Improvement of fatigue property of A7075 aluminum alloy by laser peening with handheld laser device

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Abstract
In recent years, new handheld pulse laser oscillators have been developed that are much smaller than currently-used pulse laser devices. In this study, in order to investigate the effectiveness as a laser source of laser peening (LP), rotating bending high cycle fatigue test was conducted on referenced pristine and laser-peened aluminum alloys of Al-Zn-Mg-Cu system. As a result, the rotational bending fatigue properties were significantly improved by the LP treatment. The fatigue strength is improved by about 1.5 times, and the fatigue life is extended by about 100 times compared with the fatigue property of the pristine material. It was found that the developed new handheld pulse laser oscillator can be used for the LP treatment.

Keywords Laser shock peening, Handheld pulse laser oscillator, Fatigue, Aluminum alloy

Introduction
Laser peening (LP) processing is one of peening technologies in which a metal material placed in water is irradiated with a pulse laser and peened by the generated shock wave [1]. Since conventional LP requires large-scale and high-cost laser equipment, smaller and cheaper pulse laser oscillators have been desired for further industrial applications [2],[3]. In recent years, new handheld pulse laser oscillators have been developed by ImPACT program in Japan that are much smaller and cheaper than currently-used equipment [4],[5]. In order to investigate the effectiveness of the newly-developed handheld pulse laser oscillator for LP treatment, rotating bending fatigue tests were conducted on Al-Zn-Mg-Cu system aluminum alloys.

Experimental Methods
Material
The material used in this study is A7075BE-T6511 aluminum alloy. After extruding into a bar with a diameter of 15 mm, solution heat treatment, residual stress relief treatment and artificial aging treatment were applied. Chemical composition and mechanical properties of the material are shown in Table 1 and 2.

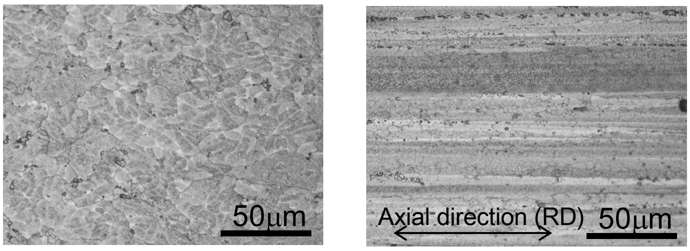
Table 1. Chemical composition of the material. (%)

Si	Fe	Cu	Mn	Cr	Zn	Ti	Ti+Zr	Al
0.08	0.19	1.6	0.04	2.6	5.8	0.01	0.02	Bal.

Table 2. Mechanical properties of the material. (Experimental data)

Tensile strength σ_B MPa	0.2% proof stress $\sigma_{0.2}$ MPa	Elongation δ %	Reduction of area Ψ %	Hardness Hv
685	631	12.6	23.4	189

Observation result of microstructure with an optical microscope is shown Fig.1. In this material, an oriented texture is well developed in the axial direction. The result of crystal orientation analysis (EBSD analysis) is in Fig.2. It is clear also from the IP map that the oriented texture in the axial direction is well developed in this material.



(a) Cross section (b) Longitudinal section

Fig.1 Observation result of microstructure.

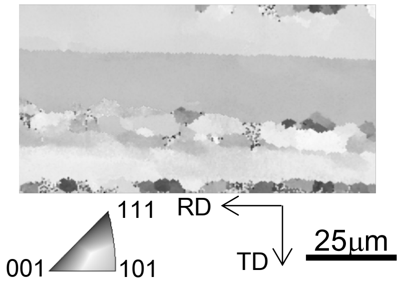
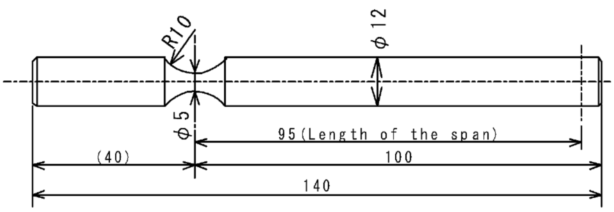


Fig.2 EBSD analysis result (IP Map)

Specimen and fatigue test

The shape of test specimens in this study is an hour glass type as shown in Fig.3. The stress concentration factor of this shape is 1.074 [6]. The LP treatment was performed only to the notch area. The laser device used in this study was a prototype handheld pulse laser oscillator provided by OPTOQUEST Co., Ltd. An over view of the laser peening system is shown in Fig.4. The LP treatment was performed with the following conditions; an irradiation energy of 1.68mJ, a spot diameter of 0.3mm, a repetition rate of 50Hz and laser irradiation densities of 400 and 800 pulse/mm^2. Cantilever type rotating bending fatigue test was carried out with a rotating speed of 4000 rpm in the air at room temperature.



(unit:mm)

Fig.3 Shape of fatigue test specimen

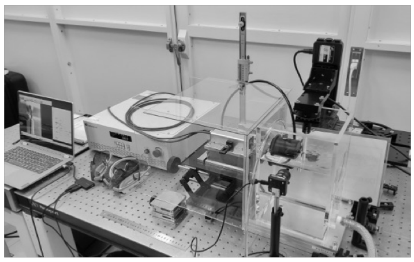


Fig.4 Laser peening system

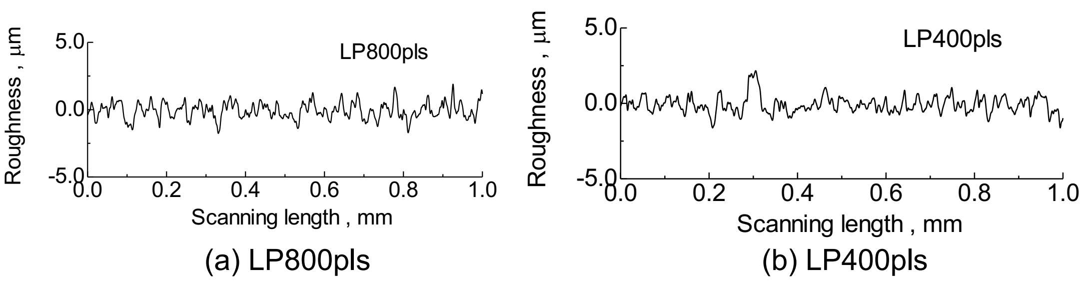
Experimental Results and Discussion

Peening effect

Surface roughness profiles and surface roughness values are shown in Fig.5. Although the surface roughness increases by handheld LP treatment, the surface roughness values are smaller than conventional SP and LP treatment values [7]. That is, fatigue strength reduction effect due to surface roughness is not significant.

	LP800pls	LP400pls
Ra	0.459μm	0.409μm
Rz	2.75μm	2.47μm

Ra : arithmetic average roughness
Rz : maximum height of irregularities



(a) LP800pls (b) LP400pls

Fig.5 Surface roughness profiles and values.

Hardness distributions of LP treated specimens are shown in Fig.6. Strain hardening due to the handheld LP treatment is slight. The hardness distribution of the LP400pls is even from 180 to 190Hv which is the same value as the base metal, 189Hv, as shown in Table 2. On the other hand, the surface hardness value was slightly increased by the LP800pls condition. The thickness of hardened layer is about 50μm and its hardness value is about 210Hv.

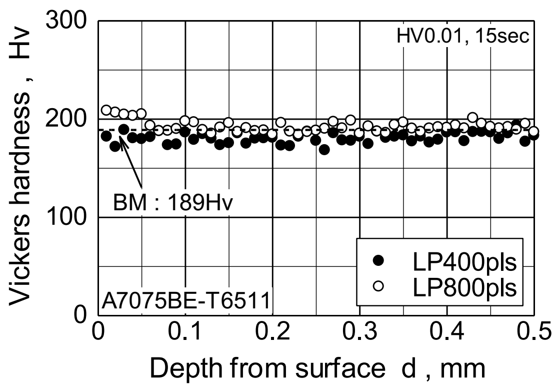


Fig.6 Hardness distributions

At this time, the residual stress distributions have not yet been measured. However, it is expected that the distributions will be similar to that of A7075 material shown in the previous report [5].

Fatigue testing results

S-N curves of fatigue testing result are shown in Fig.7. The rotational bending fatigue properties were significantly improved by the handheld LP treatment. The difference in fatigue properties between different pulse densities was not remarkable. The fatigue strength is improved by about 1.5 times, and the fatigue life is extended by about 100 times than non-peening material. It was found that the newly-developed handheld pulse laser oscillator can be used for LP processing. Typical fatigue fracture surfaces are shown in Fig.8. There was a big difference between the non-peening specimen and LP specimens. The fracture surface of all non-peening specimens were on a flat plane perpendicular to the axial direction as shown in Fig.8(a). On the other hand, most of fracture surface shapes of the LP specimens were a pointed one as shown in Fig.8(b) and (c). As the result of optical microscope observation, a lot of black oxide powder was observed on the inclined surface. That is, the inclined surface was not formed in the final fracture process, but in the fatigue process.

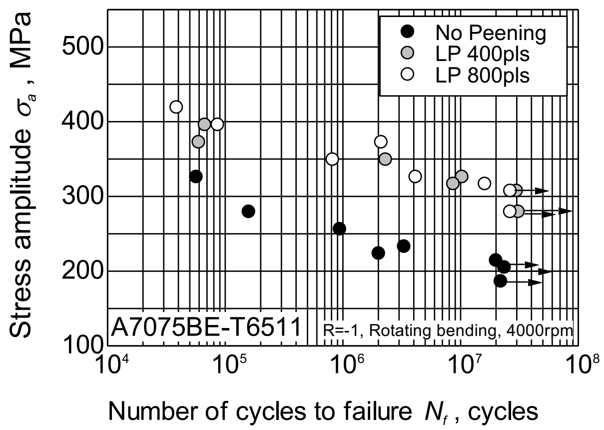


Fig.7 S-N curves of all specimens.

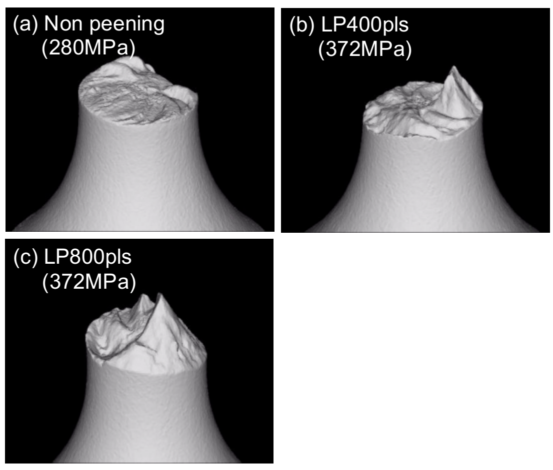


Fig.8 Typical fatigue fracture surfaces

The angle of the inclined surface to the cross section of the specimen is about 55 to 60 degree. The material used in this study has an oriented texture in the axial direction in which the (001) plane of fcc crystal structure coincides with the cross section of the specimen. The angle of slip system {111} <110> for the cross section of this specimen is 54.7 degrees. This value is the same as the angle of the inclined surface. The cause of this phenomenon is considered to be the residual stress due to the LP treatment. It is considered that the generation and propagation of surface cracks was suppressed by the high compressive residual stress. Even if the fatigue crack can be generated at surface, the fatigue crack cannot grow in mode I which is crack open mode. More than that, the large-scale glide plane decohesion occurred inside the test specimen due to the influence of the developed texture in a triaxial stress state. In any case, the fatigue property of A7075BE-T6511 material is significantly improved by LP processing with a handheld pulse laser oscillator. This new device can be widely used in the industry in the future.

Conclusions

In order to investigate the effectiveness of newly-developed handheld pulse laser oscillators as a laser source of LP processing, rotating bending high cycle fatigue test was conducted on A7075BE-T6511 material used for aircraft components. Although the fatigue fracture mechanism was significantly affected by the well-developed oriented texture, the fatigue property was significantly improved by LP processing. The fatigue strength is improved by about 1.5 times, and the fatigue life is extended by about 100 times than non-peening material. It is clarified that the newly-developed handheld pulsed laser oscillator can be used for LP processing and that it can be used in a wide variety of industrial fields.

Acknowledgments

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