Development of Indirect Laser Peening Process for forming a micro dimple and making powder deposition on the substrate

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Abstract

A modification of laser peening process has been carried out for forming a micro-dimple and introducing compressive residual stress in the materials and making powder deposition on the surface of substrates such as metal, polymer and wood using a metal foil.

In the present work, Q-switch pulsed YAG laser with a max. pulse energy of 650mJ as a wave length of 532nm has been used to generate ultra-high plasma pressure of around 5GPa in 8-10ns. The diameter and depth of dimple formed can be controlled by the beam spot size, max. pulse energy and thickness of metal foil in the range of 200 μm to 700 μm in diameter and in the range of 5 μm to 50 μm in depth, respectively. A trial of indirect laser peening was carried out to deposit MoS2 powders on A6061 aluminum alloy substrate to reduce the friction energy loss of piston for car engine. Process parameters such as laser intensity, type of metal foil and thickness of metal foil have been investigated to characterize this new process.

Introduction

Laser peening is a kind of laser surface treatment that introduces compressive residual stress on the material surface. The compressive residual stress is very effective for improvement of fatigue strength [1-2] and stress corrosion cracking of structures [3-4]. On the other hand, Indirect Laser Peening is a new laser peening process. Developed by prof. M.Kutsuna and Mr. K.Saito in 2005 (Japanese patent No.4058448). In this process, a metal foil is used to generate ultra-high plasma pressure and to make micro-dimples on the surface of substrate with deposition of metal or non metallic particles.

In the present work, process parameters of indirect laser peening (ILP) process has been investigated for the characterization of the process for the applications to machinery part such as car engine piston and piston ring as shown in Fig.1.

Fig.1 Application of ILP process to piston head

The mechanism of indirect laser peening (ILP process) is shown in Fig.2. ILP process is carried out under the water. Therefore, second harmonic wave of YAG laser (λ = 532 nm) is recommended to get effective plasma pressure for surface modification[5].
High intensity laser beam with short pulse is required to get ultra-high plasma pressure in 8 - 10 ns in the process. Many kinds of metal foil are used as a base sheet to absorb the laser power and to generate ultra-high plasma pressure of 5GPa. The plastically-deformed base sheet is used for put the high pressure upon the substrate to make a micro dimple. In the conventional laser peening, base sheet is not used to make micro-dimples on the substrate. It can be called as a direct laser peening. In addition, metallic/non metallic particles is put on the back surface of base sheet to make metallic or non metallic deposition/coating on substrate before indirect laser peening.

**Experimental Procedure**

Materials used are SK85 tool steel foil, AISI 304 type stainless steel foil, AISI 410 type stainless steel foil and SS400 mild steel foil (the thickness: 15,25,35 and 45 μm) as metal sheet, MoS2 powder for reduction of friction energy loss, and A6061 aluminum alloy plate as a substrate.

In the present work, Q-switch pulsed YAG laser with a max. pulse energy of 650mJ as a wave length of 532nm has been used to generate ultra-high plasma pressure of around 5GPa in 10-20ns. The beam spot diameter is from 200 μm to 700 μm. The diameter and depth of dimple formed can be controlled by the beam spot size, max. pulse energy and thickness of metal foil in the range of 200 μm ~ 700 μm in diameter, in the range of 10mJ ~ 650mJ in pulse energy and in the range of 15 μm ~ 45 μm in metal foil thickness. Fig.3 shows the experimental setup of indirect laser peening system in Advanced Laser Technology Research Center Co.

**Experimental Result and discussion**

The effects of process parameters such as laser intensity, type of metal foil and thickness of metal foil on the shape of dimple and deposition of MoS2 powder have been investigated. Fig.4 shows...
the example of dimples on the metal foil and Fig.5 shows the shape of dimples on the A6061 substrate. The diameter is about 420 μm and the max. depth is 79 μm. The green laser (λ = 532nm) is effective to make a dimple on the base sheet under the water as shown in Fig. 6.

![Image of dimples on metal foil](image1)

The diameter and depth of dimple on the metal foil is 661 μm and 22 μm, respectively.

![Image of dimple on piston under water](image2)

The effect of thickness of SK tool steel foil on the formation of dimple has been investigated under the condition A shown in Table 1. The one of results is shown in Fig.7. The laser intensity was 4.9GW/cm2. ~29.7GW/cm2

<table>
<thead>
<tr>
<th>Table 1 The peening condition A</th>
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<tbody>
<tr>
<td>Pulse energy (mJ)</td>
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<tr>
<td>Spot diameter (μm)</td>
</tr>
<tr>
<td>Power density (GW/cm2)</td>
</tr>
<tr>
<td>Number of shot</td>
</tr>
<tr>
<td>Thickness of metal foil (μm)</td>
</tr>
</tbody>
</table>

![Image of dimple on metal foil](image3)

The dimple on the A6061 substrate is 233 μm in diameter and 8 μm in depth was formed by ILP process as shown in Fig.8. Using 25 μm thick...
metal foil, dimple was formed as shown in Figs. 9 and 10. The dimple on the metal foil is more than 481 μm in diameter and 12 μm in depth and the dimple on the A6061 alloy substrate is 158 μm and 2 μm in depth. The higher the thickness of metal foil is, the higher laser intensity is required.

Using 35 μm thick SK steel foil, the dimple was formed as shown in Figs. 11 and 12. The dimple on the steel foil is more than 481 μm in diameter and 6 μm in depth and the dimple on the A6061 alloy substrate is 158 μm and 2 μm in depth.

Fig. 9 Dimple on 25 μm thick metal foil formed by ILP process under the 19.8GW/cm²

Fig. 10 Dimple and MoS2 powders on A6061 substrate formed by ILP process under the 19.8GW/cm² using 25 μm thick metal foil

Fig. 11 Dimple on 35 μm thick SK85 steel foil formed by ILP process under the 19.8GW/cm²

Fig. 12 No dimple and MoS2 powder on A6061 substrate formed by ILP process under the 19.8GW/cm² using 35 μm thick metal foil

Using 35 μm thick SK steel foil, the dimple was formed as shown in Figs. 11 and 12. The dimple on the steel foil is more than 481 μm in diameter and 6 μm in depth and the dimple on the A6061 alloy substrate is 158 μm and 2 μm in depth.

Fig. 11 Dimple on 35 μm thick SK85 steel foil formed by ILP process under the 19.8GW/cm²

Fig. 12 No dimple and MoS2 powder on A6061 substrate formed by ILP process under the 19.8GW/cm² using 35 μm thick metal foil

Fig. 11 and 12 shows the 35 μm thick SK85 steel foil is too heavy and hard for indirect laser peening (ILP) process as shown in Fig. 12. No dimple was formed on the substrate.

Using 35 μm thick SK steel foil, the dimple was formed as shown in Figs. 11 and 12. The dimple on the steel foil is more than 481 μm in diameter and 6 μm in depth and the dimple on the A6061 alloy substrate is 158 μm and 2 μm in depth.

Fig. 12 No dimple and MoS2 powder on A6061 substrate formed by ILP process under the 19.8GW/cm² using 35 μm thick metal foil

.35 μm thick SK85 steel foil is too hard and is not ductile for ILP process as shown in Fig. 12.
The effect of thickness of AISI 304 stainless steel foil on the formation of dimple has been investigated under the condition A shown in Table 1. The results are shown in Figs.13,14,15 and 16. The laser intensity was $4.9 \text{GW/cm}^2 \sim 29.7 \text{GW/cm}^2$.

Fig.13: Dimple on the 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 9.9GW/cm2

Fig.14: Dimple on the 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 19.7GW/cm2

AISI 304 stainless steel foil is useful for ILP process to put MoS$_2$ powder on the substrate as shown in Fig.15 and 16. Dark particles in the photo shown in Figs.15 and 16 are MoS$_2$ powder. If the thickness of the stainless steel foil increase, the amount of the powder deposited decrease as shown in Fig.17.

Fig.15: Dimple on A6061 substrate using 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 9.9GW/cm2

Fig.16: Dimple on A6061 substrate using 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 19.7GW/cm2

Figs. 15 and 16. Dark particles in the photo shown in Figs.15 and 16 are MoS$_2$ powder. If the thickness of the stainless steel foil increase, the amount of the powder deposited decrease as shown in Fig.17.
The effect of thickness of AISI 410 stainless steel foil on the formation of dimple and deposition of MoS$_2$ powder has been investigated under the condition A shown in Table 1. The results are shown in Figs.18,19,20 and 21. The laser intensity was 4.9GW/cm$^2$ to 29.7GW/cm$^2$.

At a low laser intensity of 4.9GW/cm$^2$, a deep dimple with MoS$_2$ powder can be formed as shown in Fig.19.

Gray particle in the dimple on the substrate is also MoS$_2$ in Figs.20 and 21. The diameter of dimple are about 185- and 191 $\mu$m and the depth of dimple are 11 $\mu$m and 7 $\mu$m, respectively.
Deposition of MoS$_2$ powder on A6061 substrate using AISI 410 stainless steel foil is more desirable than that by 304 stainless steel foil.

The effect of thickness of SS400 mild steel foil on the formation of dimple and deposition of MoS$_2$ powder has been investigated under the condition B shown in Table 2. The results are shown in Figs.23. The laser intensity was changed also from 4.9GW/cm$^2$ to 29.7GW/cm$^2$.

**Table 2 Indirect Laser Peening Condition B**

<table>
<thead>
<tr>
<th>Pulse energy (mJ)</th>
<th>50, 100, 200, 300</th>
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<tr>
<td>Spot diameter (μm)</td>
<td>400</td>
</tr>
<tr>
<td>Power density (GW/cm$^2$)</td>
<td>4.9 – 29.7</td>
</tr>
<tr>
<td>Number of pulse</td>
<td>1</td>
</tr>
<tr>
<td>Thickness of sheet (μm)</td>
<td>35, 45</td>
</tr>
</tbody>
</table>

The dimple formation and deposition of MoS$_2$ powder by ILP process using SS400 mild steel foils of 45 μm are possible as shown in Fig.23. It suggests that ductile metal foil can be easily deformed and put the powder into the substrate.
Indirect laser process has been developed for deposition of particles such as metallic, non-metallic materials on the metal substrate and machinery part, and for the dimple formation to introduce the compressive residual stress for improving the fatigue strength and corrosion resistance of components. One of target for application of this process is a piston for car and motorcycle engine.

**Acknowledgement**

The present work has been supported by the Government Research and Development programme for Creation of Local Innovation Industry. The title is “Development of Special Laser peening Technology”

**References**


**Meet the Author**

Dr. Muneharu Kutsuna was a professor of University, Dept. of Material Science and Engineering of Graduate School of Engineering, Nagoya University. He has retired from Nagoya University end of March 2008 and established “Advanced Laser Technology Research Center (ALTREC)” April 1st 2008. He was graduated from Nagoya University in 1974. He had been worked for Kawasaki Heavy Industry Co., Ltd for ten years from 1972 to 1982. He has studied at MIT as a visiting researcher. He has been worked for Nagoya University from 1982. His research fields include welding technology, welding metallurgy, laser material processing, And he takes the patents of Laser Roll Welding of dissimilar metal joints and Special Laser Peening (Japanese patent No. 4 0 5 8 4 4 8 ).