Development of experimental station for laser shock peening at HiLASE

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ABSTRACT

Recent development of a station dedicated to Laser Shock Peening around newly developed BIVOJ laser system will be reported. The paper also contains further plans related to upgrade of the laser system as well as plans for establishment of a dedicated sample preparation and characterization lab.

Keywords: Laser Shock Peening, Residual Stress, Fatigue Life, Diode Pump Solid State Lasers

1. INTRODUCTION

Laser Shock Peening (LSP) as a surface treatment technique for improvement to resistance to foreign object damage was already demonstrated in early 90this of last century by the General Electric Infrastructure-Aviation (GEA)[1]. Since those early days LSP as a surface treatment was demonstrated also for increase of fatigue life as well as for slowing down crack growth rate[2,3,4,5,6]. Besides improvements of fatigue life, LSP can also be applied for prevention of stress corrosion[7], cracking/corrosion[8] resistance and wear resistance.

Despite obvious benefits for industry (several applications and their impact on industry are mentioned at: https://www.lsptechnologies.com/laser-peening-roi.php), LSP is still considered as expensive and used on very limited so call critical components in aviation and power plant industry. One of limitation for LSP technology towards wide applications in industry is related to the cost and availability of suitable laser systems (so far only Procudo laser system, as a system suitable for LSP industrial applications is present on the market, while LSP as a service is provided by Curtis Write Company). Recent development in solid state diode pump laser systems is giving a hope that in the near future this limitation might be resolved.

2. BASIC PRINCIPLE OF LASER SHOCK PEENING

Basic principle of LSP was explained in several publications and here only short summary will be given. The ns laser pulses of high intensity after passing through transparent confining medium (water in the most cases) is vaporizing absorbent coating or metal surface in the case of no coating is applied (see Figure 1).

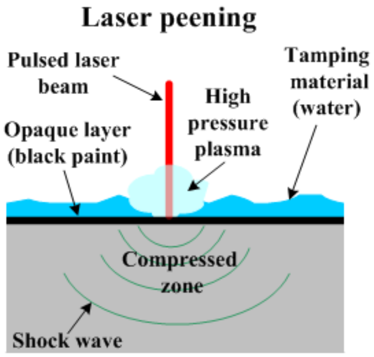

Figure 1: Basic principle of Laser Shock Peening

On such way the formed plasma, which is prevented to expand away from the surface by the confining medium, is generating the shock. The treated surface under these shockwaves is plastically deformed and compressive stresses are extended into subsurface. The plastically affected depth of material and the induced residual stress level[9] depends on a peak pressure of surface plasma. The pressure of surface plasma, which is in the level of several GPa, besides properties of material and confining medium (Z is reduced shock impedance of treated material and confining medium, while α is the ratio of thermal to internal energy)) is strongly influenced by the laser power density (I)[10]:

$$P = A\left(\frac{\alpha}{2\alpha + 3}\right)^{1/2} Z^{1/2} I^{1/2} \tag{1}$$

Taking in the account different laser pulse duration and different laser energies over treatment areas, two main processing regimes for LSP treatments have been developed in practice[11, 12]. In the so-called “high energy” regime, pulsed lasers with energy in excess of several tens of joules and interaction times of several ns is delivered to surfaces areas of 10 mm^2 and more. This approach (principally developed by Metal Improvement Company, today Curtis Write Company) uses absorbent coating (paint, metallic tape, etc.) for enhancing the laser radiation absorption and, in turn, avoiding possible thermal effects from the relatively long time of contact between the plasma and the treated material. The typical laser repetition rate is, in the case of so call lump pumped solid state lasers, was up to 5 Hz, while new diode pump solid state lasers are providing pulses up to 20 Hz. Increase of the laser repetition rate is opening possibility to also decrease processing time.

On the contrary, in the so-called “low energy ” regime, lasers with pulses in the range of several ns and with only several millijoules of energy are applied to smaller surface areas in order to keep the required threshold energy for the LSP effect. In order to cover large areas a high pulse overlapping strategy is applied. Similarly to the “high energy” regime, the effect of high pulse overlapping is able to produce a deep (around or over 1 mm) field of compressive residual stress. The laser systems with higher repetition rates available under this approach (10-300 Hz) allow for a reasonable production throughput with excellent and uniform quality.

Besides differences in the laser energy and applications with and without opaque layer, there are also difference related to a different thickness of water as tamping layer. As a consequence, today there are applications with dynamic water flow and applications done under water. Due to the absorption properties of water[13], in the first case are used laser in infrared (IR) part of spectra, while under water LSP require laser pulses in the visible (VIS) spectra.

3. LASER SHOCK PEENING AT HILASE CENTER

3.1. Diode Pump Solid State High Energy Lasers as a new LSP laser sources

As it was already mentioned, first LSP applications were demonstrated on Nd: Glass laser medium pumped by lamp systems. Those systems today, used as main laser sources for LSP at Curtis Write, are robust and industrially ready systems. Despite this particular system is not commercially available, systems with lower performances based on similar concept are offered by for example by EKSPLA, Thales and Quantel-laser. Those lasers are operating at repetition rate of only few Hz and energy is reported to be (in the case of NIF lasers) of few tenths of joule.

Great advances in laser diode technology during the last two decades, brought high power laser diodes within a wavelength range from about 800 to 1000 nm to the today’s market. Their spectrally narrow emission linewidths allow for a highly efficient energy transfer to the laser medium, while their intrinsic electrical to optical efficiency of more than 60% also keeps the internal heat load low[14, 15]. The major drawbacks of diode laser pump sources, such as their high pricing and rather low power density are, fortunately, addressed in recent developments.

As a consequence, it is not surprising that already mentioned Procudo laser system is diode pumped Nd:YLF MOPA based system. Procudo is operating at 20 Hz providing ns pulses of up to 10 J energy.

High energy laser systems during last two decades were realized on Nd^{3+} based laser media. Main reason for that was also related to limited technical solution for cooling Yb^{3+}- based laser media which at 80 K showing excellent spectroscopic properties[16]. Combining new achievements in diode pumping with know-how for efficient cooling of Yb^{3+}- based laser media to cryogenical temperatures, ns laser pulses at over 100 J energy were recently demonstrated at HiLASE laser center[17].

Figure 2. Bivoj laser system during installation at HiLASE center

Encouraged by the mentioned high energy achievements, HiLASE team with their colleagues from STFC's Central Laser Facility (CLF) at Rutherford Appleton Laboratory are planning further upgrades both in providing high energy pulses at higher repetition rates as well as to try reaching even energies above 150 J. Table 1 is summarizing Bivoj laser status as well as further upgrades and the expected time of full operation for LSP treatments.

Bivoj	**Bivoj+**	**Bivoj++**
10 J / 10 Hz* 100 J / 10 Hz**	10 J / 100 Hz	160 J / 10 Hz
*available for LSP **expected from 2020 (limited by optical isolation)	available from 2023	available from 2023

Table 1: Summary of status and planned upgrades of Bivoj laser system

Additionally to operation at nominal 1030 nm wavelength, in the near future it is expected to have operation at 515 nm which than will be used for so call under water peening.

3.2. LSP dedicated experimental station

HiLASE center building is designed on the way to have clean room dedicated laboratories for the laser development in the basement and application laboratories on the level above. As a consequence, a specially designed laser beam distribution system (LBDS) has been installed. After passing the LBDS system, laser beam is approaching the system for beam focusing in the range from 2mm x 2 mm up to 5mm x 5 mm and the monitoring system which allowing monitoring of energy in each laser pulse and beam profile (both in near and far field). The LSP setup, designed with vision to be suitable for treatments of 3D industrially relevant components, contains a robotic arm capable to carry up to 20 kg and a positioning table capable to accept samples up to 300 kg. At the moment, LSP treatment only under IR ns pulses with dynamic water flow is possible, while under-water treatment will be possible as soon as the VIS ns pulses will be available. In both cases, the laser beam position will be fixed, while the treated component will be in motion.

Energy vise, at the moment LSP treatments are only possible under 10 J laser pulses, but the whole station is prepared to accept in the future pulses up to 100 J.

Recently, the station is additionally isolated against high noise level and a strong ventilation system is added. First preliminary LSP treatments are done and treated samples are in the process of evaluation.

As it was already mentioned during the next five years, HiLASE center will be enhanced with two laser upgrades. To the best of our knowledge, LSP high energy treatments at repetition rates over 10 Hz or under big spot size (energy over 100 J) were not performed. Several technical limitations are already recognized and they will be approached during designing and developing new LSP station dedicated to treatments under those new process regimes.

3.3. Sample preparation and characterization cell

Sample preparation and a post process characterization are of great importance for the efficient process development. Therefore besides LSP station, HiLASE center is in the process of installation (Stresstech hole drilling residual stress machine) or selection (XRD, sample cutting, grinding, polishing, etc.) of suitable devices. By the end of 2018 the sample preparation and characterization cell will be ready for use.

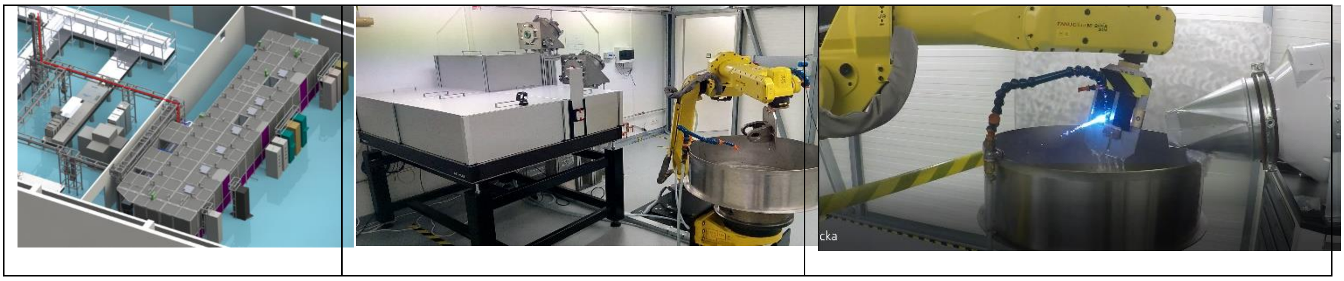

Figure 3. Schematic view showing LBDS system from BIVOJ laser system towards LSP station (left), LSP station (middle), close look on the sample during LSP treatment (right)

4. CONCLUSION

LSP is one of surface treatments with great benefits which can be integrated to the production as well as to the service procedures of metal components. Unfortunately high cost of LSP process and limited knowledge on process development are mane limitations for wider industrial acceptance of this treatment. Working in parallel on development of new laser systems and learning process development steps, HiLASE team is focused on enabling LSP industrial acceptance even to cheaper critical components.

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