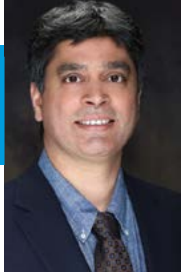

AN INSIDER'S PERSPECTIVE

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Laser Shock Peening

Peening Techniques

Rust and fatigue never take a break, and our industry tries its best to get ahead of both miscreants! We blast clean parts to remove the last trace of scale, rust, or any other contaminant to present a clean surface for a downstream coating. We shot peen parts to generate residual compressive residual stress (CRS) that will combat fatigue and enhance the productive life of the component. With peening, we have adopted several other techniques in addition to shot peening using cast steel shot, cut wire shot, glass bead and ceramic shot. Such techniques include Rotary Flapper, Ultrasonic, Needle, Laser, Vibratory, Hammer, and Cavitation peening. Individual techniques continue to be adopted under specific circumstances and to achieve desired end goals.

It is not uncommon that a process engineer encounters a situation where, despite peening the part to the approved parameters, a certain area of the component continues to experience fatigue failure. The nagging issue persists even after altering known parameters in shot peening. FMEA (Failure Modes and Effects Analysis) might reveal other design aspects about the component that may have contributed to this failure. Perhaps, it might benefit from treatment by a different peening technique that can deliver CRS beyond the realms of conventional shot peening. Let us explore one such technique—Laser Shock Peening (LSP).

When discussing LSP, we need to explore beyond our traditional evaluation norms of the process. In addition to intensity and coverage, peening results are also evaluated based on two critical parameters, (a) magnitude, and (b) depth of compression. Each of the processes listed above results in a different achievable value for both parameters. Though largely dependent on the part metallurgy, where conventional peening generates residual compression in the range of 0.002" to 0.020", LSP could generate CRS (Compressive Residual Stress) in depths 0.2" and deeper.

What is Laser Shock Peening?

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. This source of energy is well-utilized in industrial applications such as cutting, welding and common in more mainstream devices such as printers, CD players, barcode scanners, etc. The light emitted by a laser has a coherent property, and different from other sources of light. Coherent light waves have the same frequency (number of occurrences per unit time) and waveform (picture a sine wave or a sawtooth pattern) considered an ideal property for waves.

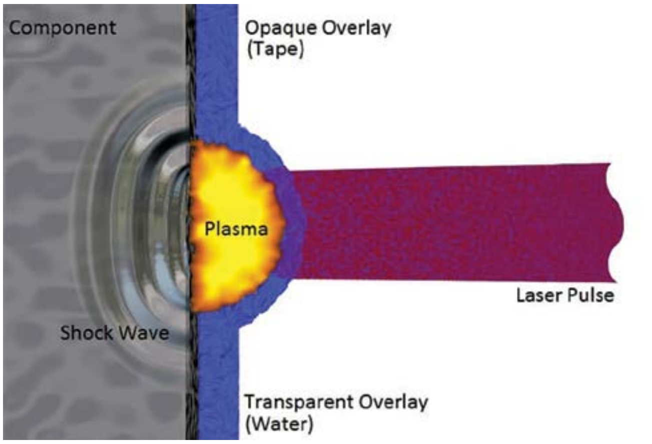
During a condition called spatial coherence, two or more such waves focus on a common spot creating a high quantum of energy that allows for operations such as laser cutting using a *continuous* wave laser. LSP utilizes this phenomenon with a high-energy *pulsed* laser to generate CRS in the component that is laser peened. When a high-energy laser pulse (nominally 10- 20 ns long) hits the surface of the metal, it generates a plasma wave that creates significant pressure to alter or reshape the microstructure (metal grain shapes) in the area. The areas surrounding the impact try to push back this distortion and regain their original shape before the impact. The result is an area of CRS. The net effect of a shot particle impacting the surface and a laser beam is the same—distortion and generation of residual compression.

However, the magnitude and depth are vastly different with both techniques, more of which will be discussed later. Due to laser shock peening's ability to deliver precision protection deep into the surface of metal components, it can result in parts lasting up to 10 times longer.

Mechanism of LSP

During laser peening, the laser pulse created by the incident beam creates an explosive plasma on the process surface that generates a shock wave. Laser peening uses a transparent layer termed "overlay" to confine this explosion and utilize and direct this shock wave energy into the component. Therefore, the term Laser Shock Peening is used to describe the process. Without the transparent overlay, this energy will disperse and not create the intended peening effect.

The most common type of overlay is a transparent overlay (often water) that is presented at an angle of 0 to 30 degrees to the surface of the component. This water is applied at low pressure to a flow that will generate a 0.5 mm - 2 mm thick layer.



Mechanism of LSP – a pulsed laser beam impacting the component with controlled peening results

A second overlay that is sometimes used in LSP is an "opaque overlay". In informal terms, this is an energy absorbing layer that is applied directly over the area being peened to protect the surface of parts made from specific metals and amplify the amplitude of the shockwaves.

Dr. Micheal Kattoura, Materials Research Engineer at LSP Technologies, Dublin, Ohio (USA) explains, "The purpose of the opaque overlay is to protect the surface of the metal part from interacting with the plasma and creating an oxide layer that generates very shallow (few microns) surface tensile residual stresses." When questioned about the processing time involved in applying and removing this layer, Dr. Kattoura added, "With high frequency lasers, typically 20 Hz or higher, the taping process tends to be longer than the actual cycle. Therefore, at LSP Technologies, we conducted several studies on peening without opaque overlay, commonly referred to as bare peening, and concluded that the shallow surface tensile stresses have negligible effects on the parts performance and can be addressed by increasing the overlaps (this term explained later) or by buffing the surface. Bare peening has become more common in the applications we work on." He did note an exception with Titanium alloys which form a brittle layer on the surface when peened without the opaque layer. This layer, also referred to as "Alpha case" contains microcracks that reduces the benefit to the fatigue life of the component from laser peening. Removal of this alpha case is typically through machining or chemical milling which requires high accuracy to continue meeting the part tolerances. Taping (opaque overlay) tends to be a requirement for such metals.

Let us evaluate some of the processing terms used in LSP and contrast them with shot peening to gain a better, comparative understanding. (See Table below.)

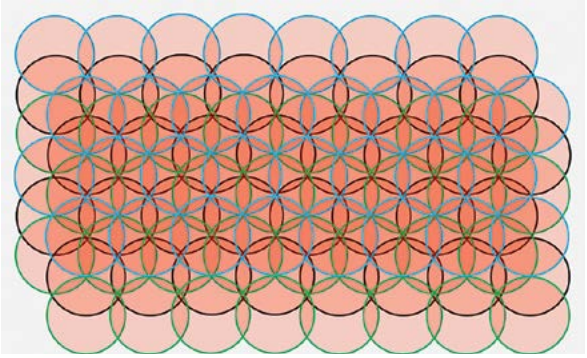
Part Geometry in LSP

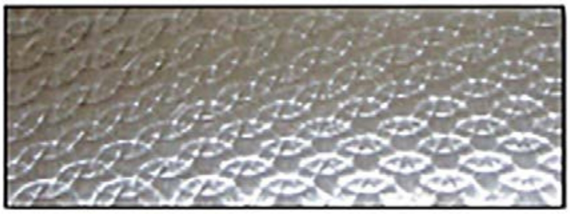
LSP is most effective when there is a direct line of sight between the beam and the area to be peened—unlike shot peening where ricochet peening is a distinct possibility due to the remaining energy in the media particle after its first impact. This presents some unique opportunities for this process that will be discussed later.

Contour (geometry) of the surface being peened influences the character of the shock waves and depth of compressive stress. Concave surfaces cause the shock wave to expand and decrease the magnitude and depth of compressive stress. The opposite is true when peening convex surfaces. LSP presents a unique challenge when peening solid cylinders like shafts. In shafts that are less than 12.5 mm (0.5"), LSP has the potential to create cracking along the center line of the cylinder or a high-core tensile stress that could lower the fatigue strength. This issue diminishes with increasing shaft diameter.

Comparison of Processing Terms

Laser Shock Peening	Shot Peening
Power Density – This is the key to generating CRS. It is directly proportional to the depth of compressive stress generated and determined by the energy of the laser (in Joules), and indirectly related to the pulse width (duration in nano seconds) and laser spot area (in sq. cm). Ideal peening treatment for a material is generally proportional to its yield strength. Strong materials such as high strength steels, Ni and Ti alloys are processed close to maximum power density (7-10 GW/sq.cm) and soft materials at lower power density (2-6 GW/sq.cm). 1 GW = 1 billion watts.	**Impact Energy** – Also referred to as transmitted energy or kinetic energy. Impact energy generated is directly proportional to the mass of the shot particle and velocity of impact (determined by air pressure or wheel speed used to propel the media). Shot size and velocity determine the impact energy delivered. Shot sizes range from 0.007" to 0.078" (SAE sizes). Some applications such as peen forming use even larger size media. Components are shot peened close to or higher than the yield strength (plastic deformation). Impact of shot particle dents the surface and continues to retain energy after the first impact, up to 3-4 impacts.
Overlays – Transparent and Opaque – Transparent overlay is a requirement in LSP to contain the shockwave and allow its propagation into the component. The requirement of opaque overlay is material dependent.	Though masking of components is common in shot peening, neither transparent nor opaque overlays are required when peening the component.
Energy Transmission in LSP is immediate and final. After the component has been impacted in a specific spot, there is no residual energy that a reflected beam will continue to possess.	**Energy Transmissio**n in shot peening is created by the impact of millions of shot particles over a period. Given the right parameters, at process saturation, energy transfer from each media particle is uniform.
Coverage and Overlap - Coverage is achieved through layering. Multiple layers are overlapped on to the target surface to increase the coverage, resulting in a uniform distribution of the residual stress and relatively smoother surface.	**Coverage** on the surface is directly proportional to exposure time and the number of particles that impact the part. Verification of coverage is through visual inspection of the part. Rate of coverage is inversely proportional to the diameter of shot particle.





A three-layer overlap pattern (top) and an example of laser peen spot pattern (below)

LSP can be used to peen inside holes wherein a series of optics (mirrors) can deflect (bounce) the beam to impact the side walls of the hole without appreciable loss of energy. This works for most hole sizes and is still an effective technique in spite of not having direct line of sight.

Part thickness also plays a crucial role, especially in thin cross-sections, much like in shot peening. Thin-walled sections such as blisks must be peened simultaneously from both sides of the part area to avoid distortion. This is valid when shot peening such parts as well. Dr. Kattoura from LSP Technologies informed me that they had successfully implemented several systems using their Procudo® 200 laser system that were capable of peening both sides of parts simultaneously without distortion.

Beam Delivery in LSP

Delivering peening media to the nozzle or blast wheel in a shot peening machine is through a blast hose in an airblast machine or feed pipe in a wheelblast machine. In comparison, beam delivery systems are of three kinds in a LSP system: Fixed, Articulated Arm and Fiber optics. Keith Glover, Head of Applications Engineering at LSP Technologies provided more insight, "As the names suggest, a fixed beam delivery system is the most straightforward where the part is articulated to expose different areas to a fixed laser beam. With more complicated geometries where manipulating the part is not possible, articulated arms fitted with a series of optics "bounce" the beam to the target when not in direct line of sight. Such systems are highly effective albeit requiring higher capital cost than fixed systems. At LSP Technologies, we have started using fiber optics to streamline this technique." (Fiber optics uses thin strands of glass fibersto transmit information through light pulses over long distances, with minimal loss.)

Shot peening media delivery systems are susceptible to energy losses due to long hose lengths, worn blast hoses and nozzles. Regular monitoring is essential to ensure that the impact energy being delivered is constant and repeatable. This is a stark difference from LSP systems where there is no physical impact or wear from the source that ultimately produces comparable fatigue strength enhancement in the component.

A Synergistic Approach

Our discussion started by introducing the possibility where shot peening alone is not able to counter the effects of fatigue on a component. All identified advantages of LSP, such as resistance to FOD (Foreign Object Damage), improved fatigue strength, increased fatigue life, resistance to crack initiation and propagation, resistance to fretting fatigue, and reduction in stress corrosion cracking, are similar to a list that could be generated for shot peening.

However, there do exist applications in the energy and aerospace sectors which demand a much higher depth of compression in target areas combined with the need to maintain a processing environment devoid of foreign particles. Such applications can greatly benefit from this combined approach.

The industry currently utilizes shot peening machines that take advantage of the increased media flow rate achieved by blast wheels to process large surface areas at high rates of productivity and combine them with nozzles to access those difficult-to-reach spots such as bores and slots, both within the same blast cabinet. Similarly, a hybrid system using both techniques, shot peening and LSP, is entirely possible in specific cases.

Shot peening is not an extension of a blast cleaning process. Whether as a stand-alone process or synergistic to shot peening, the benefits of LSP can only be gained with a higher level approach and understanding relating to materials and their behavior under fatigue-loading conditions. The process approach needs to go beyond deflecting a set of Almen strips and plotting a saturation curve to accomplish a peening operation.

Does LSP Stand on Its Own Merit as a Viable Peening Process?

Yes. LSP is fully mature and thoroughly demonstrated on a variety of metallic aerospace and metal forming components. When fatigue enhancement is mission critical, broad area coverage through shot peening combined with targeted laser peening could be the synergistic service life extension your product may require.

This article was enriched by discussions with various professionals at LSP Technologies in Dublin, Ohio. I would like to acknowledge their interest and efforts in making this an educative and informative document.