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ALUMINUM SURFACE TEXTURING BY MEANS OF LASER INTERFERENCE METALLURGY

Jian Chen[1], Adrian S. Sabau[1], Jonaaron F. Jones[2], Alexandra C. Hackett[2], Claus Daniel[1], David Warren[1]
[1]Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37831
[2]University of Tennessee, Knoxville, Tennessee, 37996

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Abstract

The increasing use of lightweight materials, such as aluminum alloys, in auto body structures requires more effective surface cleaning and texturing techniques to improve the quality of the structural components. The present work introduces a novel surface treatment method using laser interferometry produced by two beams of a pulsed Nd:YAG laser operating at 10Hz of frequency to clean aluminum surfaces, and meanwhile creating periodic and rough surface structures. The influences of beam size, laser fluence, wavelength, and pulse number per spot are investigated. High resolution optical profiler images reveal the change of the peak-to-valley height on the laser-treated surface.

Introduction

Aluminum and aluminum alloys as lightweight materials has been increasingly used in many applications such as automotive and aerospace industries. However, metallic aluminum is very reactive with atmospheric oxygen to form a layer of oxide on the surface, which affects the further manufacturing processes such as welding and other joining techniques [1]. Aluminum surface cleaning to remove oxides and contaminations is required prior to the welding and joining processes. Without proper surface preparation, seams and joints are susceptible to increased wear, degradation and, in some cases, catastrophic failure. There are many methods to remove aluminum surface oxides. Mechanical method [2] is one prevalent method due to its relative low cost. It typically uses blasting media or abrasive materials that are applied directly to the surface. Chemical stripping [3] is another widely used cleaning method. An advantage of this method is the ability to more easily remove all traces of surface oxides and contaminations regardless of shape or surface features. Although the chemical stripping method is effective, the cost associate with environmental protection, hazardous-waste management is high.

High-energy laser pulses can also be used for surface cleaning [4,5]. The mechanism is mainly due to the surface melting and ablation when the metal surface subjected to very short laser pulses (nanoseconds to milliseconds range) with high peak intensities, as well as the laser-induced shocks [6]. It's a non-contact process without abrasion and chemical impact. The controllability offered by laser enables high-precision removal of surface oxides and contaminations in the range from sub-micrometers to several millimeters. All types of organic and inorganic impurities can be removed from the surface.
This paper introduces another method for aluminum surface processing using laser interference patterning. The interface pattern is produced by two beams of high-energy laser pulses. Like the conventional laser cleaning method, surface oxides and contaminations are likely to be removed. Meanwhile, periodic structures can be formed on the surface due to the periodic intensity distribution of the laser interference patterns. This method offers the capability to control the surface texture.

Experimental setup

A 10Hz Q-switched Nd:YAG laser (Quanta-Ray PRO 230, Spectra Physics) was used to process Al specimens. The pulse width was 10 ns and the beam diameter was 8mm. The fundamental emission with the wavelength of 1064 nm was transformed to 355 nm and 266 nm using non-linear crystals. The maximum laser energy per pulse was 0.15 J at 355 nm and 0.04 J at 266 nm. The schematic setup of the laser cleaning and texturing experiments is shown in Fig. 1. The number of pulses is selected by a mechanical shutter. The primary laser beam was split into two beams and guided with mirrors onto the specimen surface. In some experiments, two identical focal lenses were used in each path of the splitted beam to focus laser beams from 8 mm to smaller sizes, hence increasing the laser pulse fluences. Periodic lines structures were formed on aluminum surface by laser interferometry patterns. The periodicity can be well defined by the wavelength (λ) and the angle (α) between two beams:

$$d = \frac{\lambda}{2\sin(\alpha/2)} \qquad (1)$$

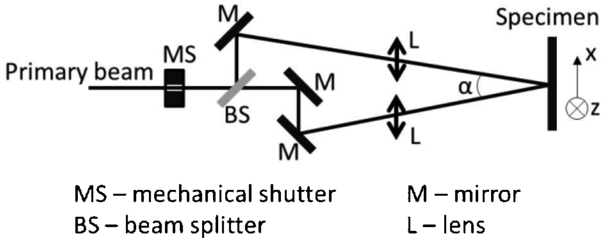

Fig. 1 Schematic setup of laser interference system

The aluminum specimen was fixed on a translation stage capable of moving in horizontal and vertical directions as indicated in Fig. 1. A LabVIEW based computer program was used to automatically control the location of the translation stage and the shutter opening time. During the experiments, the specimen attached to the translation stage was firstly moved to a predefined coordinate, followed by a shutter opening to transmit a certain number of laser pulses. Then, the specimen was moved to the next position followed by another shutter opening. By repeating this procedure, an entire surface area of about 25.4 mm x 25.4 mm was processed. Figure 2 illustrates the locations of the laser spots, with 8 mm, 4 mm and 2 mm beam diameters respectively, to cover the entire target area.

The processed specimens were further analyzed using optical microscopes and an optical surface profiler (WYKO NT9100). The influences of laser beam size, pulse fluences, wavelength and number of pulses (controlled by shutter opening time) on aluminum surface cleaning and texturing were investigated.

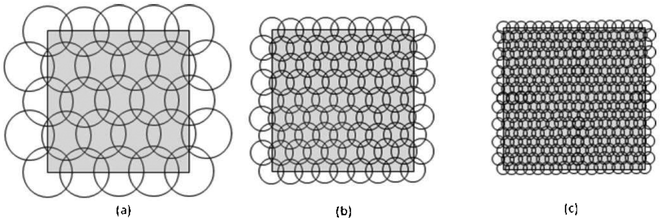

Fig. 2 Locations of laser spots to cover 25.4 mm x 25.4 mm area with beam size of (a) 8mm, (b) 4 mm and (c) 2 mm.

Results and Discussion

The aluminum specimens were firstly processed using laser at wavelength of 355 nm without using focal lenses. The pulse fluence was 0.3 J/cm^2, corresponding to the maximum power output of the laser system at this wavelength. At each beam location, the mechanical shutter was opened for 5 s to deliver 50 pulses onto the surface of each spot. For comparison, the optical microscopic image of the as-received specimen surface is shown in Fig. 3a. The rolling marks were clearly observed with the rolling direction parallel to x-axis as indicated in Fig. 1. Figure 3b shows the laser processed specimen surface. Due to strong interactions of the laser light and the periodic intensity distribution of the interference patterns, line structures perpendicular to the rolling direction were formed in some regions of the surfaces. The spacing between lines was about 3.3 μm. However, because of surface oxides and contamination on the as-received aluminum specimens, the laser absorption coefficient varied at different locations, resulting in non-uniform formation of the periodic structures across the surface.

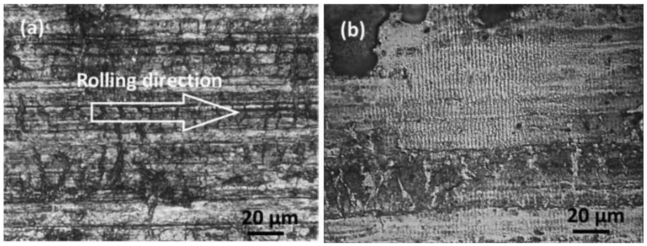

Fig. 3 Optical images of (a) as-received unprocessed alumin surface and (b) processed surface by 50 laser pulses (wavelength of 355 nm and pulse fluences of 0.3 J/cm^2).

In order to structure the aluminum surface more efficiently, higher pulse fluences were required for the laser at wavelength of 355 nm. Hence, the focal lenses were used in the subsequent experiments to resize the beam from 8 mm to 4 mm in diameter at the sample surface, correspondingly, increasing the fluence from 0.3 J/cm^2 to 1.2 J/cm^2. The specimens were processed using various pulse numbers per spot ranging from 2 to 10 (corresponding to 0.2 s and 1 s in terms of shutter opening time, respectively). As shown in Figs. 4a-4c, fairly uniform periodic structures were formed on all specimens. Compared to results in Fig. 3b, higher pulse fluence (adjusted by reducing beam size) produced more unifrom line structures at much shorter processing times at each location. Thus, a laser pulse fluence of 1.2 J/cm^2 for a 355 nm wavelength was much more efficient to process aluminum surface althoug it required more steps to cover the entire specimen area.

The 3-D surface profiles of both unprocessed and processed specimens (by 10 laser pulses at wavelength of 355 nm and pulse fluence of 1.2 J/cm^2) were further studied as shown in Figs 5a and 5b. The average peak-to-valley height on the unprocessed surface was 226 nm which was mainly resulted from the rolling marks as shown in the figure. With laser processing, most rolling marks were removed, cleaned and replaced by periodic line structures formed by laser interference. The average peak-to-valley height of the laser-structured surface increased to 392 nm. Thus, the two-beam laser processing method, compared to the conventional laser cleaning techniques, provides additional capability to tailor the surface texture and roughness.

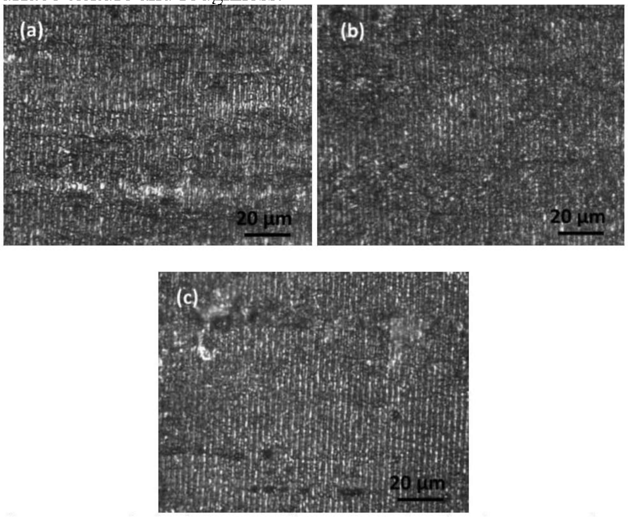

Fig. 4 Optical images of processed aluminum surfaces (wavelength of 355 nm and pulse fluences of 1.2 J/cm^2) with (a) 2, (b) 6 and (c) 10 laser pulses.

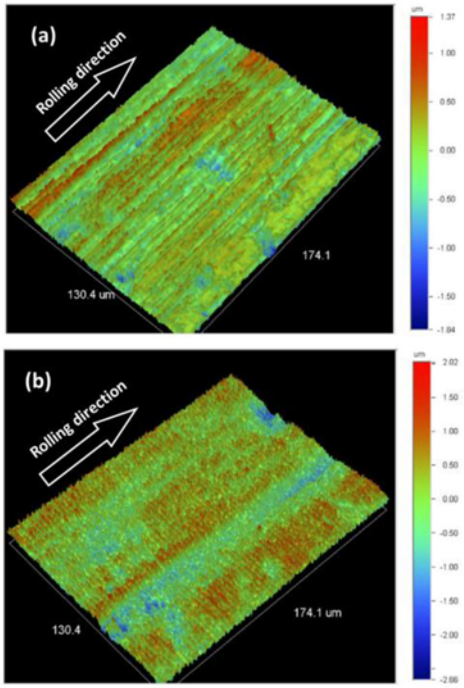

Fig. 5 3-D surface profiles of (a) as-received unprocessed alumin surface and (b) processed surface by 10 laser pulses (wavelength of 355 nm and pulse fluence of 1.2 J/cm^2).

In some experiments, laser pulses at a different wavelegth (266 nm) were used to study the effect of laser wavelength. Since the maximum laser output power at 266 nm was only one quarter of that at 355 nm, to keep the same pulse flueces of 1.2 J/cm^2, the beam size was reduced to 2 mm in diameter. Aluminum specimens were processed using 2 and 6 laser pulses at each location. Figures 6a and 6b shows the optical images of the processed surfaces. The periodic line structures with spacing of 2.5 μm were oberved, but the formation of the structures were not as uniform as those produced by 355 nm laser at the same pulse fluences as shown in Figs. 4a and 4b. One explanation is that the plasma and ejected materials formed in front of the material surface were more easily penetrated by longer wavelength [7]. The onset of plasma formation and material abalation happened within picoseconds time scales. Laser beams with shorter wavelength could be partially absorbed by plasma and reflected off the vaporized materials after a several picoseconds. Therefore, laser surface processing by 355 nm wavelength was more efficient.

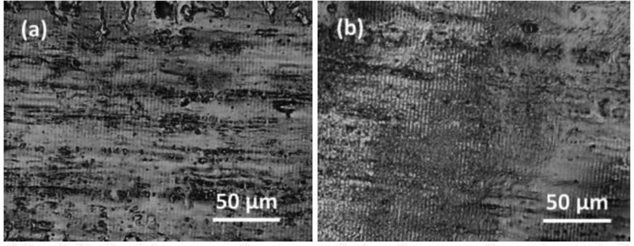

Fig. 6 Optical images of processed aluminum surfaces (wavelgth of 266 nm and pulse fluence of 1.2 J/cm^2) for: (a) 2 and (b) 6 laser pulses per spot.

Conclusion

The effectiveness of surface aluminum texturing using two-beam laser interference patterns was demonstrated. Periodic line structures were formed by laser interference patterns. The influences of laser beam size, pulse fluence, and pulse numbers per spot were investigated. With wavelength of 355 nm and pulse fluence of 0.3 J/cm^2, the line structures were only formed in some isolated regions after as many as 50 shots per spot. Increasing the fluence to 1.2 J/cm^2, large scale of uniform structuring was produced by with much less laser pulses per spot (as low as two pulses). High resolution optical profiler images revealed that the peak-to-valley height on the laser-processed surface, by 10 laser pulses at fluence of 1.2 J/cm^2, increased from 226 nm to 392 nm. When a laser wavelength of 266 nm was used, the formation of line structures on aluminum surfaces was not as efficient as that when the 355 nm wavelength was used.

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References

[1] AW AlShaer, L Li, A Mistry, The effects of short pulse laser surface cleaning on porosity formation and reduction in laser welding of aluminum alloy for automotive component manufacture, *Optics and Laser Technology*, 64, 2014, pp. 162-171.

[2] A Haboudou, P Peyre, AB Vannes, G Peix, Reduction of porosity content generated during Nd:YAG laserwelding of A356 and AA5083 aluminum alloys, *Mater Sci Eng A*, 363(1–2), 2003, 40–52.

[3] NJ Cherepy, TH Shen, AP Esposito, TM Tillotson, Characterization of an Effective cleaning procedure for aluminum alloys: surface enhanced Raman spectroscopy and zeta potential analysis. *J Colloid Interface Sci*, 282(1), 2005,80–6.

[4] YF Lu, M Takai, S Komuro, et al., Surface cleaning of metals by pulsed-laser irradiation in air, *Applied Physics A-Materials Science & Processing*, 59(3), 1994, 281-288

[5] R Rechner, I Jansen, E Beyer, Influence on the strength and aging resistance of aluminum joints by laser pre-treatment and surface modification, *International Journal of Adhesion and Adhesives*, 30(7), 2010, 595-601

[6] AC Tam, HK Park, CP Grigoropoulos, Laser cleaning of surface contaminants, *Applied Surface Science* , 127, 1998, 721-725

[7] J Stasic, M Trtica, B Gakovic, et al., Modifications of AISI 1045 steel by picosecond Nd:YAG laser at 266 nm; comparison with 532 and 1064 nm pulses, *Applied Surface Science*, 255 (19), 2009, pp. 8221-8225 Published: JUL 15 2009