Laser Heat Treating

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Current growth in the use of lasers to heat treat ferrous materials has come about as a result of an increasing awareness of the capabilities of lasers, the development of new laser technology and the successful application of this technology.

Lasers have progressed from a laboratory curiosity to an industrial tool. Most of today's industrial lasers output infrared light in the form of a beam that is converted to heat energy when it interacts with a material being processed. Cutting and welding laser systems use highly focused beams having power densities in excess of 10^6 W/cm^2 to quickly melt and vaporize metals. Because these two industrial applications total nearly 95% of all laser systems sold, the use of lasers for surface modification often is overlooked.

Surface modification applications include surface alloying, cladding, annealing and transformation hardening of materials. Unlike cutting and welding, most surface modification techniques are performed using beam power densities in the range 10^3 to 10^4 W/cm^2. At these intensity levels, surface heating or shallow melting occurs. Surface transformation hardening of ferrous materials using lasers typically is performed to improve wear characteristics and/or fatigue properties of parts.

Laser heat treating of a cast iron cylinder

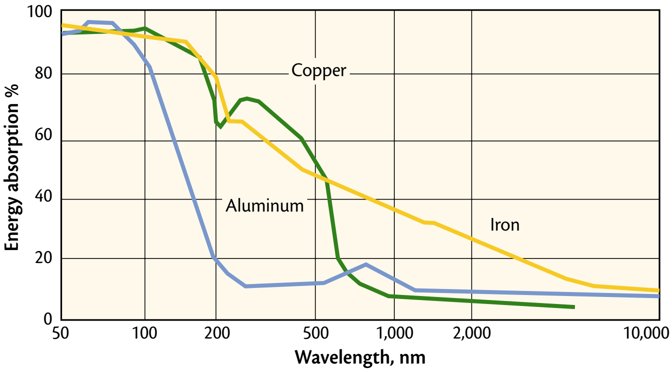

***Fig 1** Absorption vs. wavelength at room temperature for iron, aluminum and copper. Source: Ref 1.*

Because the laser light beam is finite in size, the process is ideally suited to perform specific localized area treatment. It is essential to have line-of-sight access to treat a surface. Controlled heat input, self-quenching of parts, no need for special atmospheres and process cleanliness are some advantages of laser hardening technology. In addition, these attributes often translate into reduced costs because of lower distortion and lower use of consumables.

Laser-treating mechanics

In laser processing, such as using laser energy to heat metals, laser light is directed to the workpiece resulting in absorption and reflection of light. Absorption by metals is highly dependent on the wavelength of light, material type, angle of incidence and surface condition. Figure 1 shows that, in general, the shorter the wavelength, the better light is absorbed.

Lasers used for heat treating have wavelengths that fall between 800 and 10,600 nm. Over this range of wavelengths, iron has nearly a fourfold increase in absorption. Because of such poor absorption at longer wavelengths, it is necessary to modify the surface condition of a part to efficiently absorb light. This can be done by roughening the surface, but the most common method is to apply an absorptive coating such as paints, inks, phosphates, oxides and oxyacetylene soot. Workpiece temperature also affects absorption in favor of laser heat treating. Results show that using a wavelength of 1,060 nm, absorption by steel during laser heat treatment is approximately 60% and can be improved to 85% by the addition of a suitable coating. At 10,600 nm, absorption can exceed 70% when coatings are applied to a surface. Coating application can be automated and performed in the laser cell with little to no drying time, as in the case of paints, or it can be applied in advance. Because of costs associated with the application and removal of coatings, the shorter wavelength light sources are attractive to many users.

Figure 2 illustrates the interaction of light with steel to produce a hardened layer or case. Absorption begins at the leading edge of the "spot" and terminates at the trailing edge. The time period, or exposure period, generally is less than one second. The shape of the hardened zone varies with the shape of the spot and the energy distribution across the spot produced by the beam.

There are many methods that can be used to modify the beam [2, 3], but the most common spot shapes are circular and square. A circular spot produces a hemispherical- or meniscus-shaped hardened zone, while a square spot produces a relatively flat-based, or even, hardened zone. This is a result of the energy absorbed per unit area across the surface perpendicular to the direction of travel. An excellent treatment of the thermodynamics and kinetics of this process is given in [3].

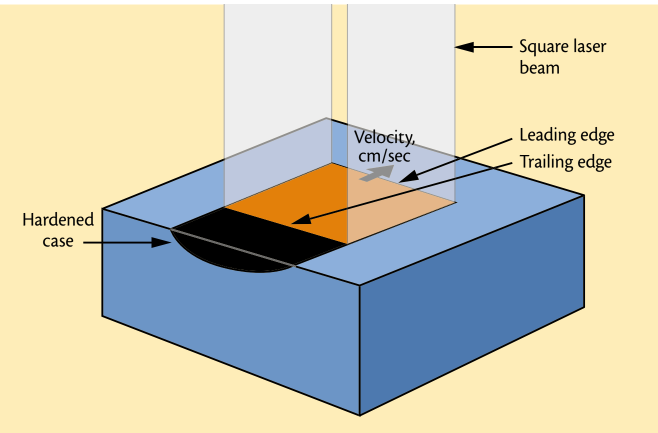

Fig 2 *Interaction between laser light and material to produce a hardened case.*

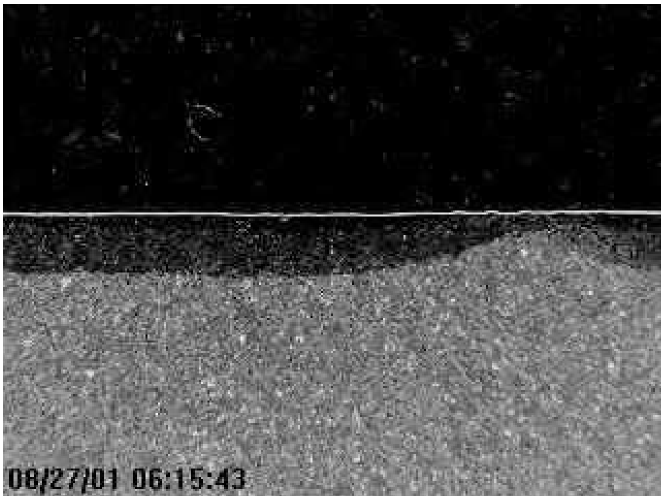

Fig 3 *Photomicrograph of a cross section of an iron-cylinder showing hardened-case profile and overlap region*

Because laser heat treating typically is performed without the use of an external quenchant, a good rule-of-thumb is that the case depth-to-section depth ratio should be approximately 1:10 for self- or internal quenching of most materials. This ratio is based on plain carbon steel of medium carbon content, and decreases with increasing hardenability.

Factors affecting treatment

The depth of the hardened zone is dependent on heat input, and can range between 0.01 and 0.1 in. (0.25 and 2.5 mm). Deep hardening requires longer exposure times and, therefore, requires closer attention to the possibility of surface melting. Because surface temperatures can exceed those typically used, caution needs to be exercised if secondary phases exist in the microstructure that could go into solution. Typical hardened depth is in the range of 0.02 to 0.04 in. (0.5 to 1 mm) for carbon steels and irons. Spot power densities in the range of 500 to 5,000 W/cm^2 are used to produce these depths of hardening. Therefore, a laser having 3,000 to 6000 W of average power is commonly used to produce a 0.4-in. (10-mm) wide hardened zone in carbon steels. Zones exceeding 0.75 in. (20 mm) wide are possible, but require either more laser power or a compromise in depth.

When using a laser to treat large surface areas, it is common to raster, or scan, the beam over the area to be treated. The resulting pattern is a series of hardened stripes separated by narrow tempered, or soft, zones. Manufacturers that use this practice specify between 10 and 20% soft area tolerated, or specify a minimum hardness in the overlap region between passes. In limited cases, it is possible to treat a surface without a soft overlap, but this requires high-speed beam manipulation and relatively small parts. In treating of shafts and cylinders, a spiral pattern is used to minimize start/stop overlap regions. Figure 3 shows a typical case produced in an iron cylinder sample.

In addition to the high speed at which lasers are able to harden irons and steels, high cooling rates permit transformation hardening of materials otherwise considered untreatable. For example, internal, or self-quenching, makes it possible to treat low carbon steels such as SAE 1117 and SAE 1020. In addition, with heat flux proceeding from the surface inward

Fig 4 *Photomicrograph of a cross section of a hardened zone in an SAE 1117 shaft. Maximum hardness is 47 HRC, with a hardness 41 HRC at a 0.5 mm (0.02 in.) case depth.*

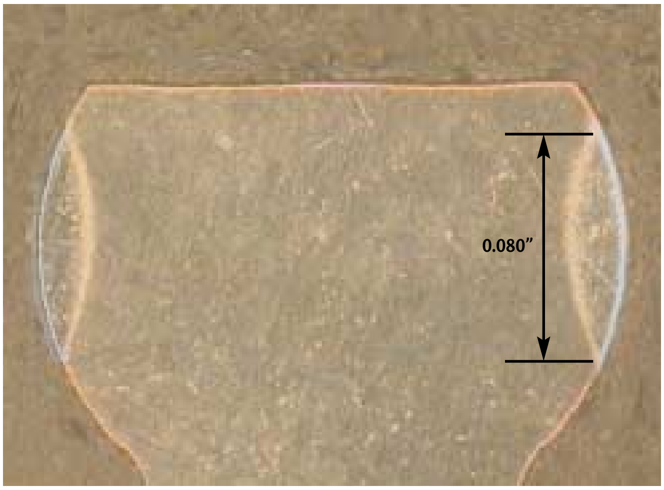

Fig 5 *Laser case-hardened SAE 4130 ball stud. Minimal heat input and precise placement results in no soft overlap and minimal heat effect on the original quenched and tempered microstructure.*

during quenching, transformation occurs from subsurface outward, producing favorable compressive residual stresses at the surface [4]. As a result, a 1 to 2 point higher hardness (HRC) commonly is reported for laser-treated materials.

The response of an SAE 1117 shaft to laser treatment is shown in Fig. 4. The sample has a maximum hardness of 494 KHN (47 HRC) within the case, and a hardness of 409 KHN (41 HRC) at a case depth of 0.02 in. (0.5 mm).

Fly et al. found a similar response to laser treatment in an evaluation of improved fatigue performance [5]. The fatigue resistance of standard SAE 1117 and SAE 1144 cold-rolled round stock improved as a result of the laser treatment, with 1117 showing greater relative improvement compared with 1144. This research also noted that fatigue resistance is further enhanced by decreasing the spacing between passes along the axis of the shaft.

While lasers are effective in hardening low-carbon steels, microstructure plays an important role. Materials having preexisting fine microstructures are ideal for laser treatment. A coarse microstructure similar to that found in annealed or spheroidized steels show poorer response due to the short cycle time and large distances over which to diffuse carbon. Ideal microstructures include those of quenched and tempered steels and austempered steels. Tools having these types of microstructures can be further enhanced by local area surface treatment to improve wear resistance precisely where needed.

Figure 5 shows a ball stud made of SAE 4130, which was quenched and tempered prior to laser treatment. Precise placement of a controlled amount of energy during laser treatment enhanced the performance of the part. Strength and toughness are not affected, which is evident in the resulting small or no heat-affected zone. With controlled heat input and rapid kinetics, it is rare to find significant heat effect of preexisting microstructures in laser-treated materials. Table 1 lists some common materials and their relative response to laser transformation hardening.

System basics

Three elements that make up a basic laser processing system are materials handling, motion and controls, and the laser light source. These system elements are not unique when considering many materials-processing cells used in industry today. Compared with prime competitors of laser technology, such as induction and flame hardening systems, the only fundamental change is the use of a laser for the energy source.

As with many other materials processing systems, materials handling is a major consideration in a laser-treating system. The issue is more than just getting parts in and out, as the economics of moving parts from one position to another can be a significant factor. From manual systems used in job shops to complete automation on the manufacturing floor, the cost of materials handling can exceed that of motion and control and the laser combined. When considering a laser system, it is important to determine as closely as possible what the laser "on-time" is for a particular product. The laser should be used to treat parts at a duty cycle of 75% or better. Because typical cycles range between less than a second to as long as 30 minutes, each application provides unique challenges.

Motion and control for laser systems often is more sophisticated than that required for competing technologies. Lasers are ideally suited to computer control, capable of being turned on and off in a matter of milliseconds. It is not unusual for

Table 1 Relative response of selected common materials to laser transformation hardening

Excellent	Moderate	Poor
Medium-carbon steels	Low-carbon steels	Spheroidized steels
High-carbon steels	Pearlitic cast iron	Ferritic cast irons
Low-alloy steels	Cast steels	

Table 2 Relative comparison of different lasers used for heat treatment

Laser type	Wavelength, nm	Absorption efficiency	Initial cost	Operating cost	Expected life
CO_2	10,600	Low	Low	Moderate	High
Nd:YAG	1,060	Moderate/high	High	High	High
HPDD	800	High	Moderate	Low	Low

Nd:YAG = Neodymium: yttrium-aluminum-garnet; HPDD = High-power direct diode

Specific localized area laser heat treatment of gray iron casting to 50 HRC at 1 mm (0.04 in.) depth

a laser process to be controlled to one-tenth of a second. Such accuracy requires close control of both of time and position.

Many cutting and welding systems are accurate to 0.001 in. (0.02 mm) and repeatable to 0.0005 in. (0.01 mm). Although most heat treating applications do not require such close control, the potential exists to treat parts smaller than the head of a pin with accuracy and repeatability. Besides providing exceptional control, laser hardening systems provide flexibility in that changeover to another product often can be performed simply by selecting a new program and exchanging tooling.

Selection of the type of laser, the third basic element of a system, can be difficult for those not familiar with the technology. The many available choices boil down to three basic technologies: carbon dioxide (CO_2) lasers, neodymium:yttrium-aluminum-garnet (Nd:YAG) lasers, and high-power direct diode (HPDD) lasers. The likely choice was CO_2 until as recently as five years ago. However, a wider choice due the commercial availability of both high-power Nd:YAG and HPDD lasers over the past several years has complicated the selection process.

Making an objective choice based upon effectiveness, cost and reliability is a difficult process. Lasers not only differ in type and wavelength, but also there are subtle differences between models and manufacturers. Table 2 provides a relative comparison of these three types of lasers, revealing that there is no clear choice of a best laser. Although some applications may be suited to more than one laser type, most applications will reveal a clear choice upon completion of the initial phase of process development and economic evaluation. If a laser is going to be new technology on your floor, implement the technology involving management, engineering, production and maintenance as a team. **IH**

References

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