Optics and Laser Technology 107 (2018) 180–185

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Picosecond laser pulse polishing of ASP23 steel

Yuan-Di Chen *, Wu-Jung Tsai, Sung-Ho Liu, Ji-Bin Horng

Laser and Additive Manufacturing Technology Center, Industrial Technology Research Institute, Tainan City 734, Taiwan

ARTICLE INFO

Article history:
Received 23 January 2018
Received in revised form 11 May 2018
Accepted 13 May 2018

Keywords:
Laser materials processing
Picosecond laser
Powder-metallurgical steel

ABSTRACT

Picosecond laser pulses, in laser polishing, induce a light-material interaction in an extremely short period of time to melt steel. The generated heat affected zones (HAZ) are almost negligible. The induced thermal distortion of the polished workpieces can be reduced notably. This paper shows a kind of powder-metallurgical steel, ASP23, polished by a picosecond laser. The purpose of this research is to reduce thermal distortion of the workpieces after laser polishing. The surface morphologies and roughness of the polished surfaces are shown as well. Fourier analysis is used to analyze the surfaces of polished materials. In addition, the microstructure of polished ASP23 surfaces is examined.

1. Introduction

Surface roughness significantly influences the characteristics and quality of steel products, such as functional dimensions, tribological performance, abrasion and corrosion resistance, optical properties, appearance, and haptics. To satisfy the needs of manufacturing industries, laser polishing is a potential technology for the automation of selective area polishing [1]. Laser polishing works by remelting surface materials, which then flow due to surface tension and the filling of microcavities or trenches, thus, smoothing the component surface [2]. In 1982, a continuous wave (CW) CO_2 laser was first employed to polish surfaces of fused silica to increase transmission damage thresholds of optical components [3]. Since then, several researchers have studied laser polishing processes for various kinds of materials, such as metals [4–6], optical glass [7,8], diamonds [9], and plastics [7]. The main applications include components fabricated by additive manufacturing [4,10,11], such as tools [12], and molds [13]. The laser polishing parameters that should be considered include laser fluence, laser travel speed, and overlapping [14]. To improve surface roughness, laser path tracks [15,16] and assist gas [16,17] should be properly selected. Following a study by Giorleo et al. [16], assist gas, N_2, mainly protects the polished area from oxidation and decreases molten drops. It is fed by a hollow pipe, which is fixed on a support. A homogeneous flux is oriented at 45° with respect to the samples. The effect of assist gas pressure on Ti surface laser polishing is studied using three different levels of assist gas pressure of 0 (no gas), 5, and 10 bar. As observed in the scanning electron microscope images, the polished surfaces on using assist gas pressure of 0 bar have molten drops and oxides, while on using assist gas pressures of 5 and 10 bar, the molten drops and oxides are reduced. For 10 bar, the laser path tracks become negligible. On the other hand, the quantitative analysis of surface roughness indicates that a higher gas pressure corresponds to a lower improvement of Ti surface laser polishing. Avilés et al. [17] discuss the laser polishing of AISI 1045 steel under atmospheric and N_2 gas environments. Micro-cracks, pores, and inclusions are observed after laser polishing under atmospheric environment. However, under N_2 environment, oxides are absent on the polished surfaces. The fatigue strength of samples polished under N_2 gas condition is about 7.5% higher than those polished in air.

The basic mechanism for laser polishing is the remelting of material in a melt zone (MZ) to flatten the surface through material relocation. Depending on the surface remelting depths, the laser polishing mechanism can be further divided into surface over melting (SOM) and shallow surface melting (SSM) [4,18]. During the SOM process, the MZ liquefies and forms a periodic surface structure due to the surface tension gradients. In contrast, SSM minimizes the peak-valley height by capillary pressure and liquid curvature. The MZ depths with SOM are far greater than the maximum distance between the peaks and valleys of the surface roughness. Laser polishing in the SOM condition can reduce high spatial frequency content, but tends to increase the maximum peak-to-valley distance of the polished surface, which limits the extent of surface roughness reduction. On the other hand, the MZ depths in the SSM condition are near the maximum peak-to-valley distance of the surface, which is usually less than 30 µm. In SSM, the remelting material is constrained to a smaller range, in which

* Corresponding author at: Industrial Technology Research Institute, No. 8, Gongyan Rd., Liujia Dist., Tainan City 734, Taiwan.

E-mail address: itria20034@itri.org.tw (Y.-D. Chen).

https://doi.org/10.1016/j.optlastec.2018.05.025
0030-3992/

the remelting material flows to decrease the surface roughness due to the action of surface tension gradient and gravity. As a result, laser polishing in SSM commonly leads to better surface roughness than that in SOM. Generally, the remelting depths in CW laser polishing can reach approximately 100 μm [1]. As a result of the great depth, CW laser polishing belongs to SOM. Pulsed laser polishing can be tuned to be under the SSM condition. To date, pulsed laser polishing processes chiefly adopt nanosecond lasers, whose remelting layer depths are 5–30 μm. According to the previous work [19] and experimental results shown in Fig. 6, the remelting depths generated by ultrafast lasers (Pulse duration of the lasers is in picosecond and femtosecond regime) should be less than 5 μm. Furthermore, laser pulse duration is a dominant factor that affects the remelting layer depth of the laser polished samples. Breitling et al. investigate the influence of pulse duration and energy density on the factor of maximum remelting depth [20]. Results show that a reduction of pulse duration or energy density can decrease the remelting depth in nanosecond and picosecond ranges. Moreover, a two-temperature model has been developed to predict parameters of the transient heat transfer of ultrafast lasers, such as electron and lattice temperatures [19]. Hohlfeld et al. demonstrate that the model can be widely used for s/p-band metals and transition metals [21].Picosecond (ps) laser have been widely applied in many fields, such as micromachining, microtexturing, and microdrilling, because of the narrow heat affected zones (HAZ) [22–26]. As compared with CW and ns laser processing, ps laser processing has the least heat diffusion to the surroundings of the desired area. Suppression of heat transfer to the surroundings improves the spatial resolution for nanoscale processing [26]. Thus, the induced thermal expansion and contraction of machined materials will be reduced and will avoid the distortion of the workpieces that occurs in large-area machining [27]. Combining these features, ps lasers has many desirable advantages for surface polishing.

The purpose of this research is to reduce thermal expansion and distortion of polished workpieces after laser polishing. In this study, a picosecond laser polishing (PLP) system is set up to investigate the respective laser polishing (LP) processes for ASP 23 mold steel. ASP 23 is a type of chromium–molybdenum–tungsten–vana dium alloyed steel, which is produced by a powder metallurgy manufacturing process. ASP 23 provides a high hardening ability, good wear resistance, and excellent toughness. Thus, ASP 23 is presently used for IC-packaging molds, cutting tools, and forging and punching die materials [28].

To decrease the surface roughness (Sa) of ASP23 after PLP, some parameters, such as pretreated surface conditions, laser fluence, scan trajectories, are studied. The surface morphologies and roughness of the experimental samples are shown as well. To realize the microstructure of ASP23 after PLP, the lateral surfaces of PLP areas have been treated with two etching methods. The microstructure of the original material, MZs, and HAZs are observed by optical microscope (OM).

2. Experimental configuration

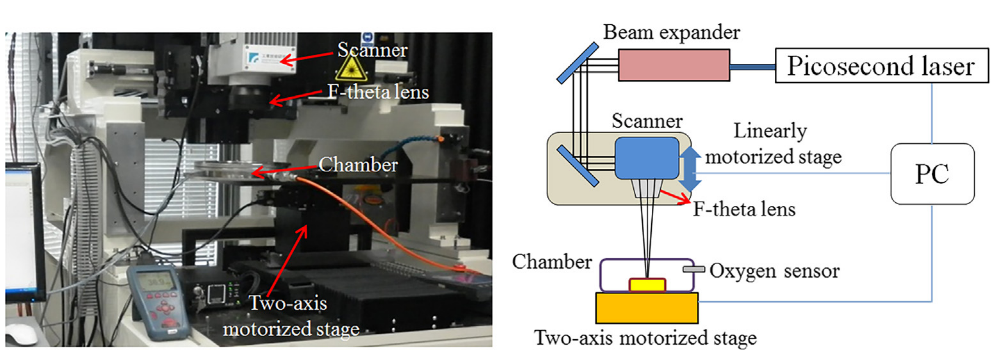
The experimental setup is illustrated in Fig. 1. A picosecond laser (Edgewave PX-series), which has a central wavelength of 1064 nm and a pulse duration of 10 ps, is used. The pulse frequency used in the following experiments is 10 MHz. Finally, the laser beam is directed into a scan head (ScanLab intelliSCAN 20, ID# 121557), which is fixed on a linear motorized stage. The motorized stage is used to adjust the distance between the sample surface and the focal plane of the laser beam. The travel speed of the laser spot is 40 mm/s, and the diameter of the laser beam at workpiece plane is found to be 68.2 μm ($1/e^2$). The scan head contains an f-theta objective (ScanLab, ID #118246) with a focal length of 163 mm.

To avoid oxidization of the polishing surfaces, nitrogen gas, controlled at 10 L/min by a flowmeter, is filled into the chamber to shield samples from oxygen. In the chamber, the oxygen concentration is measured by an oxygen sensor (SO-D0-010-A100C, SENSORE Electronic) and is limited to below 0.1%.

3. Experimental results

The samples used in the following experiments are made of ASP 23 high speed tool steel (Uddeholm Company, Sweden), whose sizes are 50 mm × 50 mm × 2 mm. Grinding, polishing, and electron discharge machining (EDM) are applied to pretreat the surfaces of the samples in this paper (The samples are machined by Jianfu Seiki Co., Ltd.). The surface roughness shown in this paper is a mean value, which is measured from five different 0.8 mm × 0.8 mm areas (using an optical profiler, Bruker Contour GT-K). Fig. 2(a) shows the morphology of a sample with an Sa of 0.22 μm, which is pretreated by grinding and polishing (sample 1). Fig. 2(b) and (c) display EDM surfaces with Sa of 0.311 μm (sample 2) and 0.934 μm (sample 3), respectively. Fig. 2(d) presents the melt track widths of three kinds of samples scanned by the picosecond laser with laser powers of from 8.4 to 30.3 W. The peak power and laser fluence are 7.9–28.5 × 10^4 W and 0.023–0.083 J/cm^2, respectively.

The results show the widths of melt tracks are proportional to the fluence of laser beams. On the same surface, the higher fluence can induce more heat to propagate along the machining surface, and heat conduction will transform more materials outside the laser spot into the melt state. In addition, at the same fluence, the melt tracks of the higher surface roughness zone are broader than that of the lower surface roughness zone. This is because a



(a) (b)

Fig. 1. (a) Schematic diagram and (b) experimental setup for picosecond laser polishing.