DOWNLOAD PDF LASER SURFACE HARDENING

Chapter 1 : National Metal Processing | We've turned the science of heat treating into an art form

LASER SURFACE HARDENING of ferrous materials is an established process used to enhance the mechanical properties of highly stressed machine parts, such as gears and bearings.

History[edit] Discovery and development s [edit] Initial scientific discoveries towards modern day laser peening began in the early s as pulsed laser technology began to proliferate across the globe. In an early investigation of the laser interaction with materials by Gurgen Askaryan and E. Moroz, they documented pressure measurements on a targeted surface using a pulsed laser. Research into the phenomenon indicated the high pressure resulted from a momentum impulse generated by material vaporization at the target surface when rapidly heated by the laser pulse. Throughout the s, a number of investigators further defined and modeled the laser beam pulse interaction with materials and the subsequent generation of stress waves. Subsequently, this led to interest in achieving higher pressures to increase the stress wave intensity. To generate higher pressures it was necessary to increase the power density and focus the laser beam concentrate the energy , requiring that the laser beam-material interaction occur in a vacuum chamber to avoid dielectric breakdown within the beam in air. These constraints limited study of high intensity pulsed laser-material interactions to a select group of researchers with high energy pulsed lasers. In the late s a major breakthrough occurred when N. Anderholm discovered that much higher plasma pressures could be achieved by confining the expanding plasma against the target surface. With the overlay in place, the laser beam passed through the quartz before interacting with the target surface. The rapidly expanding plasma was now confined within the interface between the quartz overlay and the target surface. Laser shocking as a metallurgical process s [edit] The beginning of the s saw the first investigations of the effects of pulsed laser irradiation within the target material. Mirkin observed twinning in ferrite grains in steel under the crater created by laser irradiation in vacuum. These vacancies subsequently aggregated during post-iradiation annealing into the observed voids in nickel and dislocation loops in vanadium. In , the first documentation of the beneficial effects of laser shocking metals was published, reporting the strengthening of aluminum tensile specimens using a quartz overlay to confine the plasma. Air Force, and internally by Battelle. This research explored the in-material effects in more depth and demonstrated the creation of deep compressive stresses and the accompanying increase in fatigue and fretting fatigue life achieved by laser peening. The pulsed laser used by Battelle encompassed one large room and required several minutes of recovery time between laser pulses. In the early s, Wagner Castings Company located in Decatur, Illinois became interested in laser peening as a process that could potentially increase the fatigue strength of cast iron to compete with steel, but at a lower cost. Laser peening of various cast irons showed modest fatigue life improvement, and these results along with others, convinced them to fund the design and construction of a pre-prototype pulsed laser in to demonstrate the industrial viability of the process. This laser was completed and demonstrated in Although the technology had been under investigation and development for about 15 years, few people in industry had heard of it. So, with the completion of the demonstration laser, a major marketing effort was launched by Wagner Castings and Battelle engineers to introduce laser peening to potential industrial markets. Also in the mid s, Remy Fabbro of the Ecole Polytechnique was initiating a laser shock peening program in Paris. He and Jean Fournier of the Peugeot Company visited Battelle in for an extended discussion of laser shock peening with Allan Clauer. The programs initiated by Fabbro and carried forward in the s and early s by Patrice Peyre, Laurent Berthe and co-workers have made major contributions, both theoretical and experimental, to the understanding and implementation of laser peening. They demonstrate the detrimental effect of breakdown in water limiting maximum pressure at the surface of material. In , the U. The resulting tests showed that laser peened fan blades severely notched after laser peening had the same fatigue life as a new blade. Air Force made the decision to move forward with production development of the technology. GE Aviation began production laser peening of the F fan blades in The demand for industrial laser systems required for GE Aviation to go into production attracted several of the laser shock peening team at Battelle to start LSP Technologies, Inc. Through the late s and early s, the U. Air Force continued to work with LSP Technologies to mature the laser shock peening production capabilities and implement production manufacturing cells. The laser beam was introduced into the pressure vessels through articulated tubes. Because the pressure vessels were filled with water, the process did not require a water overlay over the irradiated surface. Also, it was impractical to consider using an opaque overlay. It began to be applied to Japanese boiling water and pressurized water reactors in Their work includes both experimental and theoretical studies using low energy pulsed lasers both without and with an opaque overlay. Researchers in many countries and industries undertook investigations to extend understanding of the laser shock peening process and material property effects. As a result, a large volume of research papers and patents were generated in the United States, France and Japan. In addition to the work being done in these countries and Spain, laser peening programs were initiated in China, Britain, Germany and several other countries. The continuing growth of the technology and its applications led to the appearance of several commercial laser shock peening providers in the early s. GE Aviation and LSP Technologies were the first companies performing laser peening commercially, having licensed the technology from Battelle. GE Aviation performed laser peening for its aerospace engine components and LSP Technologies marketed laser shock peening services and equipment to a broader industrial base. In Japan, Toshiba Corporation expanded the commercial applications of its LPwC system to pressurized water reactors, and in implemented fiber optic beam delivery to the underwater laser peening head. Toshiba also redesigned the laser and beam delivery into a compact system, enabling the entire system to be inserted into the pressure vessel. This system was ready for commercial use in [25] MIC developed and adapted laser shock peening for forming the wing shapes on the Boeing â€”8. The growth of industrial suppliers and commercial proof of laser peening technology lead to many companies adopting laser peening technology to solve and prevent problems. Some of the companies who have adopted laser peening include: In the s and continuing through present day, laser peening developments have targeted decreasing costs and increasing throughput to reach markets outside of high-cost, low volume components. High costs in the laser peening process were previously attributable to laser system complexity, processing rates, manual labor and overlay applications. Numerous ongoing advancements addressing these challenges have reduced laser peening costs dramatically: These reduced operational costs of laser peening have made it a valuable tool for solving an extended range of fatigue and related applications. It does not utilize thermal effects. Fundamentally, laser peening can be accomplished with only two components: The transparent overlay confines the plasma formed at the target surface by the laser beam. It is also often beneficial to use a thin overlay, opaque to the laser beam, between the water overlay and the target surface. This opaque overlay can provide either or each of three benefits: However, there are situations where an opaque overlay is not used; in the Toshiba process, LPwC, or where the tradeoff between decreased cost and possibly somewhat lowered surface residual stress allows superficial grinding or honing after laser peening to remove the thin thermally effected layer. The laser peening process originated with high energy, Nd-glass lasers producing pulse energies up to 50 J more commonly 5 to 40 J with pulse durations of 8 to 25 ns. The processing sequence begins by applying the opaque overlay on the workpiece or target surface. Commonly used opaque overlay materials are black or aluminum tape, paint or a proprietary liquid, RapidCoater. The tape or paint is generally applied over the entire area to be processed, while the RapidCoater is applied over each laser spot just before triggering the laser pulse. After application of the opaque overlay, the transparent overlay is placed over it. The transparent overlay used in production processing is water; it is cheap, easily applied, readily conforms to most complex surface geometries and is easily removed. It is applied to the surface just before triggering the laser pulse. Quartz or glass overlays produce much higher pressures than water, but are limited to flat surfaces, must be replaced after each shot and would be difficult to handle in a production setting. Clear tape may be used, but requires labor to apply and is difficult to conform to complex surface features. The transparent overlay allows the laser beam to pass through it without appreciable absorption of the laser energy or dielectric breakdown. When the laser is triggered, the beam passes through the transparent overlay and strikes the opaque overlay, immediately vaporizing a thin layer of the overlay material. This vapor is trapped in the interface between the transparent and opaque overlays. The continued delivery of energy during the laser pulse rapidly heats and ionizes the vapor, converting it into a rapidly expanding plasma. The rising pressure exerted on the opaque overlay surface by the expanding plasma enters the target surface as a high amplitude stress wave or shock wave. Without a transparent overlay, the unconfined plasma plume moves away from the surface and the peak pressure is considerably lower. The magnitude of the plastic strain decreases with distance from the surface as the peak pressure of the shock wave attenuates, i. After the shock wave passes, the residual plastic strain creates a compressive residual stress gradient below the target surface, highest at or immediately below the surface and decreasing with depth. By varying the laser power density, pulse duration, and number of successive shots on an area, a range of surface compressive stress magnitudes and depths can be achieved. The deep compressive stresses are due to the shock wave peak pressure being maintained above the HEL to greater depths than for other peening technologies. There may be instances where it is cost effective not to apply the opaque overlay and laser peen the bare surface of the work piece directly. When laser peening a bare, metallic surface a thin, micrometer-range, layer of surface material is vaporized. The rapid rise in temperature causes surface melting to a depth dependent on pulse energy and duration, and target melting point. Due to the short duration of the pulse, the in-depth heating of the surface is limited to a few tens of micrometers due to the rapid quenching effect of the cold substrate. Some superficial surface staining of the work piece may occur, typically from oxidation products. These detrimental effects of bare surface processing, both aesthetic and metallurgical, can be removed after laser peening by light grinding or honing. Laser pulses are generally applied sequentially on the target to treat areas larger than the laser spot size. Laser pulse shapes are customizable to circular, elliptical, square, and other profiles to provide the most convenient and efficient processing conditions. The spot size applied depends on a number of factors that include material HEL, laser system characteristics and other processing factors. The area to be laser peened is usually determined by the part geometry, the extent of the fatigue critical area and considerations of moving the compensating tensile stresses out of this area. The more recently developed laser peening process, the Toshiba LPwC process, varies in significant ways from the process described above. The shorter wavelength decreases the absorption of beam energy while traveling through water to the target. Due to access constraints, no opaque overlay is applied to the target surface. The first layers applied produce a tensile surface stress due to surface melting, although a compressive stress is developed below the melt layer. However, as more layers are added, the increasing subsurface compressive stress "bleeds" back through the melted surface layer to produce the desired surface compressive stress. Newer generations of these laser systems are projected to operate at higher frequencies. This low energy process achieves compressive residual stress magnitudes and depths equivalent to the high energy process with nominal depths of 1 to 1. However, the smaller spot size will not permit depths deeper than this. Quality systems for laser peening[edit] The laser peening process using computer control is described in AMS

Chapter 2 : Laser Heat Treating & Surface Hardening

Laser surface treatments can be divided into processes involving solid state transformations and melting processes. The former category includes martensitic hardening, tempering and shock hardening while the latter includes re-melting, alloying, cladding and dispersion hardening.

Power densities obtainable by different heating methods In recent years, industrial lasers have become available for metalworking uses, including surface hardening. CO2 lasers wave length: Surface Melting Whenever the temperature of any oint of the track exceeds the melting point of the substrate material, we have to classify the treatment as laser melting. Laser Remelting The main reason for laser surface melting is to obtain better properties as a result of rapid solidification. The quenching rates can be as high as those achieved in other rapid solidification techniques, e. Most reassert efforts were directed to surface melting of cast iron, tool steels, stainless steels, titanium and aluminum alloys for improving surface hardness, refined structure, corrosion and wear resistant properties. However, cracking of the treated layer due to high residual stress and sometimes high hardness is still a major problem yet to be solved, especially in the case of cast iron [Ref. Laser remelting is of commercial interest because of its ability to alter with accuracy the properties of very localised surface regions without reprocessing the material as a whole. By choosing a suitable energy input, we can achieve rapid local heating rates above the melting temperature of the surface layer which, after the cooling process is completed, enables that we get a modified layer of desired depth. The aimed surface layer cooling rates can be quite easily achieved by rapid heat transfer into the remaining part of the cold bulk of the workpiece [Ref. The laser remelting process melts and recasts the substrate of suitable materials, in order to produce extremely fine grained structures with improved wear and corrosion resistance. This treatment may also be used to eliminate surface defects or improve the interity homogeneity, adhesion of overlay coatings applied by electrochemical techniques etc. Laser Glazing It is termed also as laser vitrification. Instead, amorphous or vitrified glass surface layers are produced. Laser Surface Alloying A high power laser beam can be used to modify not only the microstructure but also the chemical composition of a surface layer. Laser surface alloying LSA promotes melting, mixing and alloying of the alloying agent and the base substrate. Surface alloying by laser improves surface properties, such as hardness, wear and corrosion resistance while keeping unchanged at the same time the desired bulk properties [Ref. This process involves the melting of a thin alloy layer into a substrate to yield an alloyed surface layer with desired composition by controlling the extent of mixing between the alloy layer and substrate. In thermochemical treatments when additional material added parallel with surface melting the treatment is said to be "one step" and the treatment in which the additional material is placed on the workpiece before radiating the surface by laser beam said to be "two step". Different techniques of such kind of treatments are detailed below:

Chapter 3 : Laser hardening of steel gears - Appropedia: The sustainability wiki

Laser surface hardening uses a well-defined, intense energy beam as a heat source. While improving the wear properties of metals, the process allows metal to maintain ductility. The result of the hardening process to the affected area is fine martensitic grain structure.

Introduction[edit] The hardening of steel is done by heating up a workpiece to near its melting temperature then quickly quenching it. This heat treatment process causes significant changes in the microstructure of the steel which directly corresponds to its metallic properties. The Martensite W structure that is formed is responsible for the increased material hardness. The main methods of hardening are flame, induction , and laser W hardening. Laser hardening is especially attractive for surface hardening of complicated shapes or large objects because it allows for absolute control on the surface hardness and texture. The absorbed radiation from the laser heats up the surface layer to a temperature where Austenite W can form. This is dependent on the composition of the base material. The specimen moves below the table at a constant feed rate. As a point moves down from exposure to the laser it is rapidly Quenched W by the cooler regions surrounding the laser-heated area in the part. In the case of a thin part, water can be used to speed up the cooling process. This Quenching causes the change in microstructure from Austenite to Martensite. Martensite is formed when dissolved carbon atoms are trapped within the austenite face centered cubic structure during quenching. The phase diagram of steel can be seen in the phase diagram of steel. As the temperature is dropped, the Austenite becomes mechanically unstable and rearranges to form a body centered tetragonal crystal structure that is much harder then the original material [1]. Laser Types[edit] Phase Diagram of Steel Two main types of Laser used in heat treating are gas lasers and solid state lasers. Carbon dioxide lasers are usually used as they can provide hundreds of kilowatts of power output which increases the rate of heat addition to the workpiece. Gas lasers provide a relatively simple Gaussian profile of radiation which can lend itself to accurate simulation modeling. Yttrium Aluminium Garnet Nd: YAG lasers operate at 1. However, they have a much lower electrical efficiency which necessitates higher electrical power input. The radiation profile of a solid state laser is much more complicated then that of a gas laser, therefore making it more difficult for computer modeling to accurately predict how the laser would interact with the surface of the workpiece. Currently, large high powered lasers are being utilized. Significant research is going into using smaller lasers which are more cost effective [2]. Experimentation is being done with pulse lasers which allows the work peace to cool between intermittent irradiation. The most significant change in laser technology is the utilization of high power diode lasers HPDL. With wavelengths of 0. Control Systems[edit] The most important and difficult component of laser surface hardening is the control of the laser. It is extremely difficult to predict the effect the laser has on the surface because so many different factors are involved in the process. For simple parts and geometry, the control systems get a lot simpler. The most commonly used control systems use a fixed rate feed system and fixed power output. The depth of the hardened layer and effective hardness can then be determined experimentally or mathematically. However, problems occur when the material is not a certain thickness because the part does not have enough bulk to quickly cool the heated region. This often occurs at the edge of the part or changes in geometry and is evident by surface melting. More advanced control systems are being developed which utilize more complex computer systems and real-time data acquisition. Infrared[edit] Infrared W systems are one possible way to determine the real time hardness of a sample with a relatively simple implementation. An infrared monitor is used to determine the radiation produced at the weld. Testing a sample that has been processed at different feed rates can be used to determine the surface hardness in relationship to the feed rate. This can be used to determine the necessary feed rate to achieve a desired surface hardness. Using this data for calibration, a system can be put in place to vary the feed rate based on real time IR readings. This provides a way to laser harden a workpiece of unusual geometry because if the IR reading changes suddenly, the feed rate will adjust accordingly. This system can also be used to monitor the hardening depth using a similar device. These calculations are very complicated and require a large amount of processing power to compute. As computer technology increases, these systems will become more accurate and more widespread. Systems like the Abaqus and ANSYS have already been used to accurately predict phase content and microhardness [6] [7] [8]. However, they do not take into account the geometry of the part. Instead they use realtime data that is affected by part geometry. Most commonly, they use surface temperature measured by a pyrometer W. PID systems uses this data to calculate the ideal output power that is required to achieve consistent hardening. Conditions are put in place to ensure that the surface temperature does not increase above the materials melting temperature [9]. Apparatus[edit] The most simple design involves a stationary laser with a working table underneath. The workpiece is fixed to the 3-axis stage. The computer controlled stage moves back and forth along a predetermined path with some overlap. No cooling is necessary because the workpiece acts as a heat sink which quickly cools the treated area. However, this is not possible for a complicated part such as a gear as it is not a simple surface that is being treated. This requires a more complicated setup such as a 4 or 5 axis machine that can rotate the gear during the process to keep the working distance consistent distance from the laser [10]. Surface Coating[edit] Surface Reflectivity One way to improve the efficiency of the laser hardening process is to ensure that all the radiation directed on the workpeice is absorbed. This can be rather difficult because the materials that are usually being hardened are extremely reflective. One way to avoid this is to texture the surface or use a surface coating. The latter is much more effective and can reduce the reflectivity to as low as 2. The problem with these coatings is they usually have to be applied by hand especially for complicated parts like gears. They also can be detrimental to surface quality and can make real time analysis much more complicated. Surface coatings can be avoided by using a laser with a smaller wavelength such as a HPDL. This oxide layer has a significantly higher absorption so can then easily be hardened. Energy Analysis[edit] For laser hardening to be an effective method of hardening for commercial applications it must be more economical then current hardening methods. Currently, the most common method of hardening used in industry is induction hardening. The following is an energy analysis for induction hardening and the most common laser being used in industry CO2 lasers. Material Properties and Processing Parameters Property.

Chapter 4 : Laser Hardening Â« Laser Cladding Services - Oerlikon Metco

Laser Hardening Easy Contact-Free Hardening of Parts with Difficult Access. During the laser skin hardening, the material (carbonaceous material) is heated up for a short time above austenitizing temperature and is transubstantiated by fast cooling down into the martensitic structure.

Chapter 5 : Surface Treatment

Laser hardening is a heat treatment process or surface hardening process in which a laser beam is used to heat the surface of a metal part and then let it quickly cool down in surrounding air.

Chapter 6 : LASER HARDENING

Laser surface transformation hardening not only increases the wear resistance of materials but under certain conditions also increases fatigue strength due to the compressive stresses induced on the surface of the component.

Chapter 7 : Laser Heat Treating for Hardening | IPG Photonics

Surface transformation hardening of steels is an attractive application of industrial lasers in view of the enormous usage of steel for a numerous applications and the fact that a fine laser beam enables selective hardening to a required depth and width.

Chapter 8 : Handbooks - ASM International

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Laser Surface Hardening and Welding. Laser processing uses a well-defined, intense energy beam as a heat source. While improving the wear properties of metals, the process allows metal to maintain ductility.

Chapter 9 : Surface hardening - Nextema Srl

Laser heat treating is another selective hardening technique in which a spatially well-defined beam of laser light is absorbed near the surface, causing rapid heating. This heating is limited to the illuminated area, and penetration into the bulk material is limited.