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The effect of the laser spots overlap on the structure during square parts quenching

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ABSTRACT

Purpose: This paper deals with an issue of laser spots overlap and structure evaluation of the material after quenching at different spots-pitches.

Design/methodology/approach: The effect of laser spots overlap was investigated on tool steels. The material was quenched by a Nd:YAG laser Laserline LDF 4000 with a maximal power of 4 kV. The laser set was supplemented by an industrial robot.

Findings: The laser quenching is the unconventional method of heat treatment. It is characterized by a wide range of benefits, for example, narrow heat-affected area, high process speed or easy automation. However, one of the problems during square parts quenching is laser spots overlap. It leads to temper of quenched layer. It affects negatively the structure and mechanical properties.

Research limitations/implications: The main aim of this work is to set the appropriate quenching parameters and optimum spots-pitch for attainment of required heat-treatment quality.

Originality/value: This paper present the effect of the laser spots overlap on the structure during square parts quenching.

Keywords: Laser quenching; Laser spots overlap; Microstructure

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MANUFACTURING AND PROCESSING

1. Introduction

The current trend in mechanical engineering is to increase productivity while maintaining or improving the quality of manufactured products. This is one of the reasons why in recent years, such a boom in laser technology occurred in engineering. One of the fields of using lasers is surface quenching (hardening) of material. In terms of service life, the most important points of engineering components are material free surfaces because almost all fatigue cracking starts on them. [1] Therefore, ways are being searched for how to enhance the resistance of the material surface layer. In addition to the chemical – heat treatment (cementation, nitrocarburizing, carbonitriding, and nitration), surface quenching is one of the possible methods. Currently, laser surface quenching is being increasingly applied because, similarly as in other applications, laser treatment offers many advantages in comparison to conventional methods of heat treatment. [2]

Due to a high heating rate (in the order of 1000°C/s) through laser beam, only a thin surface layer of the hardened object will be affected. Heat is dissipated into the unheated core of a component, and thereby the material will be self-hardened. There is, therefore, no need for a quenching medium. As another advantage of instant heating, it can be considered the fact that only minimal undesired deformations exhibit due to the thermal influence of a very narrow region of the material. Other advantages of laser surface quenching (hardening) include the ability to work also in confined spaces and in any atmosphere because the material surface is not prone to oxidation after laser processing. The width of the hardened zone can be easily modified by exchanging optical lenses. With the process control using the pyrometer, a constant temperature of processing in each point of a component can be ensured, and thus a constant hardness. [3, 4] Moreover, the laser is controlled by an industrial robot, which ensures a uniform movement of the beam along a selected trajectory in 2D and 3D space. [5] Finally, high heating and cooling rates lead to the formation of a fine-grained structure with small carbides that has favorable mechanical properties and is not so prone to cracking. Generally, the different structure of the surface and the core component has a positive effect on the fatigue strength of the material. It is caused by the fact that martensite (surface-hardened layer) has a larger volume than the ferrite (core). Thus, in the surface-hardened layer, always an internal compressive layer is created which prevents the emergence and development of cracks when stressing the surface by tensile force.

For a correct and uniform hardening of large surface parts, it is necessary to choose appropriate process parameters and a sufficient overlap of the hardening traces so that the surface of a hardened part has homogenous properties in all points. A part of this issue was discussed in articles [6-8].

2. Experimental methods

The effect of laser spots overlap was investigated on tool steels 1.2842 (sample 19 312). The chemical composition of the investigated material is given in Table 1. The material was quenched by a Nd:YAG laser Laserline LDF 4000 with a maximal power of 4 kV and with a wave length of 1020 – 1060 nm. The laser set was supplemented by an industrial robot KUKA KR60 HA with a repeatability of ± 0.05 mm. The sample 19 312 was quenched from 1000 °C on laboratory air, the welding speed was 0.003 m/s. The laser spot had a dimension of 16 x 4 mm. There were tested three variants of laser spots overlap for each material – 0 mm overlap (0), 2 mm overlap (+2) and 4 mm overlap (+4). The scheme of these three variants is shown in Fig. 1. The hardness gradient was measured on a MicroMet 6020 micro hardness tester. The hardening depth was measured from the record of hardness gradient HV1 (550HV). The structure and phase composition were studied by the Zeiss Ultra Plus scanning electron microscopy equipped with Oxford detector for energy dispersive analysis (EDX).

Table 1.
The chemical composition of the investigated materials

Sample	C	Si	Mn	Cr	Ni	V
19 312	0.75 0.85	0.15 0.35	1.85 2.15	max 0.25	max 0.35	0.10 0.20

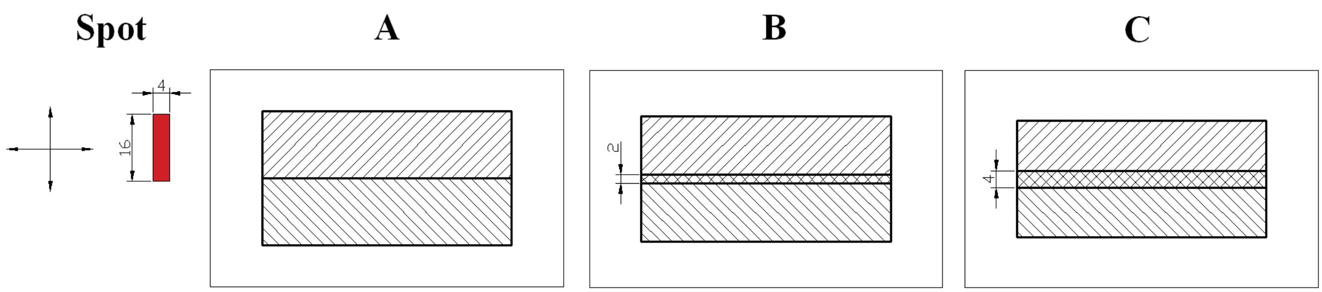

Fig. 1. The schema of three investigated variants of laser spots overlap (A – 0 mm, B – 2mm, C – 4 mm)

3. Results and discussion

3.1. Parent unhardened material 19312

The structure of material 19 312 was formed with ferritic grains of irregular shapes with dimensions in the order of units up to tens of micrometers (see Fig. 2). Inside the grains, numerous carbide precipitates were observed (see Fig. 3), as verified by EDX analysis, carried out at a Zeiss Ultra Plus electron microscope. The hardness of the parent material was about 198±6 HV1.

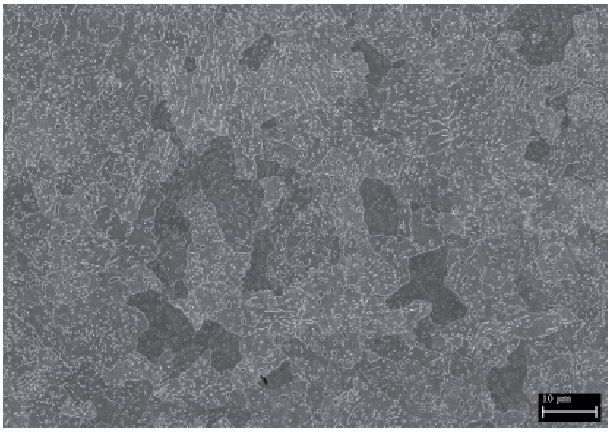

Fig. 2. Parent unhardened material 19312 (1000x)

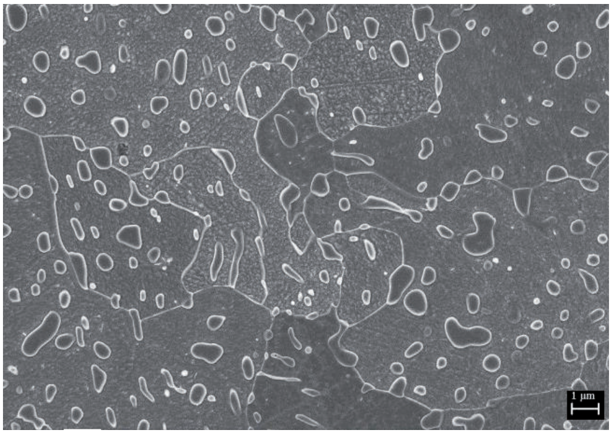

Fig. 3. Parent unhardened material 19312 (5000x)

3.2. 0 mm overlap (0)

Figure 4 shows that the choice of a gap of 0 mm between the quench spots did not cause an overlap of the hardened areas. Between the hardened areas, there is a zone in a width of approx. 1.6 mm which was not hardened. This was also confirmed by measurements of hardness. The average hardness of the material in the axis between the visibly hardened areas was 221±6 HV1. Thus, there was only a slight increase of hardness as compared with the unhardened material. In Fig. 5, a structure of the fully hardened area is shown, consisting of heterogeneous martensitic needles and primary carbides which remained unchanged after quenching. The maximum depth of hardening at the selected parameters was 0.95 mm.

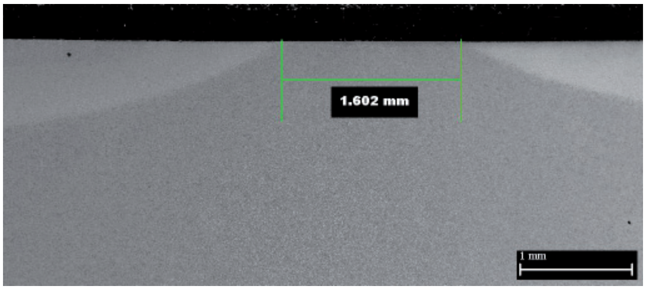

Fig. 4. Hardened material 0 mm overlap (0)

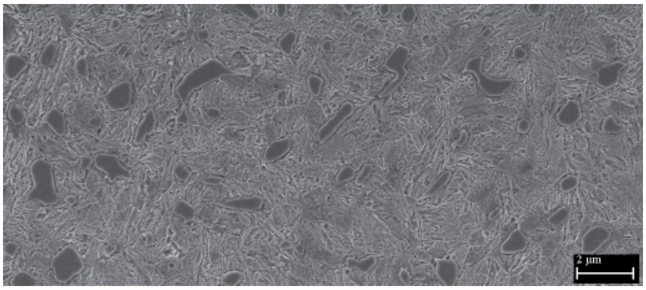

Fig. 5. Hardened material 0 mm overlap (0) (fully hardened area)

3.3. 2 mm overlap (+2)

When selecting a spot overlap of 2 mm (+2), hardening of a very narrow area also between the individual spots occurred, as seen from Fig. 6. That area, however, was very thin (approx. 170 μm) and below it, it was located material in the parent unhardened state. The thickness of the hardened area in the point of spot overlap was also determined by measuring the hardness gradient and was around 140 μm. An example of a measurement record of hardness gradient, depending on the distance from the surface of the material, is given in Fig. 7. The structure of the fully hardened area did not differ from the structure when choosing an overlap of 0 mm (0) – see Fig. 5.

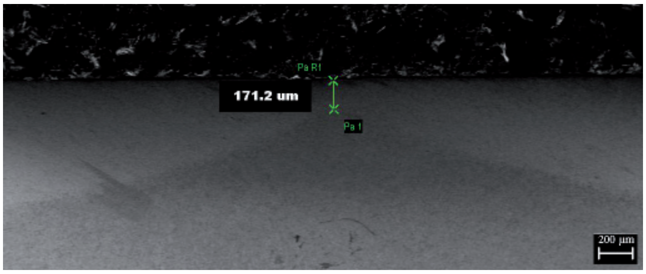

Fig. 6. Hardened material 2 mm overlap (+2)

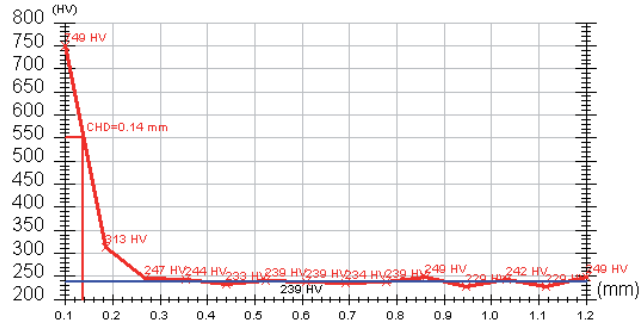

Fig. 7. Example of a measurement record of hardness gradient in the region of the spot overlap axis in the variant of +2

3.4. 4 mm overlap (+4)

With an overlap of 4 mm (+4), the material was sufficiently hardened in the entire area, as documented in Fig. 8. The depth of hardening between the spots was about 580 µm. The same conclusion was also made from the measurement of hardness gradient. An example of a measuring record of hardness dependence on the distance from the surface of the hardened part is shown in Fig. 12. In the hardened surface, there were observed three areas. First, the fully hardened material (Point 2 in Fig. 8), whose structure is shown in Fig. 10, does not differ anyway from the hardened areas in the materials with a different choice of spot overlap. Second, the transition area (Point 1 in Fig. 8) at the edge of reaching the efficiency of the laser spot. The structure of this area is indicated in Fig. 9, from which it is evident that the temperature in the transition area has not been sufficient for full austenitization of the material. Martensitic needles arose in some places only. Third, the area that was tempered when passing the second spot (Point 3 in Fig. 8). Its thickness is about 180 µm and its structure is displayed in Fig. 11.

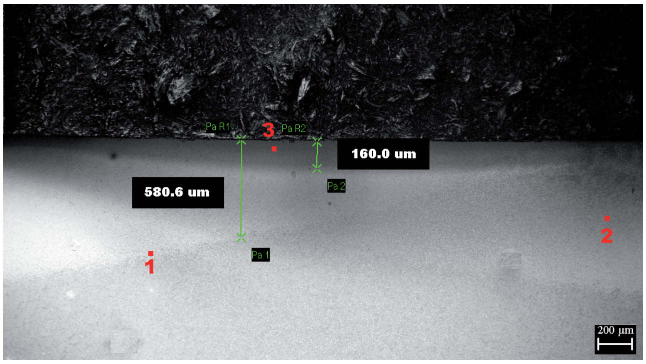

Fig. 8. Hardened material 4 mm overlap (+4)

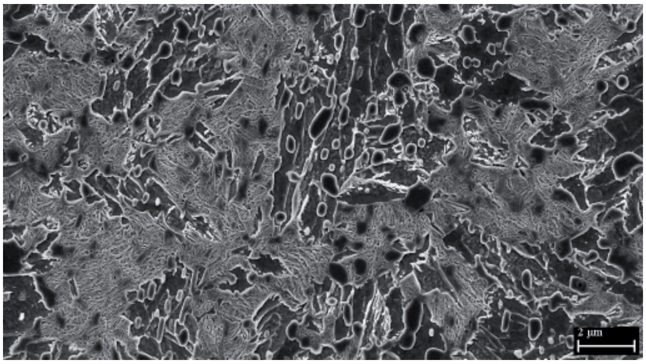

Fig. 9. Hardened material 4 mm overlap (+4) (transition area between the hardened layer and the unhardened parent material – see Point 1 in Fig. 8)

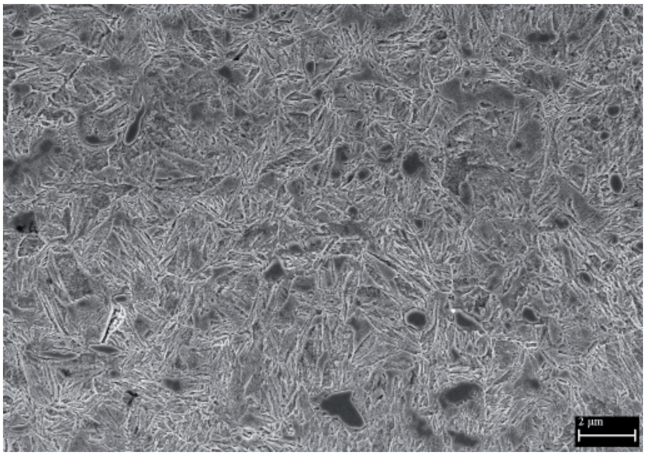

Fig. 10. Hardened material 4 mm overlap (+4) – (the fully hardened area – see Point 2 in Fig. 8)

From the hardness gradient in Fig. 12 it is obvious that hardness in the surface layer of the hardened material decreases due to a tempering of this layer. It follows an increase of hardness in the area of full hardening of the material and a slow decrease with an increasing distance from the surface. The depth of the hardened layer is 540 µm.

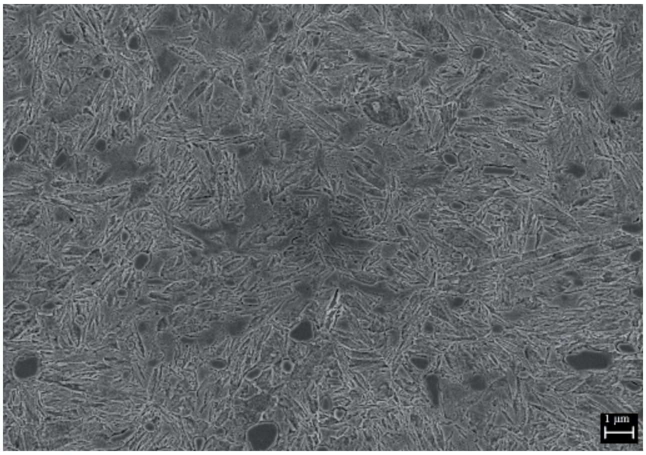

Fig. 11. Hardened material 4 mm overlap (+4) (Point 3 in Fig. 8 – the area tempered when passing the adjacent laser spot)

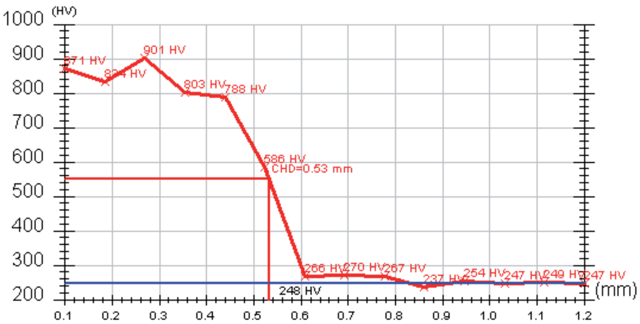

Fig. 12. An example of a measurement record of hardness gradient in the region of the spot overlap axis in a variant of +4

4. Conclusions

- A material hardening of 0.95 mm can be achieved by laser quenching (hardening) using the test parameters.
- When choosing a spot overlap of 0 mm (0), there arises an unhardened zone in a width of 1.6 mm between the lines. With a variant of +2, a spot overlap will occur, but in the area of the overlap axis, hardening depth is too small – 0.14 mm. In terms of hardening depth and achieved hardness of the hardened area, a spot overlap variant of +4 is compliant where the minimum hardening depth is 0.54 mm.
- Hardening depths in the axis between the spots for each overlap variant are summarized in Table 2.

Table 2.
The depth of hardened layer in the axis between the spots

Overlap	Hardening depth in the axis between the spots, µm
0 mm	0
2 mm	170
4 mm	580
Maximum depth of material hardenability	950

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