Comparative Impact Analysis of Laser Radiation on Steel Grades 1045 and 5140

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Abstract. There are results of experiments with deep engraving steel grades 1045 and 5140. The deep engraving was made by laser system equipped with a pulsed ytterbium fiber laser. The objectives of the work is to evaluate the change in the structure and properties of the material in the laser exposure area. Microsections of materials have been investigated and microhardness was measured for this purpose. The optimal parameters of laser material removal were considered. It is shown that various changes occur in the metal structure, which depends on the composition of the steel. In particular, when processing with identical laser parameters, tempered steel 1045 remelts and its hardness changes, while steel 5140 does not change its structure.

Keywords: steel structure, laser influence on metals, laser hardening

INTRODUCTION

There is rapidly developing production of embossed stamps (cliché) in recent years. In particular, the fabrication of stamps from hardened steel by the laser systems is popular. This manufacturing method allows avoiding additional processing after the material removal. However, there is specificity in using each type of laser as well as in application of the laser processing to a certain material. In addition, laser radiation has residual thermal effect on the material; often it leads to modification of its properties. Therefore, it makes it difficult to optimize the process and, therefore, requires the study of the processes that occur in the metal.

This work is to study the effect of laser thermal effect on the various steel grades, in particular, this paper studies steel grades 1045 and 5140.

MATERIAL AND EQUIPMENT

Material

The following steels were selected as a material for research: steel grade 1045 (constructional steel with content of carbon 0.42%–0.5%) and 5140 (constructional alloy steel containing 0.36%–0.44% of carbon and 0.8%–1.1% of chromium) [1]. The choice of material is determined by its low price, objectives and extending in this field of application.

Heat Treatment

Steel 1045 was taken from the batch prepared for the manufacture of stamps, and it had already been in the hardened condition.

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Glowing for quenching and tempering of steel 5140 was performed in electric furnaces. The quenching temperature was 850°C that allowed achieving maximum hardness and strength of the material. After quenching, the samples were cooled in oil. Then the sample had been tempered at 200°C for 30 min to give them some ductility.

Laser Treatment

The laser beam removal of the material was carried out using the laser system MiniMarker 2-20A4 equipped with pulse ytterbium fiber laser with the pulse repetition rate 20 kHz. The laser beam stroking speed was 100 mm/s at average output power 20 W. Both laser beam pass number and the pulse duration were varied [2].

This laser system was chosen due to: (1) the popularity of such complexes, (2) high absorption of 1.06 μm wavelength by metals, (3) high efficiency of fiber lasers (about 25%).

Metallographic Analysis

The metallographic sections were prepared by cutting the samples and polishing the obtained cross section areas using sandpapers of different grain size. Final polishing was performed using the polishing cloth and diamond paste. The microstructure was revealed by etching the sample in 4% solution of HNO_3 in ethanol.

Structural examination was performed using an optical microscope AxioObserver A1.m (Carl Zeiss, Germany) and software product AxioVision v.4.6.

Hardness and Microhardness Testing

Hardness of the steel 1045 was 50–51 HRC.

Hardness of the stee l5140 in the initial (annealed) condition was 212–217 HB. Hardness of the steel 5140 after quenching and tempering was 60–62 HRC and 51–52 HRC respectively.

The Micro Durometer instrument was used to determine the microhardness of material under the 50 g load.

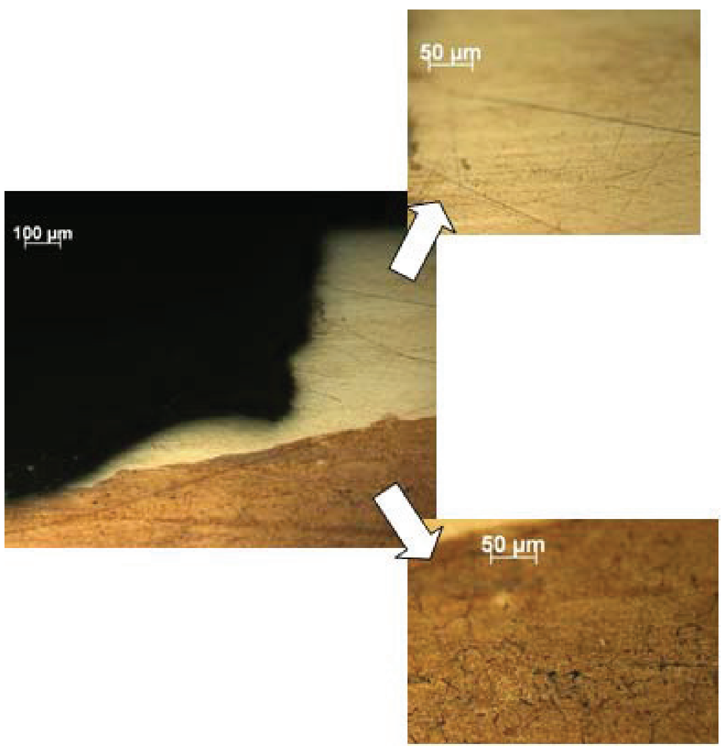

FIGURE 1. Fine grained martensite formation

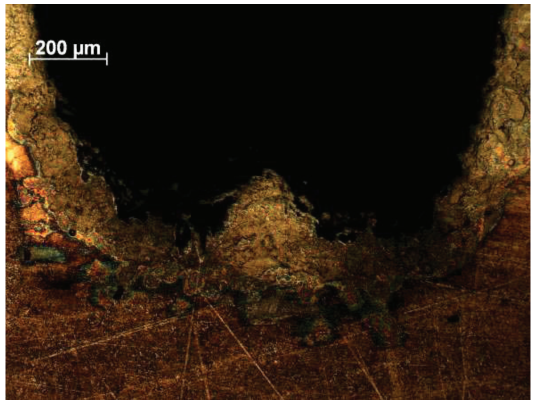

FIGURE 2. Remelted material on the bottom and sides of the hole

EXPERIMENTAL PART

The microstructure of steels shows that the treated surface area under identical processing conditions changes its properties depending on the material. Remelted material is formed in the steel 1045, while changes in the steel 5140 are not noticeable in the structure.

Let us consider a sample of steel 1045. Heating zone is formed in the fine grain structure that is different from the structure of the base metal. Laser heating feature is its perfunctory heating with high speeds and low exposure time. As a result of this treatment, there are non-etching areas. The high heating and cooling rates lead to obtaining more shallow structure. These areas are formed on the edges of holes (Fig. 1).

Thus, there is a “hardening” of the molten metal with very high speed. As a result of such “hardening”, martensite is formed even with finer grain structure other than after traditional quenching processes. Material acquires greater hardness, but becomes brittle.

Remelting of steel is occurred on the border of vaporized material and base material. It means that there was hardening with remelting stage (Fig. 2). When laser radiates on metal with power, enough to vaporize it, portion of its energy is absorbed by steam-plasma torch; another part is carried away by the reactive gas-vapor stream and the rest is absorbed by the channel wall, which melts material [3]. Pressure vapor jet operates during evaporation at the liquid-vapor border. The melt moves along the walls of the hole, while holding by vapor pressures and surface tension. When the beam moves on the surface of metal, molten material is pushed. An area with molten material stays after the beam; it cools and crystallizes [4]. Remelted material is forming on the walls. Here there is the formation of three "zones": the area of the crystallized metal, the transformation zone—zone of re-hardening and the zone of the base metal.

Now let’s consider the structure of the steel 5140 in the laser exposure area.

It should be noted, that reflow didn’t occur in the sample under similar metal processing methods [5]. Figure 3 shows that structural changes didn’t occur under the action of laser radiation. Processing by laser Minimarker 2-20A4 complex does not affect the change in the material structure and, consequently, the material properties.

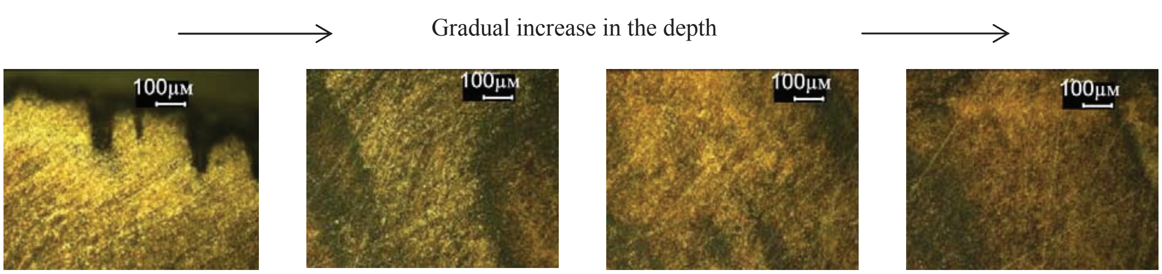

FIGURE 3. Steel structure at different depths below the zone of laser action

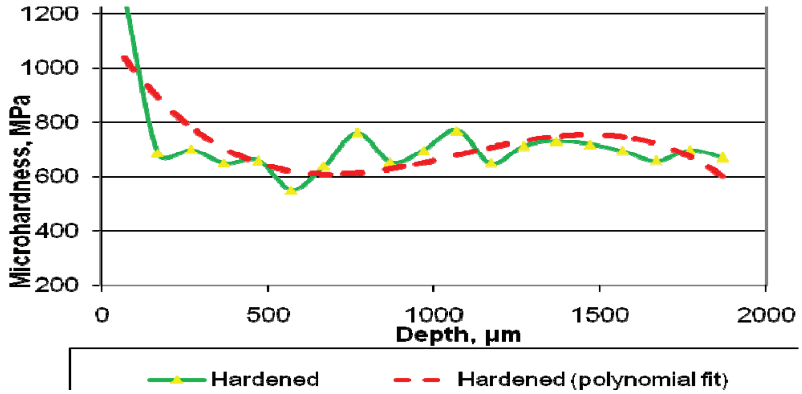

FIGURE 4. Microhardness of steel 5140 at different depths below the zone of laser action

Hence, material inside the groove must be of the same hardness as the base material. Microhardness was measured in the direction from the laser exposure area to the impact non-exposed zone to prove this assumption. Figure 4 shows that the microhardness of the material does not change in the area of laser exposure.

SUMMARY

It is established that exposure to laser radiation appears differently on the steel grades 1045 and 5140.

The structural changes of the material occur in the case of the grade 1045, where the metal is hardened after melting. A fine-grained martensite is formed; it leads not only to the increase in hardness of the material in the treatment zone, but also to a greater fragility of the sample.

However, steel 5140 does not change its structure or properties at removing of material by nanosecond laser. Use of this steel simplifies the process of making a cliche in industries without requiring additional research about changing the characteristics of the samples. It makes it possible to optimize and accelerate the cycle of production. It is assumed that the steel does not change its structure due to the presence in composition of even a small percentage of chromium.

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