Introduction of compressive residual stress into alloy steel by cavitation peening using laser cavitation

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Introduction

In case of submerged laser peening, a bubble is initiated after laser abrasion, and developed then collapsed. The bubble produces impact at bubble collapse. As the bubble behaves similar to cavitation bubble, the bubble generated at submerged laser peening is called as "laser cavitation" in the present paper.

It was believed that the shock wave induced by the laser abrasion produces peening effect in submerged laser peening, as the pressure induced by the laser abrasion was larger than that of laser cavitation by a submerged shock wave sensor [1]. However, it has been reported that the impact induced by laser cavitation collapse is larger than that of laser abrasion, when pressure wave was measured by hydrophone [2] and pressure wave in the material was measured by polyvinylidene fluoride PVDF sensor [3], [4]. Thus, it might be possible to peen the materials by laser cavitation.

Objectives

In order to demonstrate peening effect of cavitation peening using laser cavitation, impacts induced by laser abrasion and laser cavitation was measured. Residual stress of alloy tool steel was evaluated to reveal the introduction of compressive residual stress by laser cavitation.

Methodology

Figure 1 illustrates the schematic diagram of the cavitation peening system using laser cavitation. The pulse laser was used to generate the laser cavitation. The wave length, the maximum energy, the beam diameter, the pulse width and the repetition frequency of a used pulse laser of Nd:YAG laser with Q-switch were 1064 nm, 0.35 J, 6 mm, 6 ns and 6 ns and 10 Hz, respectively. The aspects of laser abrasion and laser cavitation were observed by a high speed video camera. The specimen was placed in a water filled chamber made of quartz glass. As peening intensity was affected by distances from convex lens to chamber wall s_a and from chamber wall to the specimen surface s_w, the distances were optimized by measuring arc height of Almen strip changing with the distances. Figure 2 illustrates the direction of cavitation peening using laser cavitation and the direction of the stress at the residual stress measurement. The specimen was treated with and without a black coated aluminium tape whose thickness was about 80 μm.

The used material to demonstrate the introduction of compressive residual stress into metallic material was alloy tool steel Japanese Industrial Standard JIS SKD61. The chemical composition of

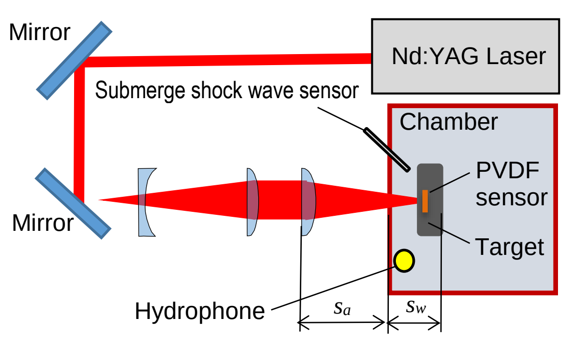


Fig. 1 Schematic diagram of cavitation peening system using laser

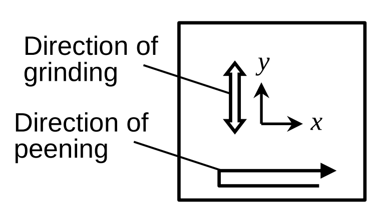


Fig. 2 Direction of laser peening and direction of stress

Table 1 Chemical composition of alloy tool steel (%)

C	Si	Mn	P	S	Cr	Mo	V
0.36	1.00	0.41	0.007	< 0.001	5.13	1.26	0.82

tested was shown in Table 1. The material was heat treated by heating at 1073 K for 80 min, 1223 K for 10 min and 1298 K for 1.5 h, then gas quenched. After quenching, the material was tempered at 823 K for 2 h and 793 K for 2 h, then air cooled. The surface of the specimen was finished by grinding process. The direction of grinding process was shown in Fig. 2.

The residual stress was measured by 2D method using an X-ray diffraction method. The used X-ray was from Cr tube operated at 35 kV and 40 mA through a 0.8 mm diameter and with an incident monochromator. The used lattice plane (h k l) was α-Fe (2 1 1) plane and the diffraction angle without strain was 156 degrees. The diffraction ring from the specimen was detected at several angles by the 2D-PSPC. The specimen was scanned by ±4 mm in x-and y-direction.

Results and analysis

In order to reveal the peening intensity of proposed cavitation peening system using laser cavitation, Fig. 3 shows the arc height of Almen strip of A-gage h changing with number of laser cavitation per unit area N_L. The Almen gage was treated by 1 pulse/mm^2 and it was treated by 4 times with and without the black tape, respectively. The arc height h was increased with the increase of N_L, and h was nearly proportional to N_L. The difference of arc height of with and without the black tape was small. When the black tape was put on the Almen strip, the impact induced by collapse of the laser cavitation to the material might be attenuated by the tape. However, the size of laser cavitation was increased, as the black tape converged the laser energy, and then bubble collapse impact was increased by the black tape.

In order to investigate the impact of laser cavitation comparing with that of laser abrasion, Fig. 4 shows the aspect of the laser abrasion and the laser cavitation, and Fig. 5 reveals the output signal from the PVDF sensor, the hydrophone and the submerged shock wave sensor. Figures 4 and 5 were recorded at the same time. As shown in Fig. 4, after laser abrasion at t = 0 ms, the laser cavitation was developed as a hemi spherical bubble, then collapsed at t = 1.03 ms. The maximum radius of the laser cavitation was about 10 mm. The second collapse was observed at t = 1.56 ms and it was also detected by the PVDF sensor. As mentioned in previous report [4], when the signals were detected by the submerged shock sensor, the amplitude of signal induced by the laser abrasion was larger than that of collapse at the laser cavitation. However, when the shock waves were detected by the PVDF sensor, which was installed in the target, the amplitude of signal of the laser cavitation was 1.5 times larger than that of the laser abrasion. As it was reported that the impact energy was proportional to the square of the amplitude of the output signal from the PVDF sensor [5],[6], the impact energy induced by the collapse of laser cavitation is 2.25 times larger than that of laser abrasion. As the impact energy at laser cavitation was affected by the air contents in water due to cushion effect [7], in the present experiment, the water was degassed by degassing membrane to enhance the impact energy at laser cavitation collapse.

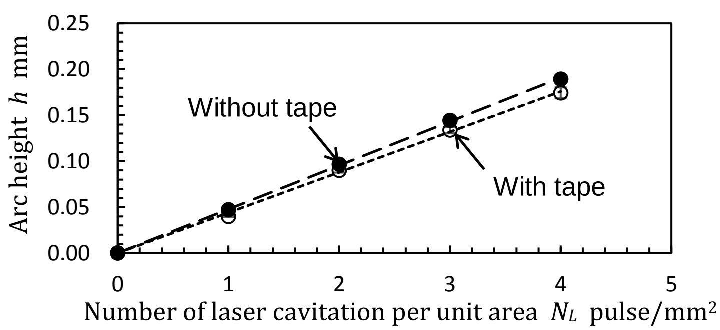


Fig. 3 Peening intensity measured by Almen strip of A-gage

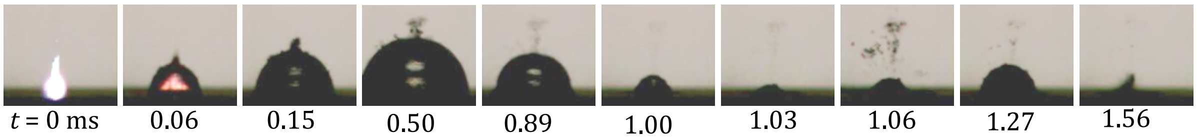
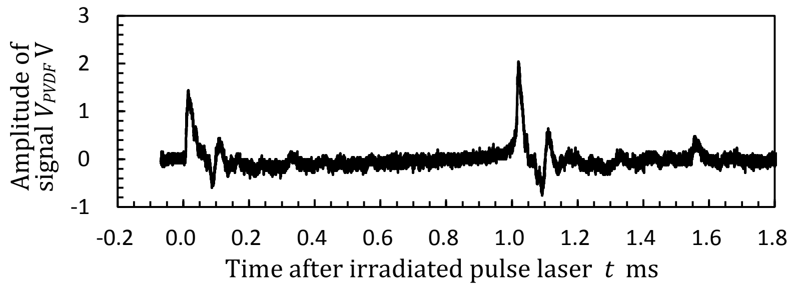
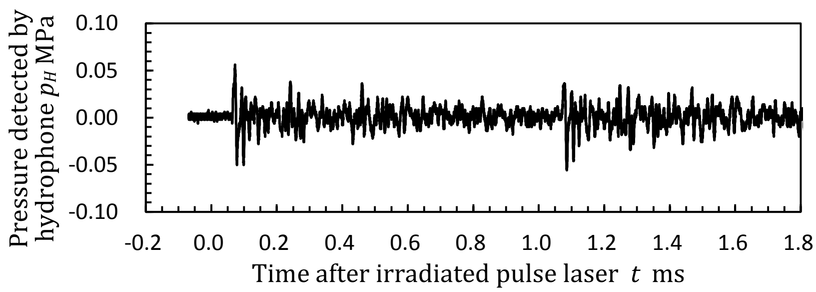


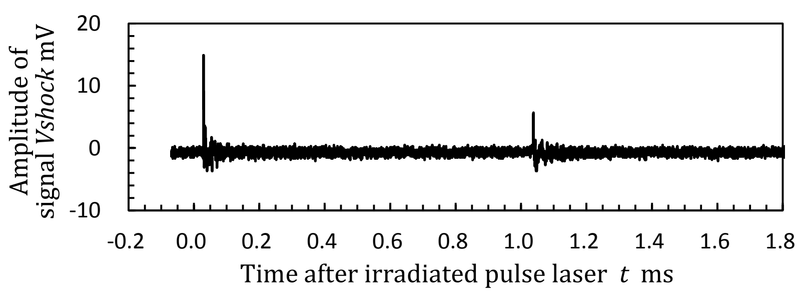
Fig. 4 Aspect of laser abrasion and laser cavitation



(a) PVDF sensor



(b) Hydrophone



(c) Submerged shock wave sensor

Fig. 5 Output signal from sensors

In order to demonstrate peening effect of proposed cavitation peening by laser cavitation, the introduced residuals stress of two specimens was shown in Fig. 6. As the specimen made of SKD61 was grinded, the residual stress on the surface before peening was about -900±30 MPa in grinding direction and about -290±20 MPa in orthogonal direction to the grinding direction. Specimen was treated by the pulse laser at 1 pulse/mm^2 with the black tape. After 12 times, i.e., 12 pulse/mm^2, the residual stresses became -985±17 MPa and -500±21 MPa, respectively. Namely, cavitation peening by using laser cavitation of 1064 nm laser can introduce compressive residual stress, although laser of 1064 nm was absorbed by water.

Figure 7 illustrates the full width at half maximum $\Delta 2\theta$ as a function of laser cavitation per unit area N_L. Although proposed cavitation peening using laser cavitation introduced compressive residual stress, $\Delta 2\theta$ was decreased with an increase of N_L as same as cavitation peening using the cavitating jet in air [8].

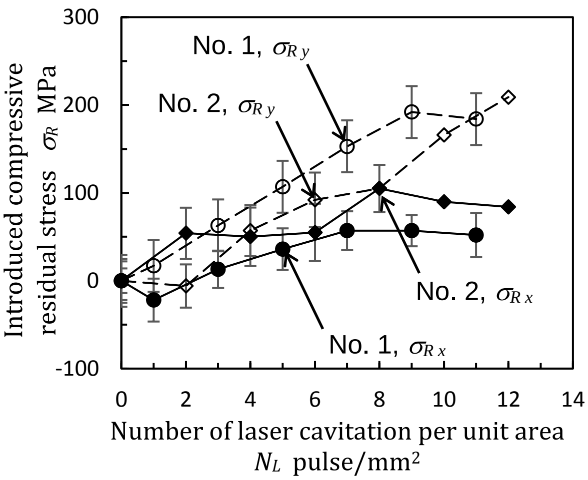


Fig. 6 Introduced compressive residual stress as a function of number of laser cavitation per unit area

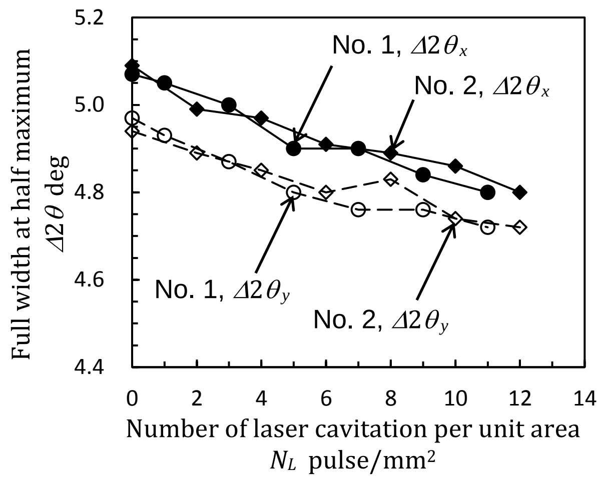


Fig. 7 Decrease of full width at half maximum as a function of number of laser cavitation per unit area

Conclusions

In order to demonstrate the mechanical surface treatment by cavitation peening using laser cavitation, impact energies induced by the laser abrasion and laser cavitation were evaluated by the PVDF sensor which was installed in the target, and the compressive residual stress of alloy tool steel was measured. It was revealed that the impact energy induced by the laser cavitation was about 2 times larger than that of laser abrasion, and the compressive residual stress was introduced by the proposed cavitation peening.

Acknowledgements

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