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Microstructural and hardness investigation of hot-work tool steels by laser surface treatment

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ABSTRACT

Laser surface treatment technologies have been used to improve characteristics of wear and to enhance the fatigue resistance for mold parts. The objective of this research work is to investigate the influence of the process parameters, such as power of laser and defocused spot position, on the characteristics of laser surface treatment for the case of hot-work tool steels. CW Nd:YAG laser is selected as the heat source. The optical lens with the elliptical profile is designed to obtain a wide surface hardening area with a uniform hardness. From the results of the experiments, it has been shown that the maximum hardness is approximately 824 Hv when the laser power, focal position and the travel speed are 1095 W, +1 mm and 0.3 m/min, respectively. In addition, the surface heat treatment width using the plano-convex lens was three times larger than that using the defocusing of laser beam. In samples treated with lower scanning speeds, some small carbide particles appear in the interdendritic regions. This region contains fine martensite and carbide in proportions which depend on the local thermal cycle.

1. Introduction

Since surface heat treatment technology using laser is very efficient and capable industrial technology, lots of researches have been carried out. Most of researches using CO_2 laser or Nd:YAG laser were investigated on pulse type laser. Researches on laser surface treatment were actively carried out until recently due to advantages of continuous wave (CW) Nd:YAG laser among recent industrial lasers than CW CO_2 laser such as higher beam quality, stable output, standardized design, and distribution of laser power(Dikova et al., 2006; Yue et al., 2006; Wang et al., 2004, 2005; Tian et al., 2005; Geetha et al., 2004). Surface heat treatment using laser beam uses the characteristics of self-quenching that cools rapidly into inside of materials without using cooling water unlike general surface heat treatment. If surface of materials is hardened, abrasion resistance, and corrosion resistance are increased because surface structure forms dense and homogeneous structure (John, 1997, 2001; Yoo et al., 2005).

In recent trend of industry, high speed, high performance, and high hardening of machining speed of a machine part are required. Therefore, parts required for mechanical working must have not only high strength but also toughness, abrasion resistance, and corrosion resistance. In particular, metal molding with the importance of surface hardness is for mass production of parts of the same quality efficiently and is applied to almost all industries such as automobile parts and electrical & electronics units and is essential element for the quality and productivity of parts. However, since it is impossible to satisfy its characteristics only with existing materials of metal mold, it is used after increasing the hardness of surface.

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Hot-work tool steel of H13 used in this study is used in precision molds by manufacturing tools for processing or various dies casting since it has advantages of high resistance of thermal shock and thermal fatigue, abrasion resistance, and heat resistant. However, it has the characteristics of large amount of changes of measurement and twisting of materials during heat treatment. It is usual to have roughing processing due to large amount of changes of measurement and to have electric discharge machining after heat treatment. It has disadvantage of generation of the difference of about 0.1–0.5 mm in the difference of measurement after heat treatment. If laser beam is used to overcome the disadvantages in the above, very efficient work process can be achieved. Reviewing results of the related research work, trend of research of most tool steels use defocusing method and surface hardening method of CO_2 laser. Vilar et al. (1995) had examined the characteristics during the generation of wave phenomena of periodic ripples on surface and value of surface roughness by observing topography of surface of specimen after laser surface heat treatment. Chen and Shen (1999) had researched on optimizing and improvement of long-pulse Nd:YAG laser surface hardening process using Taguchi methodology. When laser beam was singly irradiated and multi-irradiated, hardness value was improved to HRC 52.5–63.9 and hardened width was improved to 0.43–0.89 mm in optimum process condition. In most of related researches reviewed in the above, CO_2 laser or pulse type Nd:YAG laser with high momentary output requiring coating treatment were used for increasing absorptance of laser beam in surface.

In this study, CW Nd:YAG laser of 1.06 μm that has shorter wave length than CO_2 laser, which reflects on most metal surfaces, was used. It has advantage of not using coat absorber on metal surface because its absorptance is about 7 times larger due to shorter wave length than CO_2 laser (John, 1997, 2001). In addition, by manufacturing heat treatment optical system, research on surface hardening and abrasion resistance against surfaces was carried out. In order to treat surfaces by heat, heat treatment structure characteristics according to hardness value, hardened distribution, and beam travel speed were investigated experimentally after Nd:YAG laser beam was irradiated on the surface of H13 to provide optimum process parameters.

2. Experiment

Nd:YAG laser used in this study has wave length of 1.06 μm and its maximum power is 2.8 kW. CNC machining table attached to optical cable is LASMA 1054. In this research work, in order to obtain the wide range of the hardened area, the surface heat treatment is performed by the uniform beam technology using the optical lens with an elliptical shape. The optical lens made from the UV grade fused silica. The focal length, the width and the length of the optical lens are 195 mm, 40 mm and 40 mm, respectively.

Specimen used in this study is H13, which is hot rolled mold tool steel used a lot in mold. The chemical composition of specimen (wt.%) is 0.41 C, 1.12 Si, 0.41 Mn, 5.2 Cr, 1.23 Mo, 1.1 V, 1.3 Ni, balance Fe. Size of specimen used in the experiment was manufactured in the size of 100 mm × 50 mm × 10 mm in consideration of self-quenching. Laser surface heat treatment changes high density light energy to heat energy when beam is irradiated on specimen. At this time, restoration of high density light energy into heat energy is expressed in irradiated amount on specimen, that is, heat input capacity. At this time, value of heat input capacity (Dikova et al., 2006; Wang et al., 2005; Tian et al., 2005; Yoo et al., 2005) was calculated in the following equation. In order to evaluate the influence of the focal position on the heat input capacity, the depth and the width of the hardened area, several experiments are carried out. The heat input capacity of the hardened area is estimated using Eq. (1):

$$E = \frac{P}{\delta(a/b)V_{ts}}(\mathrm{J/cm^2}) \qquad (1)$$

where E, P, δ, a, b and V are the heat input capacity, the power of the laser, the depth of the hardened area, the minor axis of the focus, the major axis of the focus, and the travel speed (V_{ts}) of the laser, respectively.

Fine microstructure analysis and hardness were measured by treating corrosion with picric acid after etching through manufacturing specimen in order to examine mechanical and metallurgical characteristics. Hardness test has applied load of 0.5 kg using microvickers hardness test device. And characteristics of hardened layer were observed through grains and components of hardened structure by SEM and EDS analysis.

3. Results and discussion

3.1. *Characteristics of heat input capacity after laser surface treatment*

Heat energy is penetrated into inside of specimen while rapid heating phenomenon is carried out after laser beam is irradiated on surface of the specimen. In order to quantify this phenomenon, relationship of width and depth of hardness was compared after calculating heat input capacity of laser process parameters. Process parameters used in the experiment are like the following Table 1. Each heat input capacity of respective 1.038×10^3 J/cm^2 and 0.738×10^3 J/cm^2 was obtained when travel speed (V_{ts}) was each 0.3 m/min and 0.5 m/min at the position of 0 mm of focal position (z) based on focal length (*f*) of laser beam. In case of slow travel speed, that is, when it was 0.3 m/min, it showed about 300 J/cm^2 bigger than for the case of 0.5 m/min.

This phenomenon increases heat energy of free electron by reaction of a part of laser beam with free electron of inside of material when laser beam is irradiated on surface of material and a part of increased free electron is conducted into lattice within a short time of 10^{-11}–10^{-12} s. After that, in 10^{-9} s, lattice energy is delivered from electron having high energy

Table 1 – Parameters of laser surface heat treatment

Laser power (W)	1095
Travel speed, V_{ts} (m/min)	0.3, 0.5, 0.8
Focal position (z): focal length (*f* = 195) (mm)	+3 to −3
Shielding gas	Ar: 1.5 bar: 3 l/min