LightPanther: the ultimate tool for a mobile laser peening process

Shock Lite, 18 rue Charles de Gaulle, 91400 Orsay, France
shocklite@imagine-optic.com

Summary

The white paper explores Laser Shock Peening (LSP) as an advancement over shot peening, employing laser beams to induce precise shockwaves, enhancing material properties by applying compressive residual stress. Despite its effectiveness, LSP faces challenges in industrial settings due to the handling of Class IV lasers, necessitating disassembly and limited process flexibility. Shocklite's breakthrough system enables the transmission of over 60MW of energy into standard silica optical fibers, reducing speckle contrast and offering real-time monitoring for safe use.

Collaborating with Europe Technologies, the LSP process exhibits significant material reinforcement, enhancing compression in parts without surface damage, potentially revolutionizing aeronautic and naval Maintenance Repair Overhauls (MROs) and expanding to radioactive environments. In essence, the fiber injection system offers a solution to deliver laser energy without disassembly, with potential applications beyond material reinforcement, including laser cleaning, ultrasonics, and laser-induced breakdown spectroscopy (LIBS) for wider industrial use.

Laser Shock Peening, a shockingly inflexible process

Peening processes have been around for more than 150 years after the appearance of the shot peening technique in the 1870's. Such a process relies on striking metal, ceramic or glass shots on metallic parts in order to apply a plastic deformation and therefore bring a compressive residual stress to the part. This surface treatment helps the extension of the service life of parts by increasing their resistance to stress corrosion, corrosion fatigue and the propagation of surface cracks.

However, shot peening also suffers numerous disadvantages. In fact, one of these is that the applied shots can leave detrimental foreign object damages (FODs) on the treated surfaces which can be problematic for both their functionality and physical aspect. It also goes without saying that blasting shots is far from being a very deterministic and precise process.

To overcome such inconveniences, shots were replaced by laser beams which could generate more directive and precise shockwaves on the treated materials. This feature allows many practical benefits among which the high level and depth of applied residual stress and the lower generated surface roughness are the most important, allowing a fatigue life increase of parts by, at least, a factor of 5 [1].

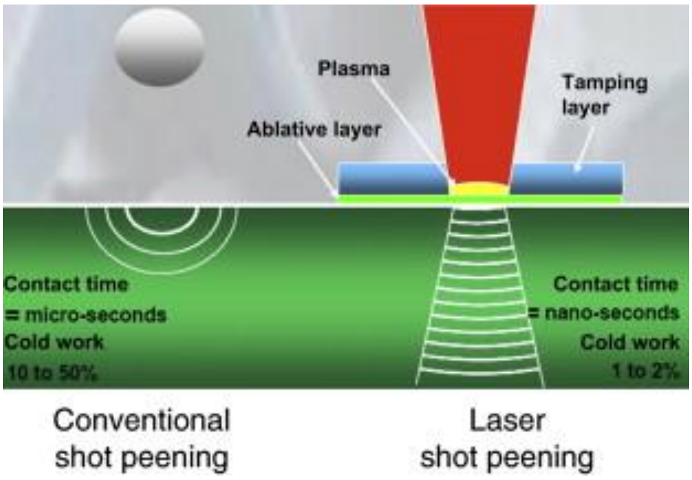


Figure 1: Principle of conventional shot peening and laser shock peening [2]

Even though Laser Shock Peening (LSP) is an exceptional tool for material life increase, it is still quite difficult to implement in industrial environments as handling a class IV laser may prove to be difficult. In fact, existing LSP solutions require parts disassembly in order to fix them on robotized arms in safe cabins. This constitutes a difficulty towards the flexibilization of the process.

Record-breaking fiber injection performances

As underlined in the previous section, laser shock peening in its initial fashion is not that well adapted for a use in environments like Maintenance Repair Overhauls (MRO) where gaining time, and therefore not having to disassemble parts, is a key parameter. A serious candidate to overcome this issue is the optical fiber to transmit the laser energy from the source to the zone to be treated.

Commercial solutions have been existing to inject energetic nanosecond laser beams in optical fibers. However, they struggle to transport the needed laser energy to generate relevant residual stress profiles, as the highest reported transmitted peak powers were in the 10-20MW range. The main enemy of a higher energy transmission is called the dielectric breakdown of the fused silica contained in optical fibers.

A common easy fibering solutions usually consist in focusing the beam thanks to a lens without further care except placing the optical fiber after the beam focus to prevent too high fluences on the air-silica interface. Such a technique is usually detrimental for high-energy transmission as only a few modes propagate in the fiber, which can lead to self-focusing. Another possible approach is to homogenize the beam with microlens arrays [3] following the Köhler integrator design, however such a design has also its inconveniences as the array design gives way to an interference pattern, and therefore intensity peaks, at the focus.

In order to pave the way for a fibered LSP process, Shocklite, the beam shaping division of Imagine Optic, has been developing during the last few years a unique beam shaping system allowing the injection of more than 60MW in the nanosecond regime in standard single-core silica optical fibers. To obtain this, particular attention was brought to shape the laser beam in the smoothest possible way at the fiber entrance interface. This is thanks to the reduction of the laser beam spatial coherence which allows much lower speckle peaks than before the beam shaping. The resulting speckle contrast decreases from 0.7 down to 0.15.

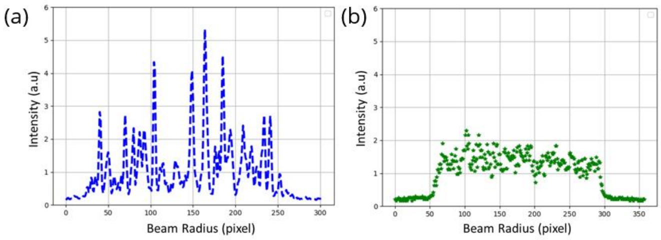
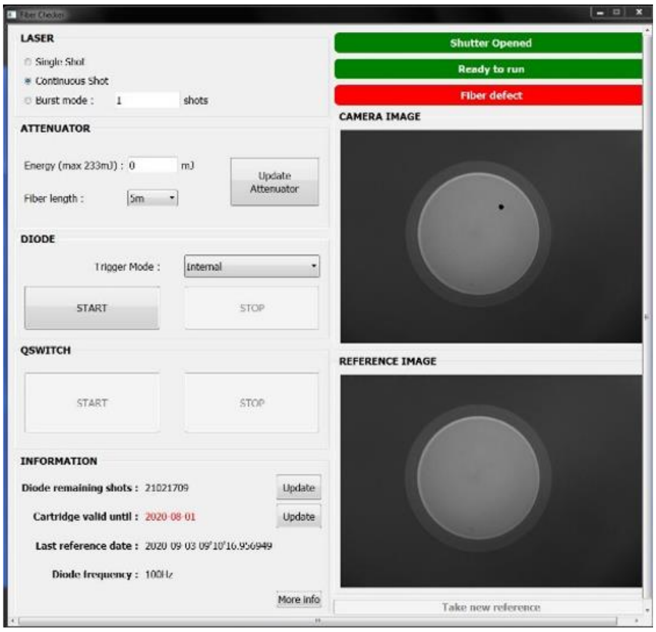


Figure 2: Laser beam profile at the entrance of the optical fiber (a) before beam shaping (b) after beam shaping

As the fibering system is intended for an industrial use, a real-time imaging module was added to the system to live-monitor the fiber entrance facet (and therefore eventual plasmas occurring inside the fiber) and stop the laser in case of any disturbance. This tool enabled us to identify the optical fiber damage threshold for a core diameter of 1.5mm to be at an incident energy of 380mJ (for a repetition rate of 10Hz) which corresponds to a peak power of 63MW at a pulse duration of 6ns. Such energy levels have not damaged a 5m fiber for more than 50 million shots.



○ Single Shot
● Continuous Shot
○ Burst mode : 1 shots

Energy (max 233mJ) : 0 mJ
Fiber length : 5m

Trigger Mode : Internal

Diode remaining shots : 21021709
Cartridge valid until : 2020-08-01
Last reference date : 2020 09 03 09'10'16.956949
Diode frequency : 100Hz

Figure 3 : Optical fiber entrance facet live monitoring

The road to a fibered LSP process

To go down this road, we teamed up with a partner of choice: Europe Technologies. It is a French company based in Carquefou, France, that has a broad experience in the manufacturing and maintenance processes of composite, plastic and metallic parts and which has developed since the 1990's the ultrasonic laser peening process.

Such a collaboration took part in the frame of a European project named FLASP, standing for **F**ibered **LA**ser **S**hock **P**eening, whose aim was to demonstrate the feasibility of a fibered laser shock peening platform and its performance of aluminum and titanium, two major materials in today's industry.

While Imagine Optic's contribution in the project was to develop the optical apparatus for the experiment comprising the fiber injection module, the optical fiber and the optical head, Europe Technologies role was to select and provide the materials to be tested in addition to accomplish the residual stress profile characterizations on the treated parts.

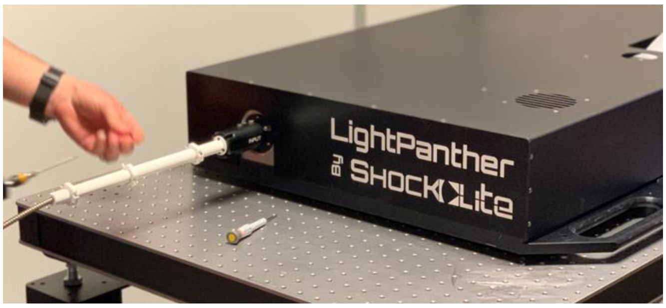


Figure 4 : The fiber injection module named the LightPanther

To focus the laser beam on the part, a compact optical module was implemented at the output of the optical fiber. Such module permitted to have a sub-millimetric spot size at a working distance of 50mm which allowed to treat the parts with up to 7GW/cm² peak power densities. Adequate water splashback management was also taken into account in order to keep a regular beam shape and fluence at the focus.

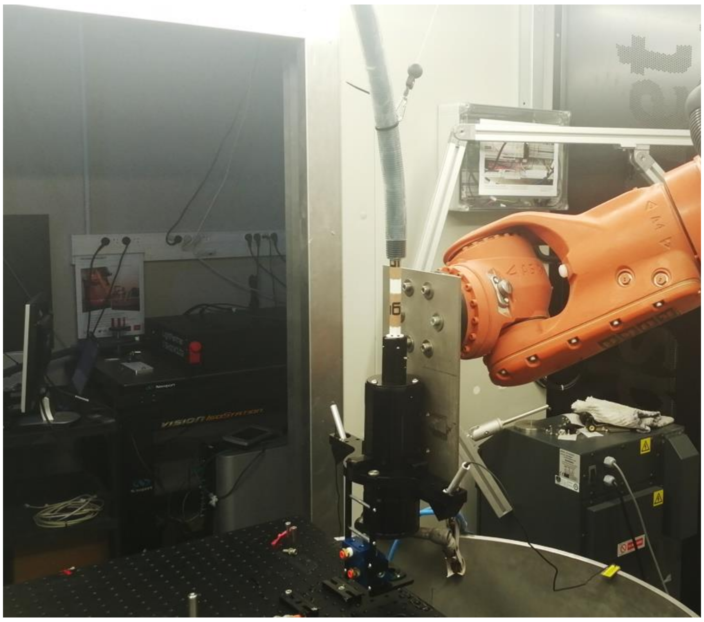


Figure 5: The FLASP apparatus installed at AlPhANOV, France

7075 T6 Aluminum and Ta6V titanium samples were treated using the FLASP apparatus, installed at the ALPhANOV facility in Bordeaux, France. When treated, these samples were then analyzed by Europe Technologies (France) using the X-Ray diffraction method in order to characterize the residual stress profile of each treated sample.

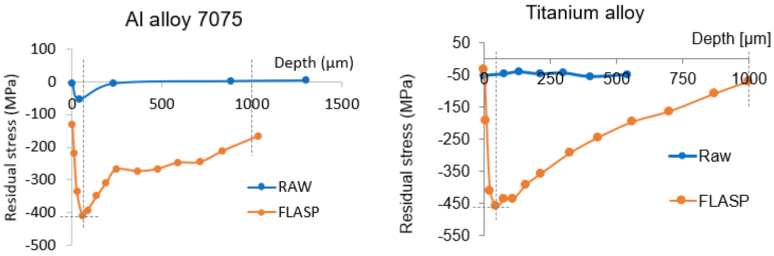


Figure 6: Residual stress measurements on (a) 7075 T6 Aluminum and (b) Ta6V titanium samples

Two sets of data were recorded for each part: the residual stress profile before (blue) and after (orange) the FLASP treatment.

Measurements showed an improvement as residual compression peaks reached values higher than -400MPa and an affected depth of more than 1mm. This compression also took part at the surface level. A minimized influence on the surface finish was also found out as the aluminum part roughness was characterized by an Ra<2µm.

In summary

The record-breaking performances of the nanosecond regime energetic laser injection accomplished very good results in terms of material reinforcement. The results obtained with Europe Technologies confirm the possibility of using the fibering system to treat metallic parts in aeronautic or naval MROs as it could also be considered to treat parts in radioactive environments. To summarize, the fiber injection system is a valuable tool to bring the laser energy to the parts without having to dismantle them.

The energy levels could also open a way for a wider industrial use of intermediate-energetic nanosecond lasers through applications such as laser cleaning, laser ultrasonics or laser induced breakdown spectroscopy (LIBS).

Acknowledgment

This work was conducted in the frame of the European project FLASP (project FLASP, Sub grant agreement n°: PUL_10 under the grant PULSATE GA 951998)

References

[1] Allan H. Clauer, “Laser Shock Peening, the Path to Production,” Metals, 9(6), 626 (2019)

[2] A. Gariépy, H. Miao, M. Lévesque, “Comprehensive Materials Processing, Volume 3, 2014, Peen forming, Pages 295-329”

[3] Y. Sano, K. Akita, K. Masaki, Y. Ochi, I. Altenberger and B. Scholtes, “Laser Peening without Coating as a Surface Enhancement Technology,” Journal of Laser Micro/Nanoengineering Vol. 1, No. 3 (2006)

without Coating as a Surface Enhancement Technology,” Journal of Laser Micro/Nanoengineering Vol. 1, No. 3 (2006)