

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 μ m ~ 700 μ m in diameter and in the range of 5 ~ 50 μ m 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 ($\lambda = 532$ nm) is recommended to get effective plasma pressure for surface modification[5].

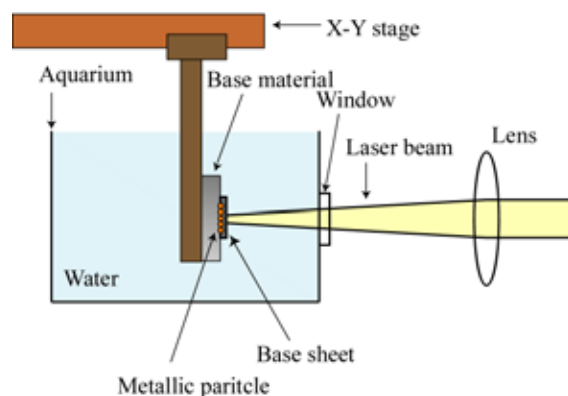


Fig.2 Experimental setup of indirect laser peening .

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.



Fig.3 Indirect laser peening system used

The peening system including the Q-switch YAG laser of 1.5J pulse energy ($\lambda = 1064\text{nm}$), X-Y table , water

bath, work piece holder, optics (focal distance = 150mm) and controller. The typical condition of indirect laser peening is as follows;

Laser intensity: 5 ~ 30GW/cm² · Beam spot diameter: from 200 μm to 700 μm , Thickness of metal foil: from 15 μm to 45 μm

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



Fig.4 Dimples on the AISI 304 metal foil

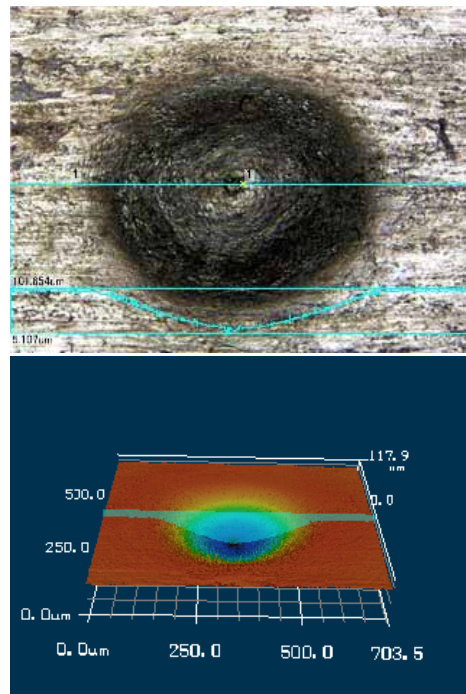


Fig.5 Shape of dimple on A6061 substrate (unit: μm)

the example of dimples on the metal foil and Fig.5 shows the shape of dimples on the A6061 substrate. The diameter is about $420\ \mu\text{m}$ and the max. depth is $79\ \mu\text{m}$. The green laser ($\lambda = 532\text{nm}$) is effective to make a dimple on the base sheet under the water as shown in Fig. 6.

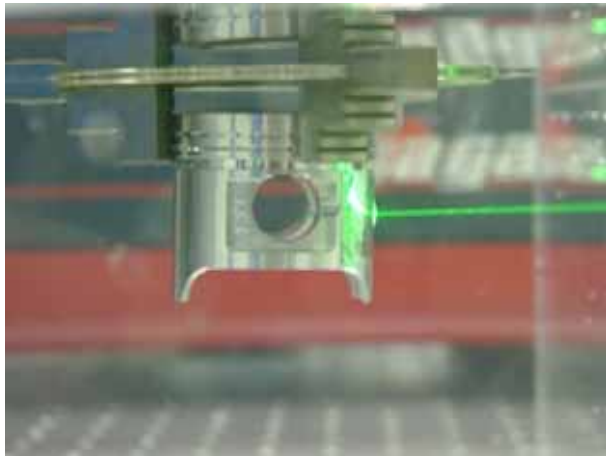


Fig.6 Photo of indirect laser peening on the piston for motorcycle under the water

Effects of type and thickness of metal foil

(1) Using SK85 tool steel foil

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 $4.9\text{GW}/\text{cm}^2$ ~ $29.7\text{GW}/\text{cm}^2$

Table 1 The peening condition A

Pulse energy (mJ)	50,100,200,300
Spot diameter (μm)	400
Power density (GW/cm^2)	4.9 ~ 29.7
Number of shot	1
Thickness of metal foil (μm)	15,25,35,45

The diameter and depth of dimple on the metal foil is $661\ \mu\text{m}$ and $22\ \mu\text{m}$, respectively.

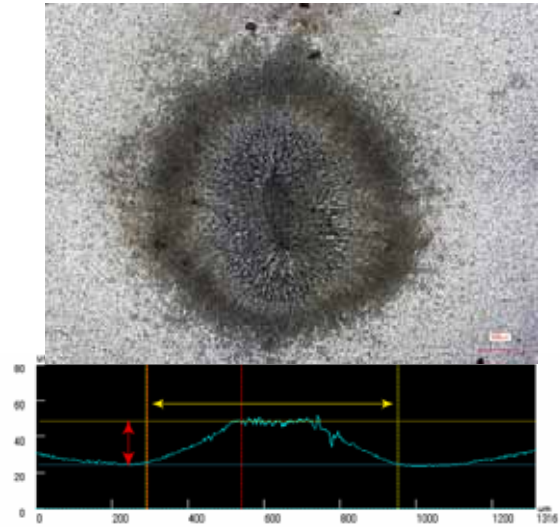


Fig. 7 Dimple on $15\ \mu\text{m}$ thick metal sheet formed by ILP process of $9.9\text{GW}/\text{cm}^2$

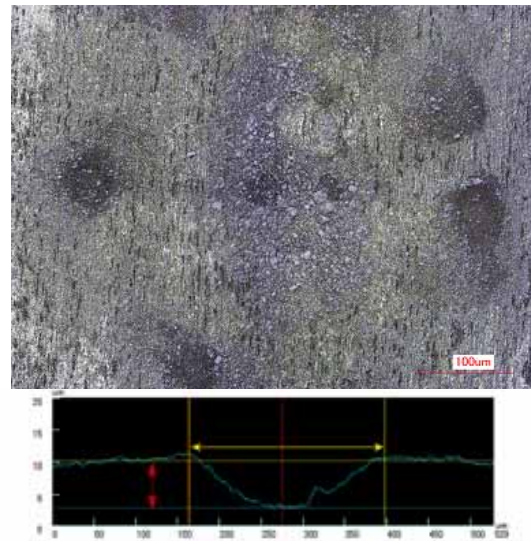


Fig. 8 Dimple and MoS2 powders on A6061 substrate formed by ILP process of $9.9\text{GW}/\text{cm}^2$ using $15\ \mu\text{m}$ thick metal foil

The dimple on the A6061 substrate is $233\ \mu\text{m}$ in diameter and $8\ \mu\text{m}$ in depth was formed by ILP process as shown in Fig.8. Using $25\ \mu\text{m}$ thick

metal foil , dimple was formed as shown in Figs. 9.and 10. The dimple on the metal foil is more than 481 μ m in diameter and 12 μ m in depth and the dimple on the A6061 alloy substrate is 158 μ m and 2 μ m in depth. The higher the thickness of metal foil is ,the higher laser intensity is required .

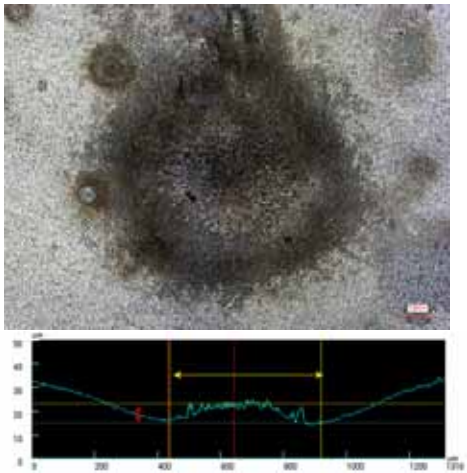


Fig.9 Dimple on 25 μ m thick metal foil formed by ILP process under the 19.8GW/cm²

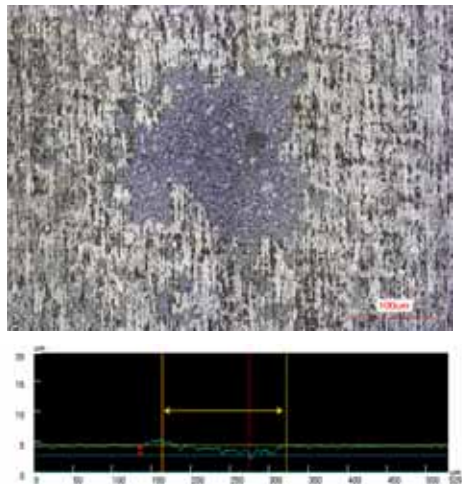


Fig.10 Dimple and MoS₂ powders on A6061 substrate formed by ILP process under the 19.8GW/cm² using 25 μ m thick metal foil

Using 35 μ m 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 μ m in diameter and

6 μ m in depth and the dimple on the A6061 alloy substrate is 158 μ m and 2 μ m in depth.

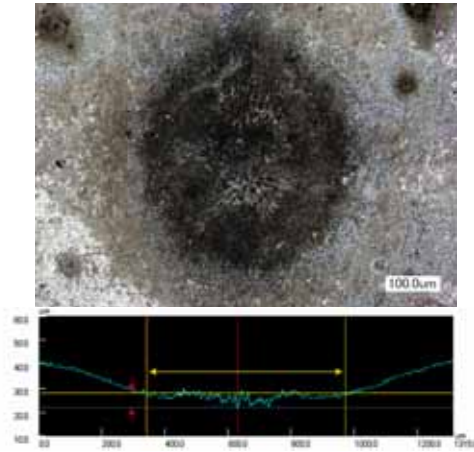


Fig.11 Dimple on 35 μ m thick SK85 steel foil formed by ILP process under the 19.8GW/cm²

Fig.11 and 12 shows the The 35 μ m 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.

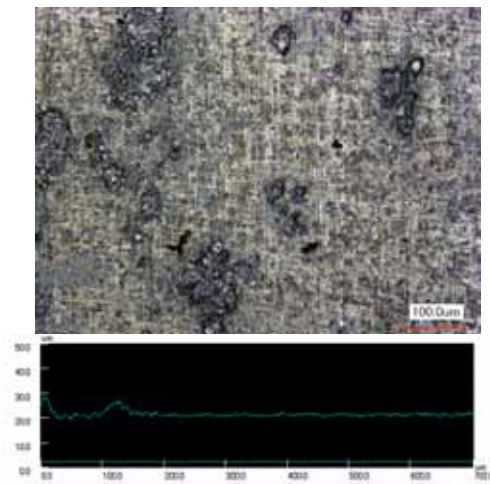


Fig.12 No dimple and MoS₂ powder on A6061 substrate formed by ILP process under the 19.8GW/cm² using 35 μ m thick metal foil

.35 μ m thick SK85 steel foil is too hard and is not ductile for ILP process as shown in Fig.12.

(2) Using AISI 304 stainless steel foil

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 4.9GW/cm². ~ 29.7GW/cm².

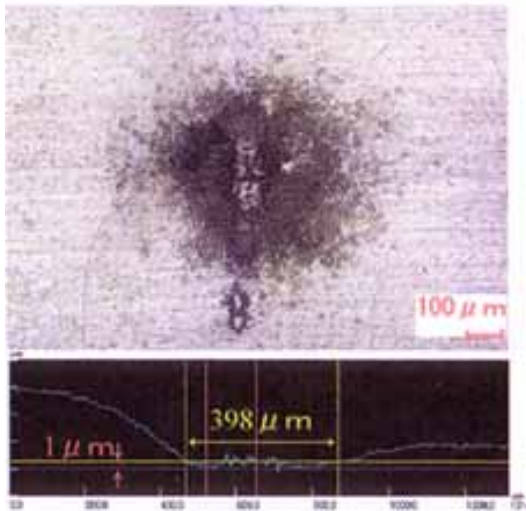


Fig.13 Dimple on the 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 9.9GW/cm²

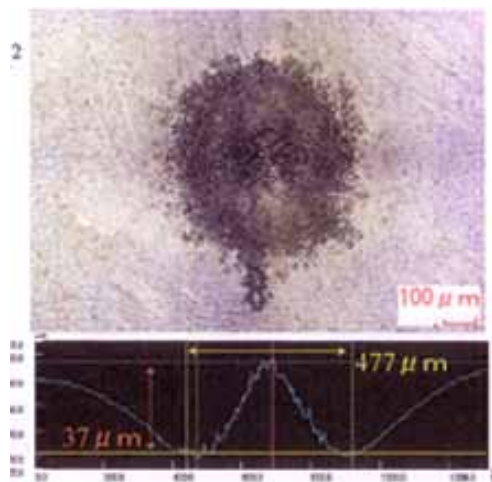


Fig.14 Dimple on the 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 19.7GW/cm²

AISI 304 stainless steel foil is useful for ILP process to put MoS₂ powder on the substrate as shown in

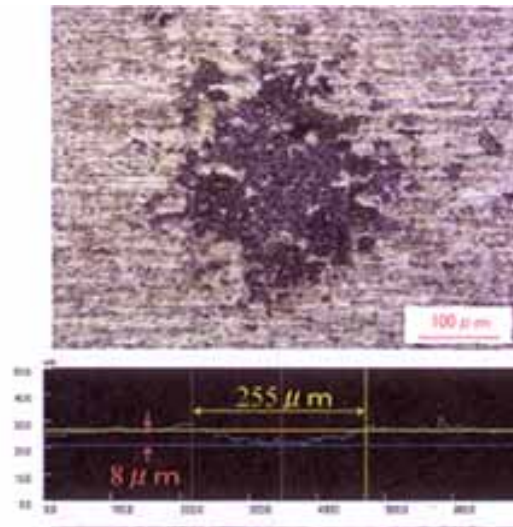


Fig.15 Dimple on A6061 substrate using 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 9.9GW/cm²

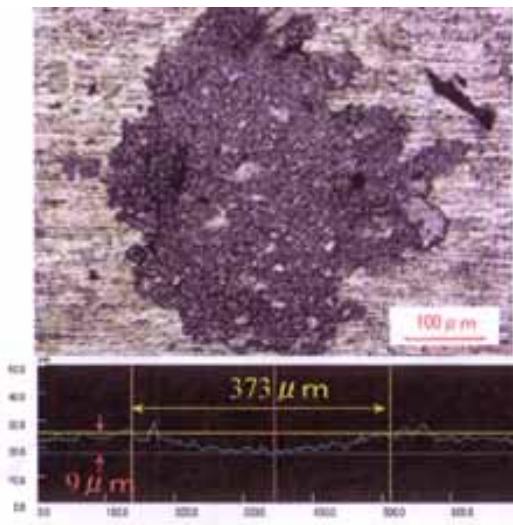


Fig.16 Dimple on A6061 substrate using 304 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 19.7GW/cm²

Figs. 15 and 16. Dark particles in the photo shown in Figs.15 and 16 are MoS₂ powder. If the thickness of the stainless steel foil increase, the amount of the powder deposited decrease as shown in Fig.17.

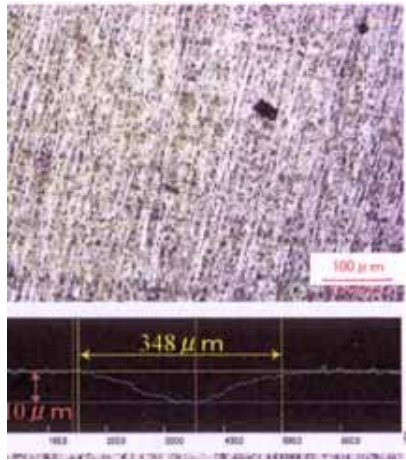


Fig.17 Dimple on A6061 substrate using 304 type stainless steel foil of 35 μm in thickness by ILP process at a laser intensity of 9.9GW/cm²

(3) Using AISI 410 stainless steel foil

The effect of thickness of AISI 410 stainless steel foil on the formation of dimple and deposition of MoS₂ 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/cm². ~ 29.7GW/cm²

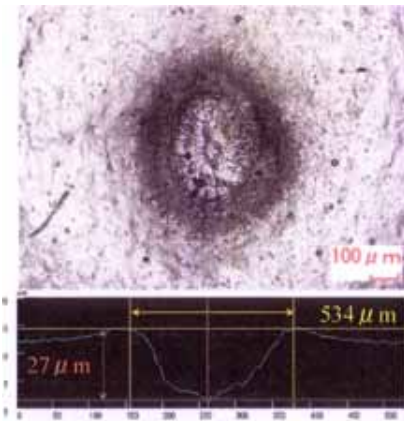


Fig.18 Dimple on the 410 type stainless steel foil of 15 μm in thickness by ILP process at a laser intensity of 4.9GW/cm²

At a low laser intensity of 4.9GW/cm², a deep dimple with MoS₂ powder can be formed as shown in Fig.19.

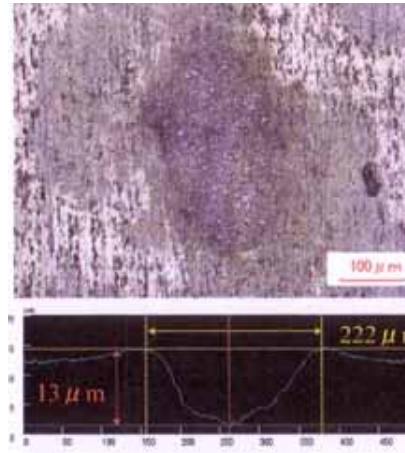


Fig.19 Dimple and MoS₂ powder on A6061 alloy substrate by ILP process using the 410 type stainless steel foil of 15 μm in thickness at a laser intensity of 4.9GW/cm²

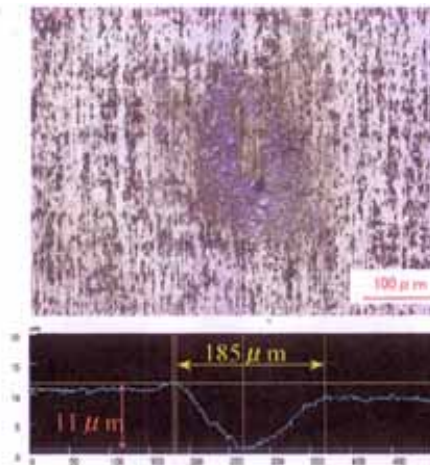


Fig.20 Dimple and MoS₂ powder on A6061 alloy substrate by ILP process using the 410 type stainless steel foil of 15 μm in thickness at a laser intensity of 19.7GW/cm²

Gray particle in the dimple on the substrate is also MoS₂ in Figs.20 and 21. The diameter of dimple are about 185- and 191 μm and the depth of dimple are 11 μm and 7 μm , respectively.

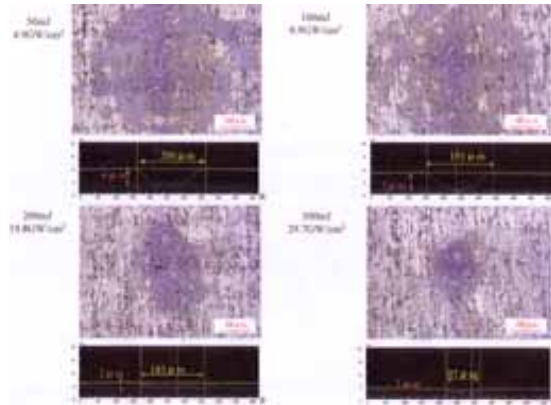


Fig.21 Dimple and MoS₂ on A6061 alloy substrate by ILP process using 410 type stainless steel foil of 25 μm in thickness at a laser intensities of 4.9GW/cm² (a), 9.9GW/cm²(b), 19.7GW/cm²(c),29.7GW/cm²(d)

Deposition of MoS₂ powder on A6061 substrate using AISI 410 stainless steel foil is more desirable than that by 304 stainless steel foil.

(4) Using JIS-SS400 mild steel foil

The effect of thickness of SS400 mild steel foil on the formation of dimple and deposition of MoS₂ 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/cm².to 29.7GW/cm².

Table 2 Indirect Laser Peening Condition B

Pulse energy (mJ)	50,100,200,300
Spot diameter (μm)	400
Power density (GW/cm ²)	4.9 ~ 29.7
Number of pulse	1
Thickness of sheet (μm)	35, 45

The dimple formation and deposition of MoS₂ 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.

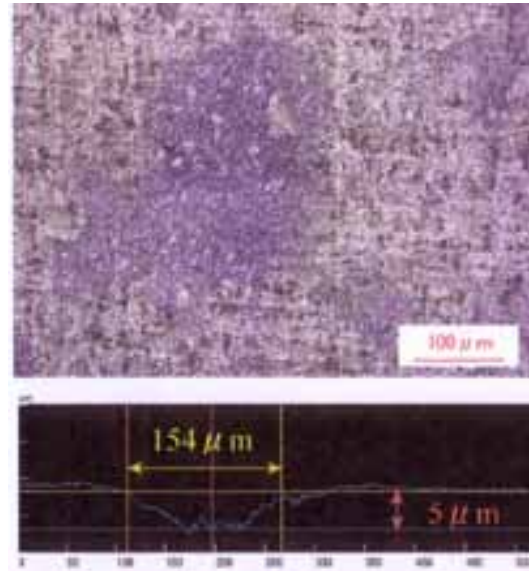


Fig.22 Dimple and MoS₂ on A6061 alloy substrate by ILP process using 410 type stainless steel foil of 45 μm in thickness at a laser intensity of 4.9GW/cm²

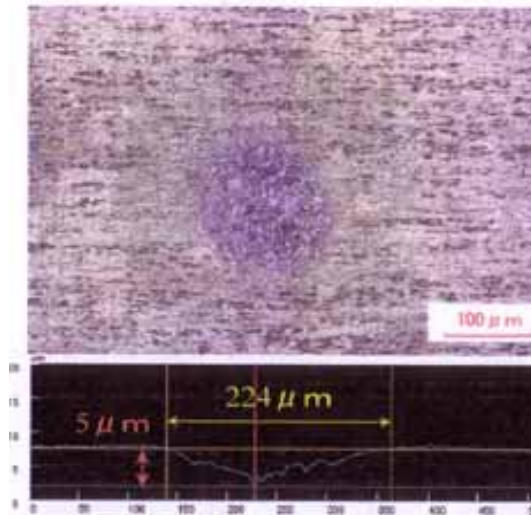


Fig.23 Pimple and MoS₂ on A6061 alloy substrate by ILP process using SS400 mild steel foil of 45 μm in thickness at a laser intensity of 4.9GW/cm²

Summary

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.

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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)..