Is the Civil Aerospace Industry ready to implement Laser Shock Peening into Maintenance Environment? Questions to be answered and minimum requirements from Aircraft Manufacturer's Perspective

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Laser Shock Peening (LSP) as surface technologies inducing residual stresses in metallic airframe is a well-established technology in aerospace industry [1], [2]. An overview of potential applications to ensure salvage for identified hot spots in terms of fatigue and crack growth performance in aircraft structures as well as to ensure the improvement of the economic and ecological impact of future aircraft structures by controlling the residual stresses has been reviewed in [3].

An example of LSP for fatigue critical components of military aircraft in maintenance environment in fixed established repair station is reported in [4], [5]. The application of LSP as retrofit solution for in service commercial aircraft is particular challenging and currently no applications are reported. Applying LSP as a structural modification in critical component of in service commercial aircraft implies treatment at the Maintenance Repair and Operations (MRO) all around the world during already scheduled maintenance to avoid Aircraft on Ground situation which can cost tens of thousands dollars a day. When a commercial aircraft is in a major overhaul maintenance, inspection programs, eventually repairs and structural modifications take place in a limited short time involving multi-skilled teams working at the same time around the aircraft making the accessibility of the structure not easy at all. Moreover it is a common understanding that the depth of compressive residual stress over 1 mm can be achieved only if high energy laser (i.e. large laser spot) is used [6]. The compressive shock wave generated by LSP has a lower attenuation travelling into the material if more planar shape as per the larger spot; while smaller spots are characterized by spherical shock waves with higher attenuation rate and shallower compressive stress.

LSP by high pulsed energy system and involving complex set up and tooling is not practical at all for in-service use (not compatible with airline maintenance constrains). To make LSP applicable at MRO and ensure reasonably simple setup and easy transportability to all around the world requires to develop a "portable" device (i.e. low energy laser). Fiber delivery system, in contrast to heavy, "rigid" and complex mirror systems, provide advantages in terms of accessibility of complex structures. On the other hand the limitation of the current capability to deliver short pulsed laser beam into silica core fiber is well known [7], [8]; 100mJ is the maximum energy possible to inject into silica core fiber (using 532nm laser with pulse width of 8nsec and fiber diameter smaller than 1mm). But this low energy system that represent a solution for compact, light LSP device is said to be not capable to induce deep compressive stress.

The authors will demonstrate in this paper that low energy LSP system ($\leq$200mJ, pulse width of $\leq$20nsec) and associated small laser spot size (e.g. 0.7mm diameter) can determine high compressive stress in the near surface of 7175-T7351 material and compression depth above 1mm (Figure 1) if peening coverage is high enough. This residual stress profile is sufficient to extend the fatigue lives of critical components opening the door for development of portable LSP devices requiring low energy laser to be applied at MROs. The compressive stresses with a low energy LSP system is performed by scanning the surface to be treated with high percentage overlap (e.g. > 60% of the spot size) and advancing the line with similar overlap in the so called stepping direction. The residual stresses at near surface is influenced by the peening strategy, resulting in higher compressive residual stress component in the stepping direction compared to the scanning direction. This effect, only typical of low energy system and small spot size, tends to vanish with increased depth into the material. The investigations showed that even with at lower energy system (such as 532nm laser and 70mJ per pulse and shorter pulse width of 8nsec) the compressive residual stress can reach a depth in excess of 1mm into the material as shown in Figure 1. LSP with fiber delivery system provides interesting benefit in terms of accessibility to complex geometries and structures in particular in MRO environment, but the focus distance to the target when fibers are used is very limited (e.g. 20mm) becoming a challenge for treatment of complex 3-D shapes. The tolerances in positioning the focusing lens to the target application are very tight (e.g. ±0.5mm) resulting in possible change of laser spot size and shape at the target. It is important to quantify the range of variation of the spot size to determine the possible drop of compressive residual stresses because of reduction of laser irradiance (in GW/cm^2) in larger spots. Figure 1 shows the drop of compressive residual stress at near surface if the spot diameter increases from 0.6mm up to 1mm.

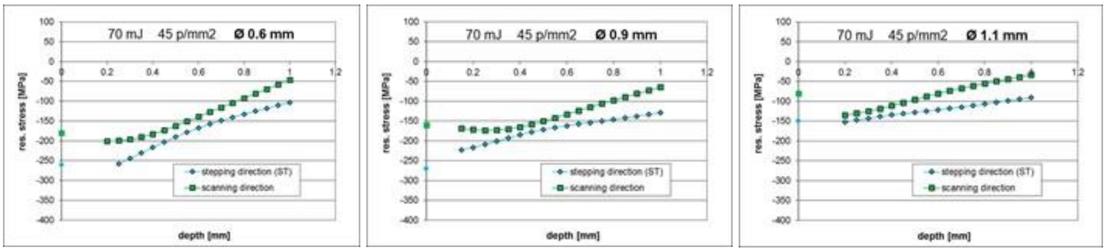
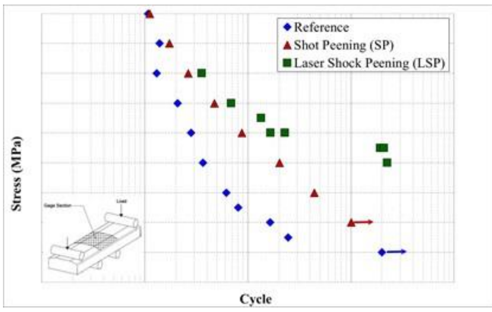
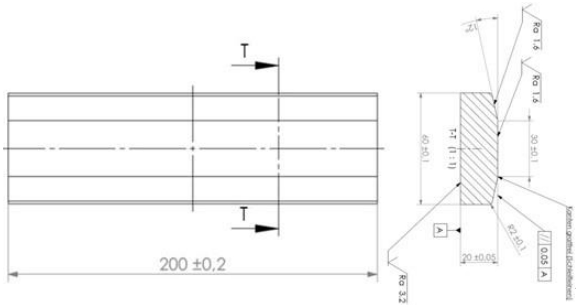


Figure 1. Residual Stress Profiles after LSP in 7175-T7351 material using 532 nm laser at 0.8 nsec pulse width and 45 pulses/mm2 at increased spot size.

The capability to extend the fatigue lives of aircraft component subjected to LSP provided by low energy system have been verified testing under fatigue cycling load four point bending coupon (Figure 2). Figure 2 a) shows the fatigue lives up to final failure of four points bending coupons made of 7175-T351. Fatigue performance of bare material (no treatment, reference) has been compared with the one after shot peening process and low energy LSP treatment demonstrating a superior fatigue lives at all surface stress levels.



a)



b)

Figure 2. Fatigue test results with stress ratio ($\sigma_{min}/\sigma_{max}$) of 0.1 of four point coupons of 7175-T7351 b).

Finally, the authors review the minimum requirements of LSP portable device to ensure the compatibility with typical MRO operational environments. Robustness, repeatability and stability of the LSP process are key features to be considered during the development of portable system. In service, the system will operate all around the world in various environments showing the need for supply chain reactivity. The system should be "easy to handle", providing appropriate training to Third Parties to operate and maintain it.

[1] D. Furfari, "Laser Shock Peening to Repair, Design and Manufacture Current and Future Aircraft Structures by Residual Stress Engineering", Advanced Materials Research Vols. 891-892 (2014) pp 992-1000, © (2014) Trans Tech Publications, Switzerland.

[2] E. Hombergsmeier, D. Furfari, N. Ohrloff, U. C. Heckenberger, V. Holzinger, "Enhanced Fatigue and Damage Tolerance of Aircraft Components by Introduction of Residual Stresses – A Comparison of Different Processes", 27th ICAF Symposium – Jerusalem, 5 – 7 June 2013.

[3] D. Furfari, N. Ohrloff, E. Hombergsmeier, U. C. Heckenberger, V. Holzinger, "Laser Shock Peening as Surface Technology to extend Fatigue Life in Metallic Airframe Structures", 35th ICAF Conference, Nagoya, Japan, 7-9 June 2017.

[4] Lt. Ken MacGillivray, B, Dane, M. Osborne, R. Bair, W. Garcia, "F-22 Laser Shock Peening Depot Transition and Risk Reduction", USAF ASIP Conf., 30/11–02/12, S. Antonio, TX, 2010.

[5] LeAnn Polin, J. Bunch, P. Caruso, J. McClure, "Full Scale Component Tests to Validate the Effects of Laser Shock Peening", ASIP 2011, Nov. 29-Dec. 1, San Antonio, TX.

[6] A. K. Gujba, M. Medraj, "Laser Peening Process and Its Impact on Materials Properties in Comparison with Shot Peening and Ultrasonic Impact Peening", Materials 2014, 7, 7925-7974.

[7] Y. Sano, K. Akita, K. Masaki, Y. Ochi, I. Altenberger, B. Scholtes, "Laser Peening without Coating as a Surface Enhancement Technology", JLMN-Journal of Laser Micro/Nanoengineering Vol. 1, No. 3, 2006.

[8] T. Uehara, Y. Sano, I. Chida, M. Yoda, N. Mukai, H. Kato, "Laser Peening Systems for Preventive Maintenance against Stress Corrosion Cracking in Nuclear Power Reactors", Proceedings of the 16th International Conference on Nuclear Engineering, ICONE16, May 11-15, 2008, Orlando, Florida, USA.