Development of a peening device with a handheld laser on a collaborative robot

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Abstract

A compact laser peening (LP) device has been developed for application to large structures such as bridges in service. The device consists of a thumb-sized handheld laser mounted on a collaborative robot, a power supply, a water circulation system, and a PC as a control unit. Various materials such as aluminum alloys and high-strength steels were laser-peened by using this device. Results of residual stress (RS) evaluation and fatigue experiments showed that LP with this device significantly improved the RSs in the near-surface layer and fatigue properties of materials.

Keywords Microchip laser, robotic arm, laser peening, residual stress, fatigue.

Introduction

LP introduces compressive RS on the surface of a water-covered component by exposing it to successive laser pulses [1]. LP is effective in preventing fatigue cracking of components under repetitive loading [2-8]. Existing LP devices [9] utilize high-power lasers assembled on large vibration-proof optical benches. Due to their volume and weight, the application of the existing LP devices has been limited to indoor research or production [10].

There is microchip laser technology [11-14] that can drastically reduce the size and weight of laser oscillators. If a microchip laser could be used as the energy source for LP, the scale of LP devices can be reduced, making it feasible to apply LP not only to production but also to on-site maintenance of existing infrastructure such as bridges in service. Based on this idea, we have developed a compact movable LP device with a handheld-type microchip laser.

Laser Peening Device with a Handheld Laser

The configuration and appearance of the prototype movable LP device are shown in Figs. 1 and 2 [15]. The device consists of two parts: a small 6-axis robotic arm equipped with a thumb-sized handheld-type laser and a power supply including a water circulation system. The power supply incorporates a built-in laser diode, which pumps the handheld laser via an optical fiber cable. The water circulation system recovers and reuses the water for LP. The device operates at 100-220 VAC and have a maximum power consumption of 400 W. The robotic arm weighs 4 kg and the device can be carried as two pieces of airline baggage. The use of the collaborative robotic arm eliminates the need for fences or other safety measures.

Effects on Surface Residual Stress of A7075

Samples of A7075-T73 aluminum alloy plates were laser-peened by the device [16]. Surface RS was analyzed by X-ray diffraction (XRD) and the RS depth distribution was obtained by alternating XRD and electrolytic polishing. The same operation was also performed on the unpeened material to evaluate the effect of LP.

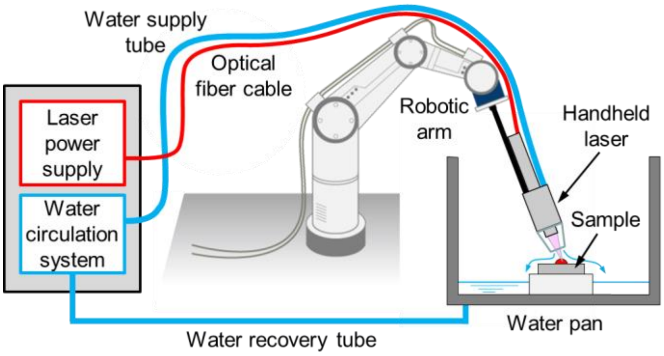

Fig. 1 Configuration of movable laser peening device

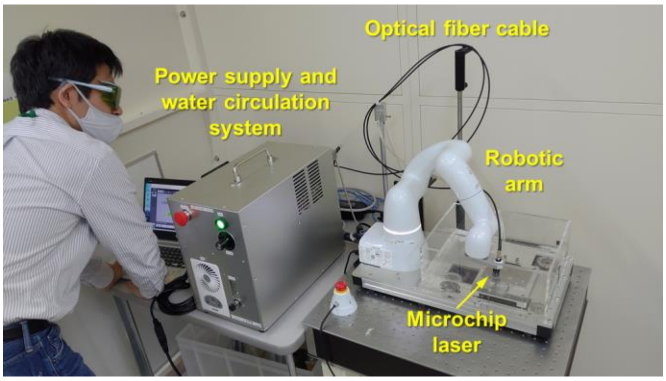

Fig. 2 Overall appearance of movable laser peening device

Figure 3 shows the results of RS evaluation for 3.2 mm (1/8 inch) thick A7075-T73 aluminum alloy plates. Here, σ_x and σ_y are the RS components parallel and perpendicular to the laser sweep direction, respectively. The irradiated laser pulse energy was 7.5 mJ, which is orders of magnitude smaller than that in the usual process with existing LP devices. The standard deviation of the regression in XRD was about ±10 MPa. The depth of compression by LP reaches about 0.3 mm from the surface for an irradiation pulse density of 100 pulses/mm^2 and more than 0.5 mm for 1600 pulses/mm^2.

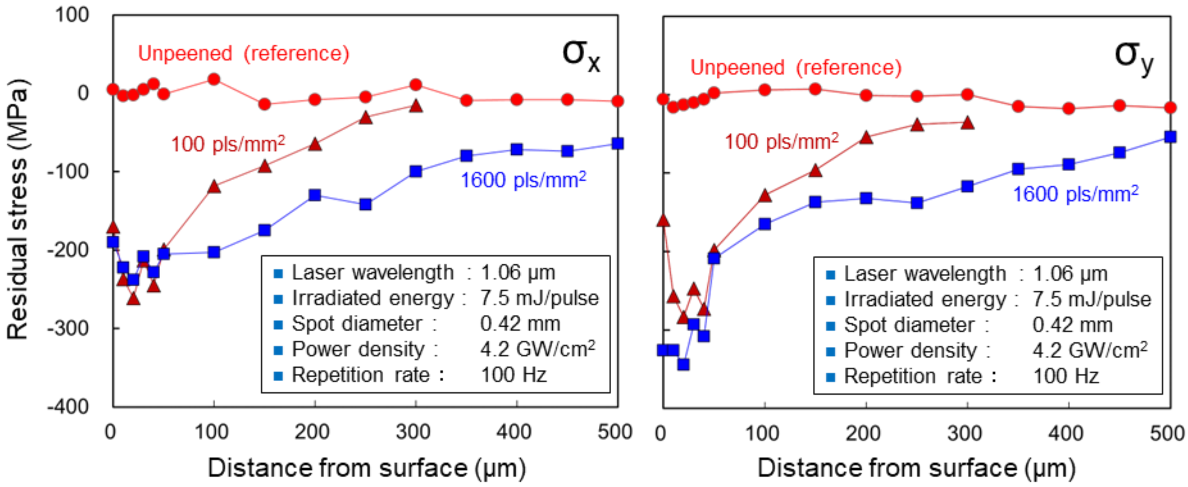

Fig. 3 Residual stress depth profiles of A7075-T73 in x-direction (left) and y-direction (right)

Effects on Surface Residual Stress of HT780

LP was applied to 9 mm thick HT780 high-strength steel plates with mill-scale on the surface. Figure 3 shows the RS profiles of HT780 obtained by the same procedure as A7075-T73. The standard deviation of the regression in the XRD measurement was less than ±10 MPa.

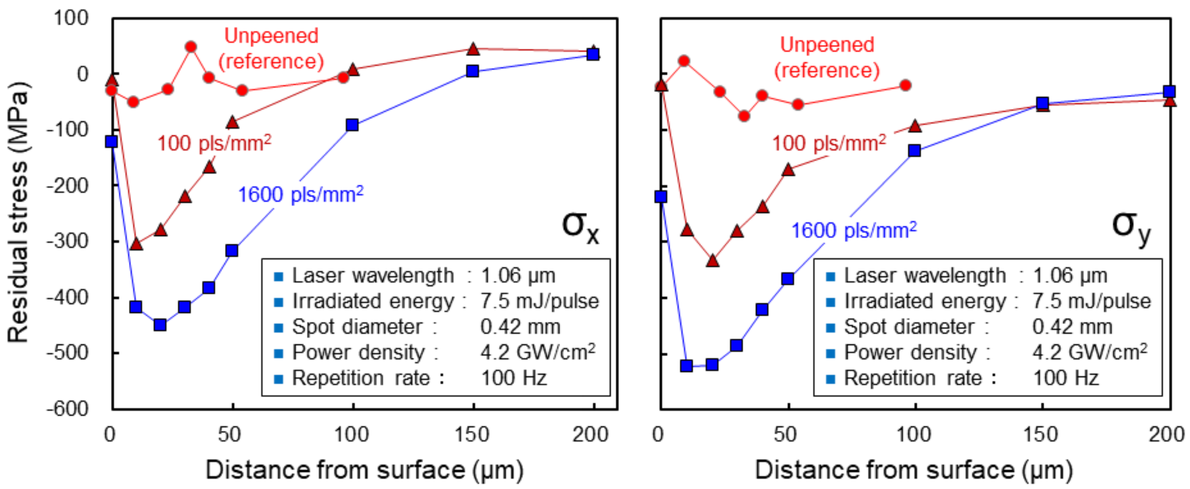

Fig. 4 Residual stress depth profiles of HT780 in x-direction (left) and y-direction (right)

On the top surface of the laser-peened material, the absolute values of the RSs are fairly smaller than those just below the top surface. This may be due to the fact that the mill-scale still remains after LP, affecting the XRD results. When the surface was slightly removed by electrolytic polishing, large compressive RSs appeared. Further experiments are needed to better understand this phenomenon.

Effect on Fatigue Properties

Fatigue experiments were performed for A7075BE-T6511 aluminum alloy samples after LP with a pulse energy of 1.7 mJ [16] and HT780 high-strength steel welded joint samples with 7.7 mJ [15]. As a result, it was confirmed that LP using a microchip laser with pulse energies less than 10 mJ significantly improved fatigue strength and life. The details are provided in the accompanying papers by Masaki and Mizuta at this conference.

Conclusions

A newly-prototyped movable LP device was applied to samples of A7075 aluminum alloy and HT780 high-strength steel with pulse energies of less than 10 mJ. The results showed that RSs in the near-surface layer were significantly improved despite the pulse energies being several orders of magnitude lower than those of the existing LP devices.

The existing LP devices are bulky and cannot be used outdoors, thus their applications have been limited to indoor production [9,10]. With the commercialization of compact and high-power microchip lasers, movable LP devices could be used for a variety of applications. In particular, when combined with a small collaborative robotic arm, LP can be easily applied in a variety of situations, such as post-weld processing at construction sites and infrastructure maintenance.

Acknowledgments

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