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Downsizing for New Flexibility in Laser Shock Peening

Laser Peening without Coating for Process Versatility and Surface Excellence on Challenging Part Areas

Introduction

Laser Shock Peening (or Laser Peening) is well-known for its high intensity and impact to achieve high residual stresses in extraordinary depth when compared to shot peening. Now Professor Yuji Sano from LAcubed and his team from SANKEN, Osaka University have succeeded in developing an extremely compact and mobile demonstration unit for Laser Peening without Coating (LPwC). A new bonding technology between optical components realizes a laser head with the typical size of a pen for the peening of specific and critical part areas with an amazing surface quality.

Professor Sano is considered one of the pioneers of the industrial use of laser peening since he developed LPwC for Toshiba Corporation in the 1990s to combat stress corrosion cracking (SCC) of components in nuclear power plants. In close co-operation with the Japanese team, sentenso in Germany built a small automated system with the laser head that peened a 3D surface and was controlled by an industrial robot. In a live demonstration in December, 2022 at the ECOMAT development centre of Airbus in Bremen, sentenso and the laser experts showed a typical application on aluminium samples in front of about 30 development engineers and material scientists. Immediately afterwards, sentenso was able to prove the induced residual compressive stresses with the help of the mobile μ-X360s X-ray stress analyser. LAcubed and sentenso are now proceeding to develop industrial applications for various materials and parts.

Technical explanation of the system

The LPwC system consists of a finger-sized laser mounted on a 6-axis compact robot arm, a power supply box, and a PC as a controller. The power supply box has a laser diode inside which pumps the laser at the tip of the robot arm via an optical fibre cable. Water used for LPwC can be recovered and reused by a water circulation system inside the power supply box. The complete system weighs only 20 kg and can be operated on 100-230 V with a maximum power consumption of 400 W.

The finger-sized laser was realized by a novel architecture using monolithic microchip laser technology developed by Professor Takunori Taira of the Institute for Molecular Science (IMS). He integrated all optical components into a single chip by room-temperature bonding to achieve robustness of laser oscillation against vibration and temperature changes. Thus, the laser can be operated stably under ambient conditions without air conditioning, typically as an end effector of a robot.

The mobile LPwC system that can be carried as two pieces of check-in baggage on an airplane. Operation can be re-started within one hour after arrival on site.

Laser and process parameters

The effect of LPwC is governed by its main process parameters:

- irradiated pulse energy,
- laser spot size, and
- pulse density (number of pulses irradiated per unit area).

The LPwC system uses a laser with pulse energies as low as 1 to 10 mJ, three-orders of magnitude less than current LSP systems. Thanks to low-energy laser pulses, the ablation volume is much less than with current technology, resulting in superior surfaces with a roughness Ra typically 1 μm after processing. The laser spot size on the sample is as small as 0.2-0.5 mm, making it much more adaptable to complex 3D geometries. However, the smaller spot size reduces the working speed.

Coverage and working speed

In LPwC, the surface is sequentially irradiated with successive laser pulses as if a wall is tiled, so the concept of the “coverage” is different from shot peening. The coverage in

Characteristics and advantages of LPwC versus traditional LSP

Criteria	Traditional LSP	Downsized LPwC
Setup	Typically needs a container for generator and two robots for laser head and part	Desktop size generator, finger-to palm-sized laser head, setup depending on size of working area, allows for automated machines with small footprint in serial production
Part preparation	Needs ablative coating prior to peening	Works without coating
Controllability of stress induction	Not easy to control process area precisely due to large spot size	Can control process area precisely by using small spot size
Versatility in process direction	Fixed laser direction	Flexible, all directions
Adaptability to parts with various thicknesses	Works well on thick parts, hardly applicable to thin parts due to distortion	Works for both thick and thin parts due to sensitive control of stress level and stress depth
Adaptability to edges	Not to be used on edges or close to functional areas	Can work close to edges (even on edge) and functional areas
Adaptability to different materials	Works for almost all metal materials	Works for almost all metal materials including some ceramics
Difficult-to-reach areas	Not to be used in narrow areas or inside holes	Small laser head allows access to narrow areas, applicable even in holes (under development)
Surface quality after peening	Major increase of surface roughness	Smooth surface, roughness Ra typically 1 μm, thin oxide film forms on surface
Working speed	Typically up to 2 m^2/h	Typically only up to 30 cm^2/h
Mobility	Possible, but heavy and bulky equipment of approximately 2 m^3	Smallest execution can be carried in two suitcases including robot, setup completes in less than one hour after transport

LPwC means how many pulses hit one point on average, and simply calculated by $(\pi D^2/4) \times \rho$, where D is the laser spot size (diameter) and ρ is the pulse density (number of pulses irradiated per unit area).

The area that can be peened with a single laser pulse is small, therefore typically 100-800 pulses are irradiated on 1 mm^2. The corresponding working speed is 36-4.5 cm^2/h based on the current pulse repetition rate of 100 Hz. Since the working speed is roughly proportional to the average laser power, the working speed of LPwC is much smaller than the traditional LSP.

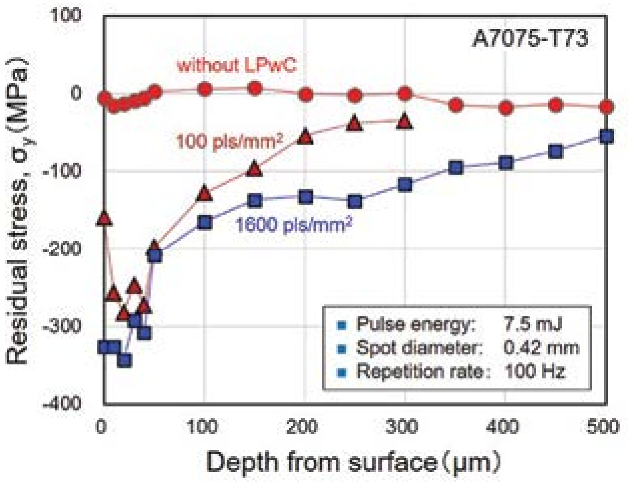
Typical use cases

Since the pulse energy of the finger-sized laser is 1-10 mJ and the laser spot size is 0.2-0.5 mm, the depth of compression by LPwC is shallow; typically, 0.1-0.6 mm. Therefore, LPwC is effective for application to thin parts that would be distorted by the traditional LSP. Furthermore, the small spot can follow uneven surfaces, making it suitable for peening applications to precision parts with 3D shapes. sentenso identifies several typical use cases:

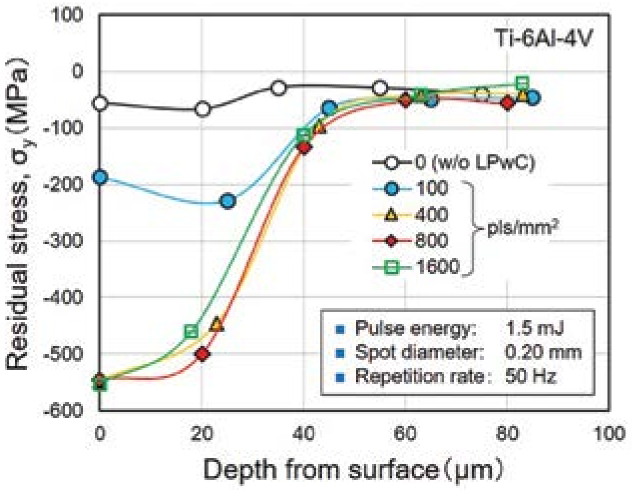
- on thin sections,
- along edges or cut-outs,
- close to functional areas, such as thread ends,
- on narrow geometries, such as tooth roots of small gears of module <0.3 mm, pitch <1 mm
- on narrow lines, such as laser welds

Stress profiles and fatigue test results of aluminium and titanium alloys

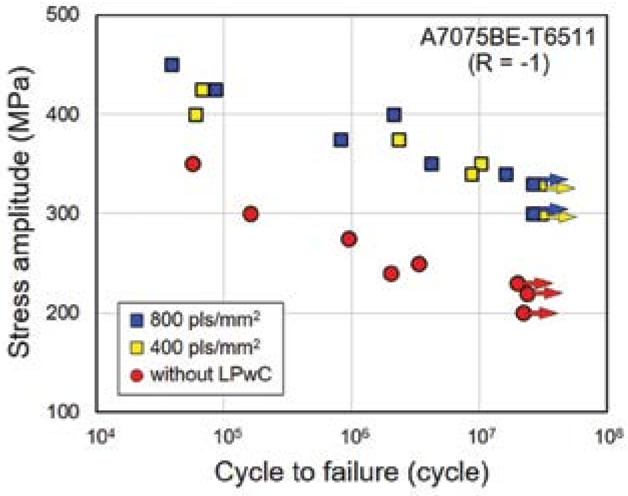
LPwC was applied to an aluminum alloy A7075-T73 with an irradiated pulse energy of 7.5 mJ and a spot size of 0.42 mm. The pulse density was varied from 100 to 1600 pulses/mm^2. Surface residual stress was measured by X-ray diffraction (XRD) using an X-ray stress analyser μ-X360s, and the depth profile was estimated by alternately repeating XRD and electrolytic polishing of the sample. Compression reached a depth of 0.3-0.6 mm depending on the pulse density. For harder materials at lower pulse energies, e.g., 1.5 mJ for Ti-6Al-4V, the depth of compression was found to be as shallow as 0.05 mm.



Residual stress depth profile of A7075-T73



Residual stress depth profile of Ti-6Al-4V

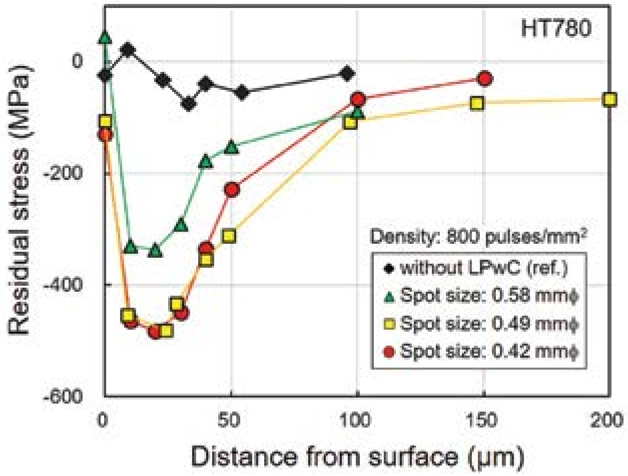


Fatigue test results for A7075BE-T6511

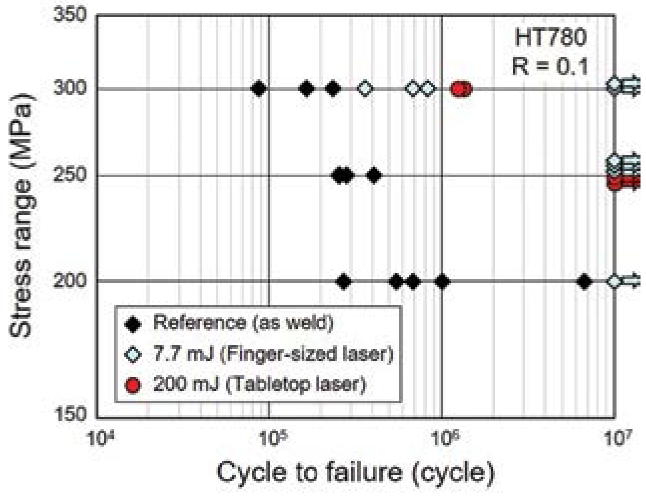
The effect of LPwC on improving fatigue properties was confirmed. Rotating-bending fatigue tests were conducted for aluminum alloy A7075BE-T6511 samples after LPwC with an irradiated pulse energy of 1.7 mJ, a spot size of 0.3 mm and pulse densities of 400 and 800 pulses/mm². The induced depth of compression was shallow, approximately 0.15 mm, but the fatigue strength was improved by 50 MPa and the fatigue life was extended by 100 times compared to the unpeened reference.

Stress profiles and fatigue test results of high-strength steel

Improving the fatigue properties of welded joints is an attractive application. For example, welding largely reduces the benefit of using high-strength steels due to softening and resulting tensile residual stresses. To recover the fatigue properties and the benefits of using high-strength steels, welded joint samples of a 780 MPa grade high-strength steel HT780 were subjected to LPwC with a pulse energy of 7.7 mJ, spot size of 0.49 mm and pulse density of 800 pulses/mm². Uniaxial fatigue tests showed that LPwC was evidently



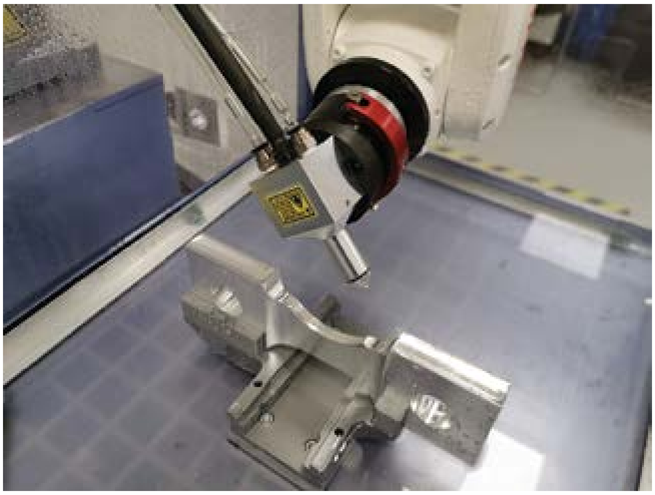
Residual stress depth profiles of HT780 base metal



Fatigue test results for HT780 welded joint samples effective and improved the fatigue strength of the weld joint samples by at least 50 MPa, although there was a large scatter in fatigue data due to manual welding. LPwC with pulse energy of both 7.7 mJ and 200 mJ were equally effective in improving fatigue properties. Process conditions can even be optimized to obtain higher compression on the top surface.

Benefits and outlook

LPwC is as simple as irradiating a water-covered sample with successive laser pulses. No ablative coating or other pretreatment is required for the sample. LPwC has a small laser spot, which makes it easy to precisely follow the shape of a 3D part, but it has the restriction of a low-working speed. Therefore, the development of higher energy lasers within a size that can be manipulated by robots is underway. Currently, the team around Professor Sano have realized a palm-sized 25 mJ × 100 Hz laser and expect to achieve 1 mm depth compression into aluminum alloys. Furthermore, there is potential to increase the pulse repetition rate to the kHz range in the future to compensate for the low-working speed.



LPwC of a 3D-shaped sample by using an industrial robot.

In the coming months, the peening experts from sentenso and Japan will intensify their co-operation to work out potential applications with pilot customers and with an open mind for ideas of interested process engineers. Furthermore, there is a number of universities and institutes looking into multinational research projects.

To watch a video on Downsized LPwC, scan the QR code or visit https://share.sentenso.de/s/LSPwC. ●