

Lasers in Manufacturing Conference 2017

Femtosecond-laser-induced surface texturing of Al-Si alloy for lower friction surface

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Abstract

We have investigated femtosecond-laser-induced surface texturing of Al-Si alloy for reducing friction. Although it had been reported for typical metal substrates such as stainless steel that the Laser-Induced Periodic Surface Structure (LIPSS) had effects for lowering the coefficient of friction, we focused our experiments on the Al-Si alloy used in industrial equipments. It was demonstrated that the surface roughness could be controlled by adjusting irradiated laser fluences due to the differences of ablation properties between Al and Si. It was confirmed that the coefficient of friction was reduced about 20% for the textured surfaces.

Keywords: Femtosecond laser; laser processing; Aluminum alloy; LIPSS; low friction ;

1. Introduction

It had been reported that pulsed laser irradiation near ablation threshold could produce periodic surface structure called LIPSS (Laser-Induced Periodic Surface Structure) for various materials such as dielectrics, metals, and semiconductors, Driel et. al., 1982, Fauchet et. al., 1982, Bonse et. al., 2002. Those laser-induced micro- or nano-sized texturing had been investigated for industrial applications as they had effects of reducing friction on sliding surfaces, Yasumaru et. al., 2008, Eichstädt et. al., 2011. Among the various metal materials, we focused on Al-Si alloy as a light-weight material used in industrial equipments, e.g. a

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piston rod or a cylinder. Unlike the stainless steel, which is well-known metal alloy and homogeneous mixture of Fe, Cr, and some other elements like Ni, the Al-Si alloy is inhomogeneous mixture of Al and Si, where crystalline grains of Si are dotted in Al matrix as shown in Fig.1.

We performed surface texturing experiments of the Al-Si alloy with a femtosecond laser and studied the effects of lowering the surface friction, Fujita et. al., 2014.

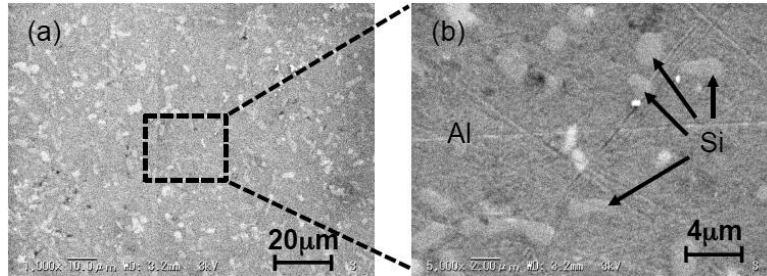


Fig. 1. (a) SEM image and (b) a magnified view of Al-Si alloy surface before laser processing, where crystalline grains of Si are dotted in Al matrix.

2. Experiments

Two types of Al-Si alloy were used in the experiments, an eutectic and a hyper-eutectic Al-Si alloy whose Si content was 9.6-12% and 14.5-16%, respectively. To put it simply, bigger crystalline grains of Si were embedded in Al matrix for the hyper-eutectic Al-Si alloy. A Ti:Sapphire laser (pulsewidth of 100 fs, wavelength of 800 nm, pulse repetition rate of 1 kHz) was focused with $f = 150$ mm lens on the samples.

Before the texturing experiments, we evaluated ablation rate of metal Al and crystalline Si. Fig.2 shows ablation rates as a function of laser fluence for Al and Si. Quite interestingly, the fitting curves for Al and Si intersected each other. Ablation threshold for Si was lower than that for Al, whereas the ablation rates for Al were larger than that for Si. It is expected that laser irradiation with fluence between ablation threshold for Si and Al results in selective ablation of Si. Meanwhile, laser irradiation with fluence above ablation threshold for Al results in predominant ablation of Al.

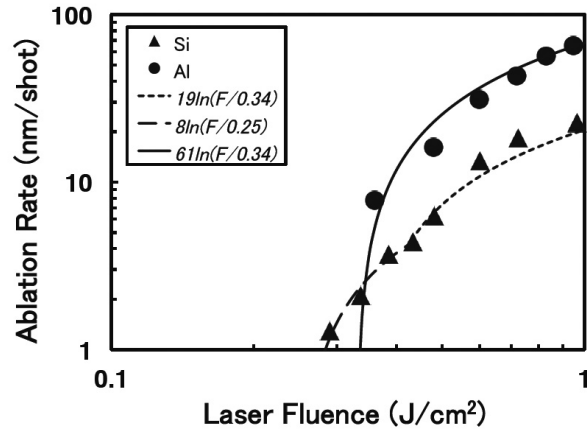


Fig. 2. Ablation rates as a function of laser fluence for Al and Si.

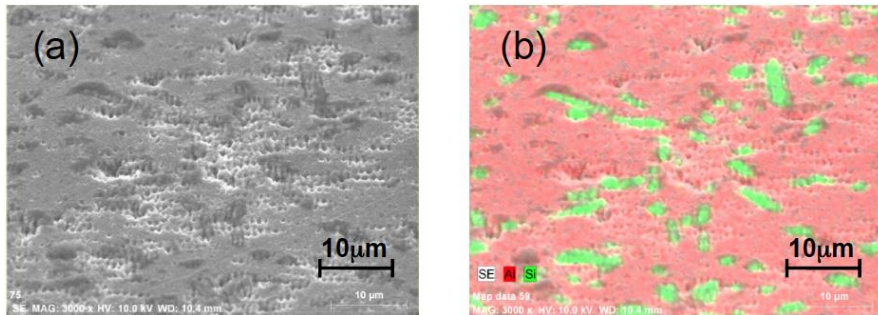


Fig. 3. (a) an SEM image and (b) EDS mapping of eutectic Al-Si alloy after laser irradiation below ablation threshold for Al, where Si was selectively ablated. Slight depressions on the surface were observed.

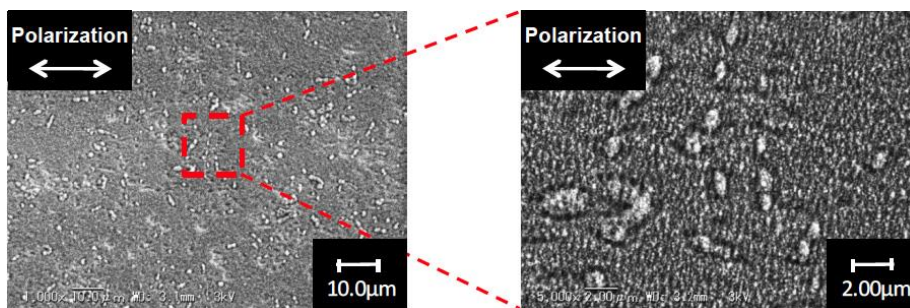


Fig. 4. SEM images of eutectic Al-Si alloy after laser irradiation above ablation threshold for Al.

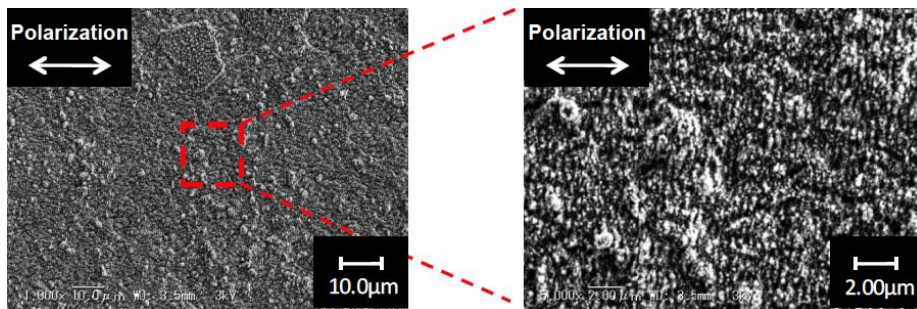


Fig. 5. SEM images of hyper-eutectic Al-Si alloy after laser irradiation above ablation threshold for Al.

Fig.3 shows (a) an SEM image and (b) EDS mapping of eutectic Al-Si alloy after laser irradiation below ablation threshold for Al, where grains of Si were selectively ablated and slight depressions (凹) on the surface were observed. Also LIPSS were observed at the depressions.

Fig.4 and Fig.5 shows SEM images of eutectic and hyper-eutectic Al-Si alloy after laser irradiation above ablation threshold for Al, respectively. Irradiated laser fluences were $0.36 \pm 0.01 \text{ J/cm}^2$ for both cases and number of irradiated pulses were 50 for Fig.4 and 25 for Fig.5. In both figures, small projections (凸) of Si from the surface were observed. Also on Al matrix, LIPSS were clearly seen.

We measured the coefficient of friction of the laser-treated samples using ball-on-disk tribometer. The ball diameter was 12.7 mm, applied load was 4.9 N and sliding speed was changed from 0.01 to 0.65m/s. Daphne Hydraulic Fluid 32 was used as lubricant. Compared to the untreated samples, more than 15% reduction of the coefficient of friction at the sliding speed over 0.2m/s was observed for the surface of Fig.3. Similarly, 27% reduction at the sliding speed of 0.56 m/s was observed for the textured surface of Fig.5.

3. Summary

We have investigated femtosecond-laser-induced surface texturing of Al-Si alloy for reducing friction. It was found that the ablation threshold for crystalline Si was lower than that for metal Al, whereas the ablation rates for Al were larger than that for Si. By adjusting irradiated laser fluences below or above the ablation threshold for Al, the surface roughness could be controlled so that the surface had depressions or projections. It was confirmed that the coefficient of friction was reduced about 20% for the textured surfaces.

Acknowledgements

A part of this research was supported by a NEDO grant for “Development of Innovative Technology for Energy-Saving”.

References

- Bonse, J., Baudach, Krüger, S., J., Kautek, Lenzner, W., M, 2002. “Femtosecond laser ablation of silicon—modification thresholds and morphology”, *Applied Physics A: Materials Science and Processing*, 74, pp. 19-25.

- Driel, H.M. van, Sipe, J.E., Young, J.F., 1982. "Laser-Induced Periodic Surface Structure on Solids: A Universal Phenomenon", *Physical Review Letters*, 49, p.1955.
- Eichstädt, J., Römer, G.R.B.E., Huis in't Veld, A.J., 2011. "Towards Friction Control using laser-induced periodic Surface Structures", *Physics Procedia* 12, pp.7–15.
- Fujita, M., Somekawa, T., Ozaki, T., Yoshida, M., Miyanaga, N., Nakase, T., Kobayashi, T., 2014. "Femtosecond-Laser-Induced Surface Texturing of Al-Si Alloy for Lower Friction Surface", *Rev. Laser Engineering in Jap.*, 42, pp.341-344.
- Yasumaru, N., Miyazaki, K., Kiuchi, J., 2008. "Control of tribological properties of diamond-like carbon films with femtosecond-laser-induced nanostructuring", *Applied Surface Science*, 254, pp. 2364-2368.