

Structure–property correlation in laser surface treated AISI H13 tool steel for improved mechanical properties



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ABSTRACT

The present study concerns laser surface hardening (LSH) and melting (LSM) of AISI H13 tool steel using a high power continuous wave diode laser. Depth of surface hardened or melted layer increases with increase in incident laser energy density. Surface melting occurs at a higher laser energy density ($> 75 \text{ J/mm}^2$) and leads to the formation of inhomogeneous microstructure comprising non-uniform distribution of retained austenite, carbides (along inter-dendritic boundary) and martensite with their respective volume fractions varying with depth. Application of intermediate laser energy density ($50\text{--}75 \text{ J/mm}^2$) yields a hardened layer with dispersion of ultrafine mixed carbides (M_{23}C_6 , M_7C_3 , MC or M_2C). Laser treatment with a very low laser energy density ($< 50 \text{ J/mm}^2$) leads to formation of an over-tempered microstructure consisting of low carbon martensite and coarse carbide precipitates. Micro-tensile studies with specially machined samples from the surface melted zone following LSM with a laser energy density of 100 J/mm^2 records a high yield strength of 1310 MPa along with poor ductility, marked by brittle failure. On the other hand, a similar sample from laser surface hardened zone treated with a laser energy density of 62.5 J/mm^2 yielded even higher yield strength of 1460 MPa with a maximum elongation of 3.6%. Though both LSH and LSM produced higher yield strength compared to hardened and tempered AISI H13 tool steel, LSH yielded a combination of higher elongation (3.6%), than that after LSM (0.97%), with high yield strength and hence was considered a better option.

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1. Introduction

Laser, as a source of coherent and monochromatic radiation and a directed source of non-contact heating offers a wide scope of application in surface engineering of ferrous and non-ferrous materials [1–3]. Laser surface engineering of steel based substrates may be classified into laser surface hardening, melting, alloying and cladding. Laser surface hardening involves the laser assisted heating of the surface of steel or cast iron to austenitizing temperature followed by self-quenching to induce martensitic transformation on the surface. This type of surface hardening is a frequently used technique for improving surface hardness and wear resistance of steel components with adequate carbon content/equivalent ($> 0.4 \text{ wt\% C}$). Similarly, laser may also be used as

a source of heat to melt the near surface region of steel/cast iron components with higher carbon content to homogenize and refine the surface microstructure and improve the surface dependent mechanical properties like wear and abrasion resistance [3,4].

AISI H13 steel is a hot working tool steel which contains chromium, molybdenum and vanadium as the main alloying ingredients and are commonly used in forging dies, hot gripper dies, hot nut tools, hot header dies, brass forging/pressing dies, aluminum base dies, aluminum alloy casting and extrusion dies, zinc die casting dies, extrusion mandrels, plastic molds, cores, die holder blocks, hot press dies and hot working punches [5]. The heat treatment schedule commonly applied for the above-mentioned applications especially for the dies in hot forming applications comprises hardening followed by tempering with a hardness of 44–48 HRC [6,7].

During hot forming of aluminum alloys, dies made up of hot working tool steels get exposed to severe operating conditions like thermal and mechanical fatigue (up to 700°C), high pressure and high erosion from flowing molten alloy, resulting in surface

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damages like heat checks, erosion and chemical attack in prime locations, thereby limiting the service life of tools [6]. Bulk mechanical properties like (tensile/compressive) strength and toughness can be improved by tailoring the microstructure using conventional heat treatment. In this regard, it may be noted that high yield strength and tempering resistance at the die surface may delay thermal fatigue crack initiation. It has been observed that thermal fatigue cracking may be reduced by incorporating the maximum amount of carbide forming alloys in solid solution without reducing the toughness significantly, which is achieved by rapid cooling from austenitizing temperature leading to the formation of uniformly distributed alloy carbides [8]. Several surface treatments were attempted to improve the surface properties of such steel for enhanced erosion resistance like nitriding (gas, plasma CVD and PVD), boriding, composite overlaying (using laser, TIG/MIG), laser surface melting and laser shock peening [9–12].

In the past, several attempts were made to understand the effect of laser surface melting on the performance of hot work tool steels [13,14]. It was observed that the fatigue strength of the laser surface melted specimens decreases remarkably compared to that of the base metal due to brittle microstructure with carbide precipitation at grain boundaries. However, detailed investigation on the genesis of such brittle microstructures and influence of laser parameters on the same developed due to laser surface melting was not attempted.

In the present study, a detailed investigation of the laser surface engineering of quenched and tempered AISI H13 tool steel has been undertaken using a high power diode laser with different process parameters to cause both melting and hardening of the surface and study the influence of laser parameters on the microstructures and relevant mechanical properties (microhardness and tensile strength) of the laser treated components. In addition, the optimum processing zone for laser surface engineering (hardening or melting) has been derived following a detailed structure–property–process parameter correlation exercise using relevant characterization tools and routines.

2. Experimental

In the present study, hot work AISI H13 tool steel (0.4 wt% C, 0.4 wt% Mn, 5.2 wt% Cr, 1.5 wt% Mo, 1.0 wt% V, Fe balance) plates with dimensions of 100 mm × 100 mm × 12 mm in hardened (austenitized at 1030 °C for 10 min followed by gas quenching) and tempered (at 620 °C for 2 h) conditions were used as substrate. The surface of the substrate was mechanically polished (to a roughness level of 0.9 μm) and subjected to laser irradiation with a

6 kW continuous wave diode laser (wavelength ~915 nm) delivered through an optical fiber head mounted on a 6-axis Robot with a laser spot size of 20 mm × 5 mm and about 285 mm working distance between the laser head and the substrate. Fig. 1(a) depicts the laser surface hardening and melting treatment process schematically. The laser beam used in laser surface hardening and melting was analyzed using LASERSCOPE UFF 100 (supplied by M/s Prometec GmbH, Germany) at focus. System is integrated with PROMETEC LASERMETER along with the beam absorber to measure power. Fig. 1(b) depicts the laser intensity distribution of the laser beam (20 mm × 5 mm) at focus for an applied laser power of 2000 W. It is observed that the only 18 mm of the laser beam width showed more than 60% of laser energy density necessary for adequate heat input for melting/hardening. From this intensity distribution it can be concluded that the width of the melted/hardened zone can be smaller than the actual laser beam width (20 mm) due to this trapezoidal (near top-hat) intensity distribution profile along the width. Laser optic head was equipped with an optical pyrometer (MAURER, Series KTR 1475) to record online surface peak temperature of the processing zone. Laser processing was conducted using argon gas at 2 bar pressure as shrouding gas supplied using off-axis rectangular nozzle (with opening of 20 mm × 4 mm). The main process parameters for surface hardening and surface melting were laser power and processing speed. The detailed parametric combinations used in the present study are summarized in Table 1. The laser energy density as mentioned in Table 1 is calculated using Eq. (1).

$$\text{Laser energy density (J/mm}^2\text{)} = \frac{\text{Laser power (W)}}{\text{Processing speed (mm/s)} \times m \text{ (mm)}} \quad (1)$$

where m is the dimension of focused laser spot on the substrate surface parallel to the lasing direction as shown in the schematic diagram (Fig. 1).

Following laser surface hardening or melting, the size and shape of the treated zone were measured using image analyzer software from the cross-sectional stereographs and micrographs. Microstructure of the laser hardened/melted surface was characterized by a scanning electron microscope (SEM) (Hitachi Model

Table 1
Summary of laser parameters used for laser processing.

Size of focused laser spot	Rectangular spot 20 mm × 5 mm
Laser power	From 900 W to 2500 W
Linear speed	From 2 mm/s to 8 mm/s
Laser energy density	From 22 J/mm ² to 130 J/mm ²
Shrouding gas	Argon at 2 bar
Working distance	285 mm

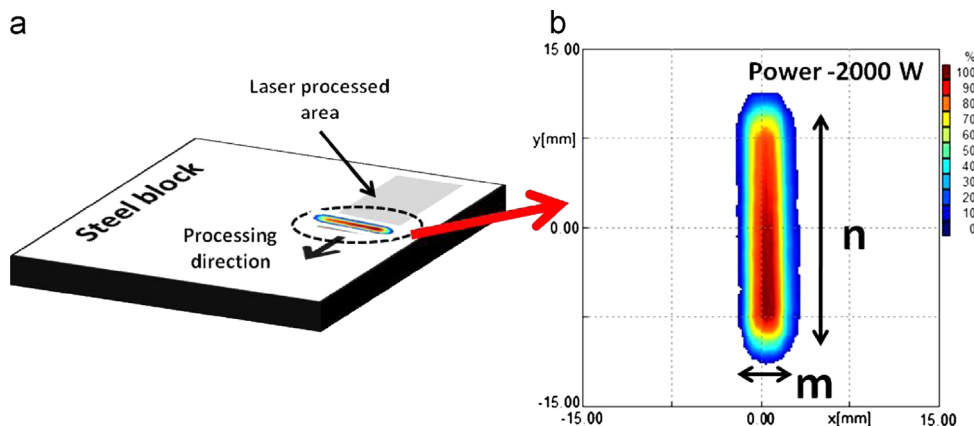


Fig. 1. (a) Schematic of laser surface processing zone and (b) the size and shape of the focused laser beam with laser intensity distribution contour across the beam.

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