Case hardening with direct diode lasers

Case hardening is used in many industries to improve the wear characteristics and extend the lifetime of steel parts, such as cutting tools and bearing surfaces. Laser heat treatment is one of several selective hardening techniques, the CO_2 laser performing this task in niche applications for over 30 years. However, in the past few years the high power direct diode laser has emerged as a viable alternative source with broader applicability.

Case Hardening

For industrial case hardening, the goal is to transform a thin outer layer of steel into martensite, so as to produce a hard-wearing, long-life surface. Because hardening is typically performed after a part has been dimensionally formed, it should ideally not introduce any physical distortion of the part shape. Typical products which are case hardened include bearing surfaces, cutting tools, pump parts, valve seats and sealing surfaces, drive train components, gears and cams, forming tools, stamping dies, turbine blades, locks, and hand tools.

Steel is an alloy of iron and carbon. At room temperature it typically exists in a relatively low carbon content form known as ferrite, but at high temperature it changes its crystalline structure and can accept a higher concentration of carbon atoms; this form is called austenite. If cooled slowly, the material rejects the excess carbon atoms and recovers its original form, but if the steel is cooled rapidly (quenched) the excess carbon can be trapped in a normally metastable, high carbon form termed martensite. The presence of the excess carbon distorts the normal crystalline structure of steel, making the strained lattice very hard.

Material	Maximum Hardness (Rc)	Maximum Depth (mm)
Carbon Steels		
1080	68	2
1075	68	2
1045	60	1.5
1030	50	0.75
Heat Treatable Alloys		
4140	68	2
4340	68	2
Heat Treatable Stainless Steel		
420	65	1.6
410	50	0.5
Cast Irons		
Gray	65	1
Ductile	55	0.75

Table 1. Maximum case depths and hardnesses that can be achieved using a diode laser on a variety of metals. Actual results depend on carbon content and part geometry. Maximum Depth and Hardness can not always be achieved simultaneously

Selectively hardening by diode laser

(a) saw blade tooth tip

(b) drive face of gear teeth

(c) camshaft lobe showing selective hardened outer layer of lobe

In laser case hardening the laser beam is absorbed close to the surface, causing rapid highly localized heating. Depending upon the particulars of the part size, shape and material, the bulk heat capacity of the part typically acts as a heat sink for the extraction of heat from the surface, therefore enabling self-quenching.

Laser Hardening Advantages

The ability to precisely control the physical extent of the illuminated region together with the short timescale of energy transfer into the material give rise to the main benefits of laser surface modification: rapid processing, precise control over case depth and minimal part distortion. In some cases, laser processing produces a hardened layer with a smaller grain structure and superior wear resistance and/or improved fatigue strength. Maximum case depths and hardness that can be achieved using the latest diode laser system are listed for a variety of metals in table 1.

Laser heat treating has a particular advantage over other processes if the part has a specific, limited surface area that needs to be case hardened, or is so large that it is cost prohibitive to heat treat by conventional means. The figure shows several examples of parts selectively hardened by a diode laser.

Laser hardening is inherently suited to a one piece flow, making it well suited and easier to integrate into the Lean manufacturing environment; in contrast to the majority of heat treatment processes that are batch in nature.

High Power Diode Laser Benefits

A significant advantages of direct diodes over CO_2 lasers derives from the output wavelength. Whereas parts have to be painted with an absorptive coating for heat treatment with the 10.6 μm output of the CO_2 laser the shorter (~ 1 μm) wavelength of the diode lasers is more efficiently absorbed, so eliminating the need for surface treatment chemicals and environmental compliance issues.

For the majority of laser hardening applications, the laser beam is scanned in order to achieve total coverage. For this, a CO_2 laser the beam must be expanded and homogenized whereas the diode laser naturally outputs a homogeneous beam that is well matched in size to many hardening tasks and which can be readily shaped to match the requirements of a specific task.

The higher electrical efficiency of the direct diode laser, its instant "on" capability and reduced maintenance costs, all translate into lower operating costs than a CO_2 laser. The smaller size of the direct diode laser also has advantages over the CO_2 laser in ease of integration.

As a result of all the improvements that the direct diode laser has brought laser heat treatment has become an increasingly attractive proposition for many hardening applications.

Maximum case depths and hardness that can be achieved using the latest diode laser system are listed for a variety of metals in the table.

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