilities (Table 2) in terms of transverse speed when compared to 2kW CW laser. The minimum speed at which transformation hardening could be achieved was 3.5m/min. A micrograph of sample produced at this speed is shown in Figure 7, which shows a maximum treated depth of 0.7mm. The maximum hardness in the laser treated zone was measured at 755 $HV_{0.3}$ (6mm spot diameter, 4.5m/min) compared to a parent material valve of $300HV_{0.3}$.

Table1: Transformation hardening results (low carbon steel)

Power kW	Spot size mm	Speed m/min	Hardened area		Hardness $HV_{0.2}$	Surface conditions
			Width (mm)	Depth (mm)		
1.7	5	4	2.7	0.2	540±30	Uncoated
1.7	5	1.5	4.5	0.7	613±31	Uncoated
1.7	5	1.5	5.1	0.7	582±20	Graphite coated
1.7	5	0.5	6.25	0.6	742±43	Uncoated
1.3	5	1.5	3.5	0.6	593±10	Uncoated
1.3	5	1.5	4.2	0.5	751±57	Graphite coated
1.3	5	1.1	4.2	0.7	640±35	Uncoated
1.3	5	1.1	4.5	0.8	770±92	Graphite coated
1.3	5	0.5	5.1	1.3	651±22	Uncoated

Surface condition affected the size of the hardened area of the samples. At the same processing parameters, the graphite coated sample tended to show more surface melting than uncoated samples. This is to be expected owing to the higher absorptivity of the coated surface and the effect of carbon on the melting point of steel. At the same processing speed, the hardened zones were generally wider but not that much deeper in the coated samples. The samples were coated to assess the effect of surface conditions rather than the possibility of alloying the steel with carbon. In general, with CO_2 samples are always coated to improve the absorptivity.

Table 2: **Transformation hardening results (low carbon steel)**

Power kW	Spot size mm	Speed m/min	Hardened area		Hardness HV $_{0.3}$	Surface conditions
			Width (mm)	Depth (mm)		
3.0	6	5	6	0.5	746±20	Uncoated
3.0	6	4.5	6	0.5	755±9	Uncoated
3.0	6	4	6.25	0.62	752±31	Uncoated
3.0	6	3.5	6.5	0.7	697±40	Uncoated
3.0	6	3	6.5	0.8	750±35	Uncoated

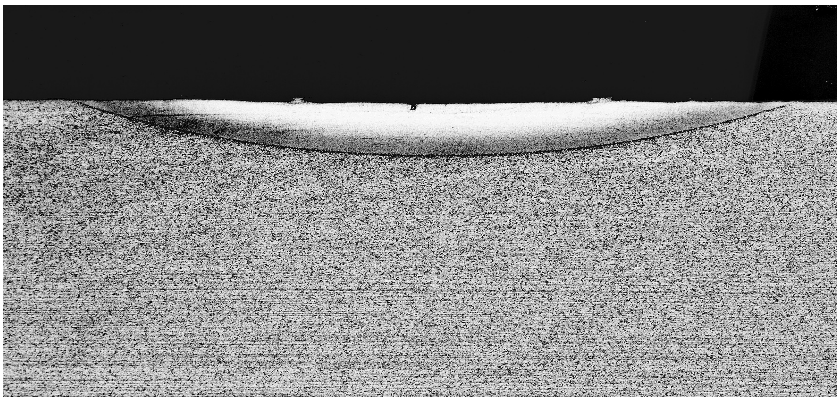


Figure 7: Transverse section of laser hardened track in low carbon steel 3.5m/min, 6mm spot size

5. APPLICATIONS

Automotive and machine tool industries have been responsible for much of the laser heat-treatment process development and some of the applications are listed in the Table 3.

Table 3: Few industrial application of laser transformation hardening

Industry sector	Component	Material
Automotive	Axel bearing seat	AISI 1035 steel
Automotive	Blanking die	Tool steel
Automotive	Engine valve	Alloy steel
Automotive	Gear teeth	Steel
Automotive	Shaft	Steel
Automotive	Piston ring	Steel
Automotive	Steering gear housing	Malleable cast iron
Domestic good	Typewriter interposer	AISI 1035 steel
Machine tools	Cutting edge	Steel
Machinery	Gear teeth	AISI 1060/ low alloy steel
Machinery	Mandrel	Martensitic stainless steel
Machinery	Press brake tools	Steel
Machinery	Tool bed	Cast iron
Power generation	Turbine blade edge	Grey cast iron
Railway	Diesel engine cylinder	Cast iron

6. SUMMARY

The availability of new laser sources, CAD software, process control equipment and understanding of the laser heat treatment process has resulted in a growth in a number of industrial applications. The principle laser surface engineering applications are summarized in Table 4.

Table 4: Summary of laser surfacing

Process	Laser type	Process description
Transformation hardening	CO_2 and Nd: YAG	Local hardening, with case depth up to 2mm
Cladding	CO_2 and Nd: YAG	Deposition of a second material onto surface
Surface alloying	CO_2 and Nd: YAG	Local alloying to change the surface properties
Shock hardening	CO_2 and Nd: YAG	Produce hardened surface layer by using pulses of laser energy
Surface homogenization	CO_2 and Nd: YAG	Alter the microstructure by remelting

7. REFERENCES

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