For some, the thought of using lasers for heat treating may seem a bit too high-tech, but the following article outlines its many benefits in a wide variety of applications.

Laser heat treating advances for the gear industry

By Joel DeKock, Ph.D.

Laser technology has been used for many years with much success in industries such as power generation, hydraulics, hand tools, and machine tools. Showing great promise for the gear industry, laser heat treating is an emerging trend, especially for a gear manufacturer who needs short runs, specials, or limited treatment requirements. Benefits include lower tooling costs, low heat input, the ability to treat special features or hard to reach areas, and less tuning and set-up time required.

Laser heat treating is the most common process in the group of surface modification techniques that include alloying, glazing, and cladding. "Heat treating" could imply a number of processes common to metallurgical practice. We will focus on the transformation hardening process using lasers to produce changes in surface properties.

What Does Laser Heat Treating Do?

Light produced by a laser is an industrial tool. Light is directed to the workpiece using optics, which cause materials to heat, melt, or vaporize. Laser transformation hardening is performed using low average power densities that heat a specific area without melting the surface. Because lasers are readily integrated into CNC machinery, the amount and placement of laser energy can be very accurately controlled.

Laser heat-treating utilizes High Power Direct Diode Lasers (HPDL), Carbon Dioxide (CO2) lasers, and Continuous Wave Neodinium:Yttrium-Aluminum-Garnet (CW Nd:YAG) lasers to provide energy to heat the surface of metallic materials. Lasers differ in their physical construction, beam delivery technology, and in the wavelength of the light (beam) produced. Direct Diode and Nd:YAG lasers are better absorbed by irons and steels than are CO2 lasers. When light impinges on a clean metal surface, energy is both absorbed and reflected. Lasers have relatively low absorption efficiencies, but today it is a common practice to improve absorption of the incident light to 80 percent or better by applying coatings, compared to 35 to 40 percent absorption without coatings.

Coatings

Typical coatings include paint or inks containing carbon black or graphite, oxyacetylene soot, oxides, and phosphates. Coating thickness is carefully balanced because thick coatings may produce inconsistent depth, and coatings that are too thin do not adequately enhance absorption. Phosphate and carbon coatings tend to provide the most consistent results.

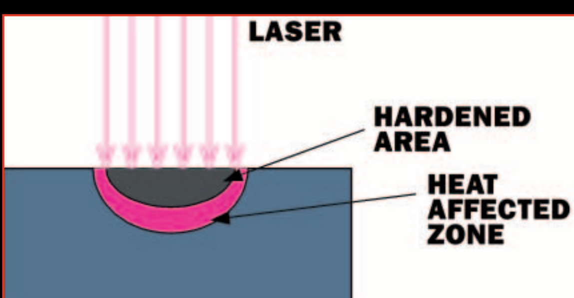

Figure 1 — Cross-section view of material response to laser heat treating

How Much Power?

Another factor in the laser heat treating process is power intensity. When heat treated material absorbs the beam, the beam intensity must be powerful enough so that the energy absorbed is greater than the energy conducted away. Power intensity (watts/area) used to perform laser heat-treating is generally between 500 and 5000 W/cm2.

If you shape a laser beam to produce a nearly square beam of light, as shown in Figure 1, material under the beam is affected by the laser energy, resulting in two heat-affected regions: the hardened case, and the heat affected zone. When the energy into the material under the beam is greater than the energy out, the result is a rapid increase in temperature near the surface. In the case of irons and steels with sufficient carbon content, rapid heating to a temperature above the austenitizing temperature followed by rapid cooling results in a hardened layer, or "case," at the material surface with a very small heat affected zone.

Benefits of a Self-Quenching Process

A more efficient and faster cooling process than external quenching is self-quenching. The laser heat treating process is often self-quenching. Some laser-hardened components have sufficient mass to be self-quenching and don't need external quenchants such as water and oils.

The efficiency of self-quenching becomes evident when treating materials otherwise considered non-heat treatable. Steels with as little as 20 points of carbon (i.e. 1020 steel) can be treated to provide a case with a hardness in the 45-50 Rc range.

Case Depth

One can predict case depth produced given the operating parameters and appropriate equations for heat flux. O. Sandven, in his Metals Handbook regarding Laser Surface Transformation Hardening, provides an excellent technical discussion on how case depth can be calculated and on the process in general. Lower laser power densities require longer dwell times to produce the same case depth achieved at a higher power density. Note that if there is insufficient mass available to provide self-quenching at low power densities, full case hardening may not occur if the hardenability of the material is marginal. Then you'll need external quenchants, or you will need to change to a material of higher hardenability.

Table 1 lists common materials and responses to laser heat treating. Responses are very similar to those of other processes; the laser hardening advantage is that the process is effective with as little as 20 points of carbon. Laser heat treating is best suited to materials with fine grain structures such as austempered and quenched and tempered material since laser heat-treating is very fast. In contrast, the coarse microstructures of cast irons or steels are sluggish in response to laser heating due to the nature of the material.

Laser Heat Treating Can Benefit Your Business

Laser heat treating offers the following advantages:

- No special environments are required
- External quenchants are usually not needed
- A clean process with minimal part distortion due to very close control of a minor amount heat input to the part
- The beam can be shaped using focusing optics to heat-treat very specific areas. All that is required is line-of-sight access to the area that requires improvement.

Since laser heat-treating is performed within the shop environment without external quenchants, lower consumable costs are realized. Post-processing costs are lower due to minimal distortion as a result of the low heat input. Surface damage such as decarburization is avoided. The only environment control typically required is adequate exhaust to remove smoke from contaminants or coatings. Quenchants are only employed when deep cases are required, or if treating materials of poor hardenability.

What Kinds of Industries Can Benefit from the Process?

Like other heat treating methods, laser processes improve material performance by changing wear resistance strength. Often lasers are used in transformation hardening, but they can also be used to temper or soften material. Gear industry applications commonly suited to laser heat treating include gears or sprockets, keyways, bearing journals, splines on shafts, bearing races, and contact points. Non-gear applications are engine cylinder liners, extrusion dies, ball studs, couplers, valves and seats, and hand tools. Lasers are versatile because the base material is not affected past the treatment zone, and the toughness and strength of the materials are retained.

Figure 2 shows sections of a large shaft treated on both a bearing journal surface and the end splines. The base material is an AISI 1026 equivalent cast steel. In this case treatment was

Table 1 — Relative hardening response of common materials

Relative Hardening Response to Laser Heat-Treating

Excellent	Good	Poor
Medium Carbon Steels	1020 Steel, High Carbon Steels	1010 (Low Carbon) Steel
Low Alloy Steels	Ferritic Cast Irons	Austenitic Stainless Steels
Pearlitic Cast Irons	Tool steels	Wrought Iron
	Martensitic stainless steels	Non-Ferrous Materials

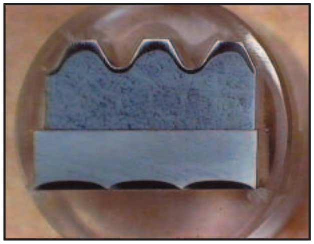

Figure 2 — Cross-section samples from a large shaft. Laser heat treated for general wear improvement. Upper sample from splined end of shaft. Lower sample from a bearing journal surface.

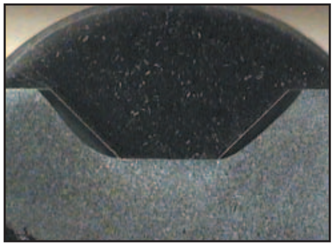

Figure 3 — Cross-section sample of a bearing race that has been heat treated. Only the bearing surfaces have been treated to improve wear with minimal distortion

Figure 4 — Specialty valve laser heat treated to a controlled depth. Treated without overlap by moving laser beam at high speed.

performed by a beam with an overlapping spiral pattern. Improvement in wear resistance increased product life by 600 percent.

Figure 3 shows a laser treated bearing race, which is part of a split ring assembly. The design lends itself to laser treatment because the ring can be disassembled for treatment. The material treated is AISI 1060. With a split race, the laser starts and stops off the part, and thus overlap tempering is not an issue since each half of the race is treated independently.

Figure 4 shows a specialty valve. The material treated is AISI 52100, and the valve seat is treated by spinning the beam around the seat at approximately 10,000 rpm to keep the material at temperature. The benefits of this approach include no temper zone created by start/stop overlapping, and it is much safer to move the laser beam than it is to have the part in motion.

The Beam Scanning Process

Lasers are ideally suited to local area hardening applications and can harden large areas by using different beam scanning techniques. For example, when scanning the beam with side-by-side passes, the beam can overlap the previous pass or leave a space between passes. Either way, a narrow "soft" area is present between the passes. Scanning techniques can also produce continuous cases without soft zones for smaller parts such as valves and seats. By carefully controlling the power and the dwell (exposure) time, case depths from a few thousandths to over 0.100" can be produced.

Laser Equipment

With the introduction of economical CW Nd:YAG and HPDL lasers over the last five years, there is considerable interest in laser heat-treating because of integration flexibility and the potential lack of coatings required to enhance energy absorption.

CO2 Lasers

CO2 lasers are popular for some applications because of the following:

- Proven technology is available to apply them
- Purchase costs are lower
- There is an availability of lasers at higher powers
- The technology is more mature

CO2 lasers are readily available in powers up to 12 Kilowatts. Many optic choices for shaping beams are available for a CO2 laser, but the most common is a square- or rectangular-shaped beam. For example, a square integrated spot 1cm in size on 1044 steel will produce a case .9mm deep at a power and speed of 4600 watts and 75 inches per minute. A 0.2" diameter ball stud can be case hardened 0.02" deep in less than one second using only 350 Watts. Generally speaking, intensities in the high range are used to produce case depths of <1mm at speeds of >1.0 m/min, and lower range intensities are effective in producing case depth up to 2.5 mm in materials of good hardenability.

CW Nd:YAG and HPDL Lasers

A major benefit of CW Nd:YAG and HPDL lasers is that they have a very uniform power density across the beam, which allows them to be readily integrated. The light emitted can be shaped using relatively simple optics.

Since both Nd:YAG and HPDL lasers have nearly the same wavelength, their performances are similar. These lasers can be used without bothering with absorptive coatings because metals more readily absorb their near-infrared wavelengths. Like CO2 lasers, optics can be used to shape the light beam, but there are fewer options. These two laser types do have significant application differences. Nd:YAG (and CO2) laser light diverges very little when traveling through air and can be applied at extended working distances. HPDL light diverges very rapidly and must be used at short working distances. HPDL is seen as an attractive option because of reasonable purchase cost per watt output and the lowest operating cost of the three laser types.

Application Guidelines

Laser transformation hardening utilizes laser technologies to treat surfaces in a controlled process that is fast, clean, and efficient, and it is ideally suited to local area hardening and hardening of components with complex geometry. If an area provides line-of-sight access it can usually be treated.

There are some general guidelines for the types of components or material that can be laser heat treated:

- Small or thin components may need high power densities and short dwell times to avoid the use of external quenchants.
- High power lasers that deliver 3000 - 5000 W/cm2 of energy are necessary when heat treating medium carbon steels at high production rates. Depending upon the component and process, case depths from a few thousandths to over 0.1" can be achieved using power densities between 500 and 5000 W/cm2. Steels with as little as 20 points of carbon can be effectively treated.
- Materials with coarse structures, such as cast irons and annealed steels, require longer dwell times than austempered or quenched and tempered materials.

Shop-Floor Ready

If performed properly, laser transformation hardening produces a case that is superior in hardness and fatigue properties, typically one-to-two Rc points harder than other processes. With internal quenching, the case provides residual compressive stresses at the surface, which is effective in improving fatigue life. Laser transformation hardening is a sound and proven technology that is shop-floor ready.

ABOUT THE AUTHOR:

Joel DeKock, PhD, is the applications manager for Preco Laser Systems, LLC, which is located in Somerset, Wisconsin. Preco is a premier provider of laser systems and contract services, specializing in laser welding, heat treating, and cladding. DeKock can be reached at (800) 77-LASER (775-2737). Visit online at [www.precolaser.com].

REFERENCES

1. O. Sandven, Laser Surface Transformation Hardening, Metals Handbook, ASM, 9 Ed., Vol. 4, pp. 507-517.
2. M. Kikuchi, et al., The Influence of Laser Heat Treatment Technique on Mechanical Properties, Proceedings of the Laser Materials Processing Conference-ICALEO'81, Laser Institute of America, 1981.
3. Fly, et al., Low Power Laser Heat Treatment to Improve Fatigue Life of Low Carbon Steel, Proceedings of the Laser Materials Processing Conference-ICALEO'95, Laser Institute of America, Vol. 80, 1995.