Optics & Laser Technology 74 (2015) 36–42

Contents lists available at ScienceDirect

Optics & Laser Technology

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

Laser controlled melting of H12 hot-work tool steel with B_4C particles at the surface

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ARTICLE INFO

Article history:
Received 9 March 2015
Received in revised form
1 May 2015
Accepted 17 May 2015
Available online 5 June 2015

Keywords:
Hot-work tool steel
Laser melting
B_4C particles

ABSTRACT

Laser controlled melting of pre-prepared H12 hot-work tool steel surface is carried out. B_4C particles in the carbon film are located at the workpiece surface prior to the laser treatment process. Nitrogen at high pressure is used as an assisting gas during the laser melting. Morphological and metallurgical changes in the treated layer are examined using scanning electron microscope, energy dispersive spectroscopy, and X-ray diffraction. Microhardness of the treated surface is measured and the residual stress formed at the treated surface vicinity is obtained using the X-ray diffraction technique. It is found that a dense layer consisting of fine grains is formed at the treated surface. Microhardness of the treated surface improves significantly because of fine grains, nitride compounds formed at the surface and micro-stresses developed due to mismatched of thermal expansion coefficients of B_4C and the base material. The residual stress formed at the surface is suppressed by the self annealing effect of the initially formed laser scans.

1. Introduction

Laser surface treatment of metallic substrates has several advantages over the conventional treatment techniques. Some of these include precision of operation, shallow heat affected zone, short processing time, local treatment, and low cost. H12 hot-work tool steel has excellent impact toughness, good resistance to thermal fatigue cracking and it is widely used for hot tooling applications. The tribological properties of the alloy surface can be improved through laser controlled melting [1]. Although laser controlled melting provides fine grains and dense layer at the surface, thermal stress developed in the treated layer is high, which limits the practical application of the treated surface. The pre-treatment of the alloy surface enables to reduce the residual stress and improves the microhardness of the treated surface. In addition, hard particle injection at the surface during the laser treatment process is possible through preparation of the alloy surface prior to the laser treatment process. This improves considerably the surface hardness of the alloys [2–4]. However, due to the mismatch between the thermal expansion coefficients and the base alloy, micro-stresses can be formed in the near neighborhood of the particles, which contributed to the residual stresses formed in the treated layer. Consequently, investigation into metallurgical and morphological changes, and residual stress formed in the laser treated pre-prepared alloy surface becomes essential.

Considerable research studies were carried out to examine laser treatment of steel surfaces. Laser surface modification of hot-work tool steel was studied by Dobrzanski et al. [5]. Their findings revealed that fine grains and dendritic structures were formed in the laser remelted zone with the crystallization direction depended on the heat obstruction from the laser beam influenced zone. Laser surface hardening of hot-worked tool steel was investigated by Lee et al. [6]. They showed that the surface hardness of the alloy increased almost twice of the base material hardness after the laser treatment process. Surface roughness and wear behavior of laser treated tool steel was even examined by Kasman and Saklakoglu [7]. They indicated that friction coefficient and wear rate were affected by the process parameters in which case, average friction coefficient and wear rate increased with increase in laser pulsing frequency. The properties of laser alloyed tool steel surface were investigated by Bonek et al. [8]. They showed that the fine grain martensite structure was responsible for hardness increase at the treated surface. Laser melting of tool steel surface was examined by Majumdar et al. [9]. They indicated that microhardness of the treated surface improved. notably and nitride compounds were formed at the surface because of the high pressure assisting nitrogen gas. Laser surface modification of tool steel was studied by Brabazon et al. [10]. Their findings revealed that the hardness profile through the surface was related to the laser treatment conditions and resultant microstructure. Surface modification of tool steel under YAG laser irradiation was

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http://dx.doi.org/10.1016/j.optlastec.2015.05.012
0030-3992/

investigated by SeDao et al. [11]. They showed that penetration depth of the microhardness varied greatly with the laser processing parameters. Discrete laser spot transformation hardening of tool steel was examined by Jiang et al. [12]. They indicated that the maximum diameter and depth of transformation hardening zones with no surface melting increased with the increase of laser pulse energy. Thermal stability of laser nitride iron and stainless steel by annealing treatments was studied by Carpene et al. [13]. They showed that stainless steel had good thermal stability for nitrogen upto 500 °C; however, a gradual decrease in nitrogen concentration was observed at elevated temperatures. Laser micro/nanostructuring of tool surface was examined by Kulkarni and Chang [14]. Their findings revealed that ripple patterns were generated at the laser treated surface and the average period of the ripples was approximately equal to the laser wavelength. Laser treatment of alumina surfaces was investigated by Yilbas and Ali [15]. They indicated that laser treatment improved the tribological properties of the surface due to the presence of the hard particles and nitride species formation. Laser surface heating and model studies were presented by Shuja and Yilbas [16,17]. They demonstrated that laser power intensity and scanning speed had significant effect on the temperature field in the irradiated region. Thermal stability of a laser treated die material for semi-solid metal forming was investigated by Aqida et al. [18]. They showed that rapid heating and cooling from the laser glazing process, a metallic glass layer was developed which exhibited an average microhardness of 900 HV. Thermal fatigue properties of laser treated steels was examined previously [19]. They indicated that carbides and oxides elements were detected on the sample surface after the thermal fatigue test.

Although laser treatment of tool steel surface was investigated previously, the main interest was laser gas assisted nitriding of the treated surfaces [1]. However, the influence of the hard particles, which are injected at the surface, on the hardness and microstructure of the treated layer was left obscure. Consequently, in the present study, laser gas assisted treatment of pre-prepared H12 hot-work tool steel surface is carried out. The tribological and morphological changes in the laser treated layer are examined using scanning electron microscope, optical microscope, energy dispersive spectroscopy, and X-ray diffraction. Microhardness of the treated surface is measured and the residual stress developed at the surface vicinity is obtained using the XRD technique.

2. Experimental

A carbon dioxide laser (LC-ALPHA III) in pulse mode was used in the laser treatment experiments. The focusing lens was used to obtain the focused laser beam diameter of 0.3 mm at the workpiece surface. Nitrogen assisting gas emerging from a conical nozzle and co-axial with the laser beam was used. In laser surface treatment experiments, several tests were conducted incorporating the different laser parameters. The optimum surface treatment conditions were assessed based on the combination of laser parameters resulting in the depth of treated layer of 40–50 μm and giving rise to defect and asperity free treated surface. Increasing laser power 10% results in high thermal stresses in the surface region, which in turn causes micro-crack formation at the surface; however, the proper selection of laser output power and laser scanning speed gives rise to crack free surface. This situation can be observed from Fig. 1, in which SEM micrographs of laser treated surfaces due to two different laser output power settings. The laser treatment parameters selected based on the optimum treatment conditions are given in Table 1.

The workpiece used was hot-work tool steel (H12) with the size of $10 \times 20 \times 2.5$ mm^3. The water soluble phenolic resin was mixed with 5% (wt) of B_4C powders and the mixture was applied by painting technique at the workpiece surface to form a layer with almost uniform thickness. The average powder size was 0.5 μm. Fig. 2 shows SEM micrograph of B_4C particles used in the experiments. With the multiple treatments in argon environment at 6 bar pressure in a furnace at temperature ranges 150–400 °C, the phenolic resin film was transformed into a carbon film accommodating 5% B_4C particles at the workpiece surface. It should be noted that almost uniform carbon layer was formed into a uniform film under the high pressure and temperature; in which case, pores formed in the carbon film, due to evaporation of water, was collapsed under the high pressure while resulting in almost uniform thickness carbon film. The pre-prepared workpiece surfaces were scanned by a laser beam according to the parameters given in Table 1.

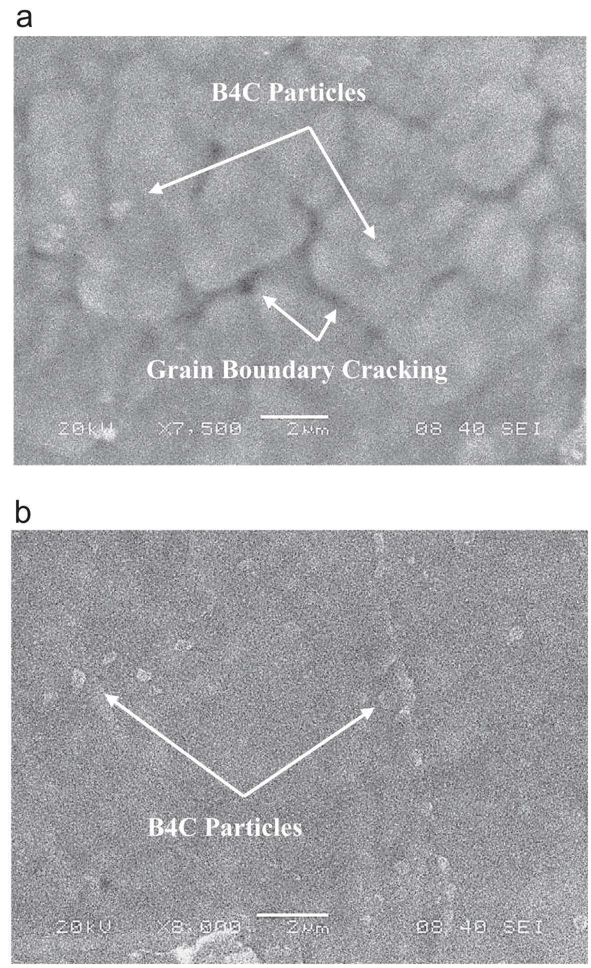

Fig. 1. Laser treated surface at two laser output power intensities. (a) Laser treated above 15% laser selected output power and (b) laser treated at the selected output power.

A JEOL JDX-3530 Scanning Electron Microscope (SEM) was used to obtain micrographs of the cross-section of the workpieces after the tests. Energy Dispersive Spectroscopy (EDS) analysis was carried out at six different locations at the cross-section of the laser treated workpieces. The error related to the EDS analysis is estimated based on the repeatability of the data, which is on the order of 3%. A Bruker D8 Advance having CuKα radiation was used for X-ray Diffraction (XRD) analysis.

The residual stress formed at the surface vicinity of the laser treated workpiece was obtained using the XRD technique, since the position of the diffraction peak exhibits a shift as the specimen is rotated by an angle ψ. The relationship between the peak shift and the residual stress (σ) is given by [20]