The effect of the laser spots overlap on the structure during square parts quenching of 1.7225 steel

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Abstract. Laser quenching is a modern technology of material processing. A high speed of the process, extremely high speeds of heating (in order of 1000 °C/s) and absence of cooling medium after heating are the biggest advantages of heat treatment by unconventional technology. Moreover, laser quenching could be in some cases only one possible way how to heat treat the material's surface. This article deals with the problematics of laser spots overlap during square parts quenching. It is necessary to set optimal distance between two neighboring tracks. If this distance is too low, the second pass of the laser can temper the previously hardened track. On the other hand, the stripe completely without heat treatment remains in the surface if a too long distance between the quenching tracks is used. The optimal distance of laser spots at quenching of 1.7225 steel was searched under present research. It was verified that at least 4 mm overlap is needed.

1 Introduction

Laser technologies are one of the modern ways of processing material. Nowadays, they are applied in a number of engineering applications from cutting, welding to heat treatment. The most advantages of laser technologies are their productivity, economy, ecology and moreover, they are often the only one alternative for the production of a particular part. One of the most used applications of lasers is in material's surface heat treatment. The component life is dependent on the quality of the material's surface because almost all fatigue cracks and material's wear start on free surface [1]. Therefore, the possibilities are being looked for an increase of material's surface layer resistance. Surface quenching is one of the possible ways how to prevent from cracks formation and premature wear [2, 3]. Moreover, the surface quenching by using laser technology has many advantages in comparison with conventional methods of thermal treatment [4]. Laser quenching reaches heating rates in an order of 1000 °C/s, thanks to that, only a thin surface layer of material will be thermally affected. No quenching medium is also necessary because the heat from the surface layer is taken away into the unheated core of a material, and thus, material self-quenching will occur. A significant advantage is also the formation of minimal undesired deformations in the material because the thermal affected area is very narrow. The width of the quenched zone can be easily modified by replacing the lens or changing of quenching parameters [5, 6]. The repeatability of the process is high because the whole process is controlled by an industrial robot [7].

When a surface quenching of square parts by means of a narrow laser spot is carried out, it will not occur a hardening of the entire surface being processed with one pass of the quenching head, but a gradual rasterization of the area to be heat-treated must be performed. During this rasterization, the distance of each quenching "tracks" must be suitably adjusted to avoid an unwanted interaction of the already quenched material with the laser beam passing in the next step by one track next to the treated surface. If the overlap of the individual spots is set too large, the first track may be accidentally tempered during the second pass of the beam and thus, it may affect the resulting mechanical properties. If, on the contrary, there is an insufficient overlap of the spots, narrow stripes will be formed between the quenched tracks in the material which will remain heat-untreated, which will again affect the resulting mechanical properties [8-10].

Adjusting the appropriate laser spot overlap degree is different for each type of material. This paper deals with the study of an appropriate degree of overlap of laser spots on steel 1.7225 (ČSN 15142).

2 Materials and experimental methods

The optimal degree of overlap of laser spots was studied on 1.7225 steel (15 142 sample). The chemical composition of the investigated material is presented 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 wavelength 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 15 142 was quenched from 1000 °C on air, the welding speed was set on 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 the experiment is shown in *Fig. 1*. The depth of material quenching was measured from a record of hardness gradient measurement. The 550 HV1 hardness was considered for the fully quenched material. The hardness gradient was measured on a MicroMet 6020 microhardness tester at a load of 1 kg (HV1). The structure and phase compositions were studied by the Zeiss Ultra Plus and Tescan Vega SB scanning electron microscopes equipped with Oxford detectors for energy dispersive analysis (EDX). The overview structures were studied by a light optical microscope (LOM) Nikon Epiphot 200.

Table 1. The chemical composition of the investigated materials

Sample	C	Si	Mn	Cr	Ni	Mo
15 142	0.38		0.60	0.90		0.15
(1.7225 steel)	0.45	0.40	0.90	1.20	0.50	0.30

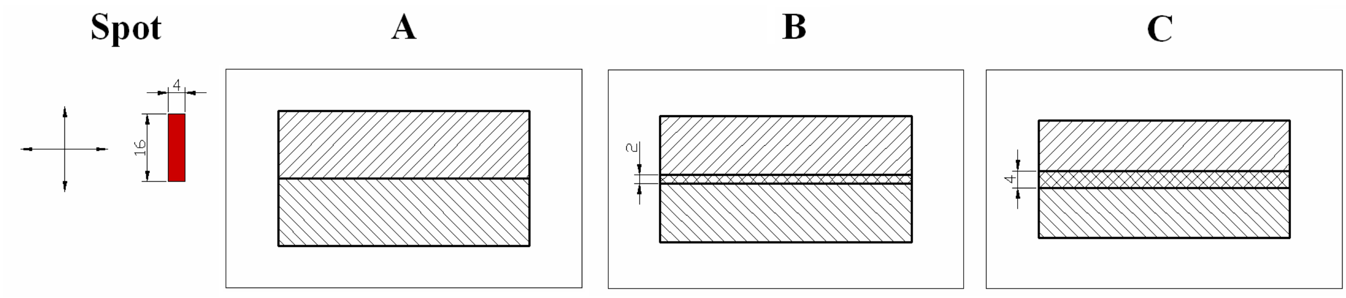

Figure 1. The schema of three investigated variants of laser spots overlap (A - 0 mm, B - 2mm, C - 4 mm).

3 Results and discussion

3.1 Unquenched 15 142 steel

The initial material used for tests of laser spots overlap was ferritic – perlitic type steel. The ferritic grains are visible as a darker background in SEM *Fig. 2*. Perlite is present in the granular form (small lighter areas in *Fig. 2*) – previously referred as coarse sorbite. There were also observed the elongated precipitates in the structure (see black needle-like precipitate in detail in *Fig. 2*). These particles were identified by EDX as manganese sulfides. The hardness of the ground material was 242 HV1.

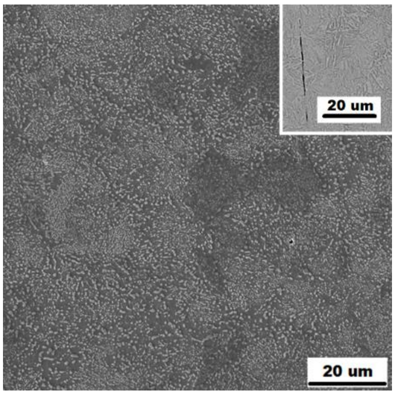

Figure 2. Structure of ground unquenched 15 142 material (SEM, 2000x, SE, HV 20 kV, 3% Nital etchant)

3.2 The overlap of 0 mm (0)

The first tested overlap value was 0 mm. It is clearly visible from *Fig. 3* that this overlap is completely insufficient for a continuous quenching of surface parts. There is no overlap in the axis between the individual quenching spots. The width of the unquenched belt was about 3.15 mm. In comparison to the previously investigated and published materials 19312 [11] and 12050 [12], the width of this unquenched belt was larger; 0.41 mm for material 12050 and 1.6 mm for material 19312. From these data, it can be concluded that the hardenability of the material studied within this article is the lowest of all three examined steels.

Fig. 4 shows the structure of the fully quenched area. The quenching speed was not sufficient for the fully martensitic structure formation. Martensitic needles were formed only in some places where the super-critical cooling speed has been achieved. The upper bainite was the main phase in the structure. The clusters of carbides are also visible in *Fig. 4*. In the belt between the unquenched material and the fully quenched area, there was formed a transition band. The structure of this transition area is formed by ferritic grains with dimensions of 5 – 10 μm (see *Fig. 5*). These ferritic grains are soft and may adversely affect the resulting properties of the quenched layer. The effective depth of the quenched area in the axis of the laser spot is 430 μm at the used process parameters (measured by microhardness testing – see *Fig. 6*).

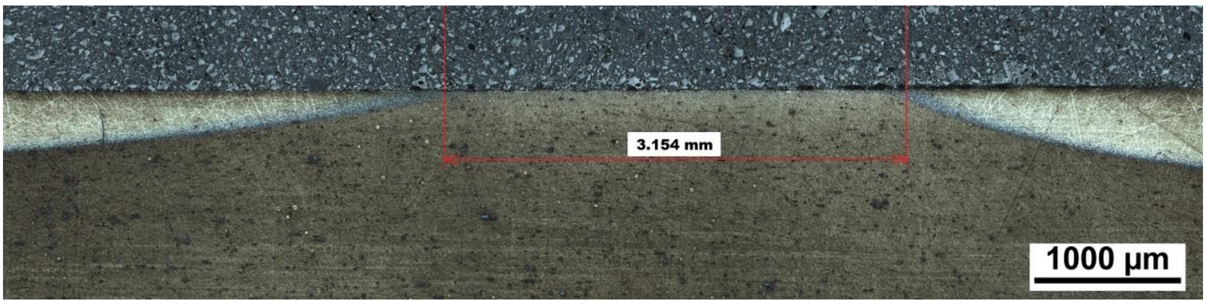

Figure 3. Quenched material – 0 mm overlap of laser spots (0) – LOM, 50x, 3% Nital etchant

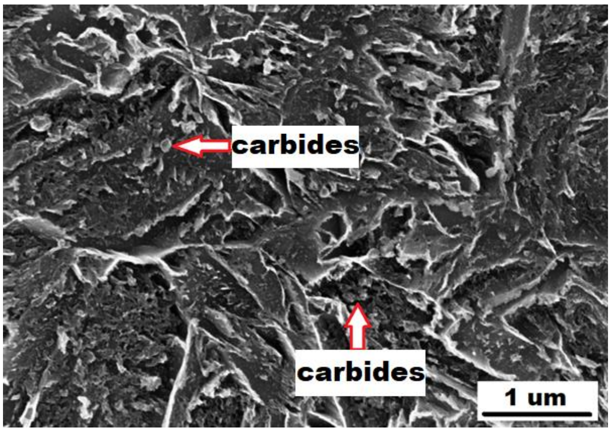

Figure 4. Fully quenched area of 15 142 steel – 0 mm overlap of laser spots (SEM, 1000x, InLens, HV 20 kV, Nital etchant)

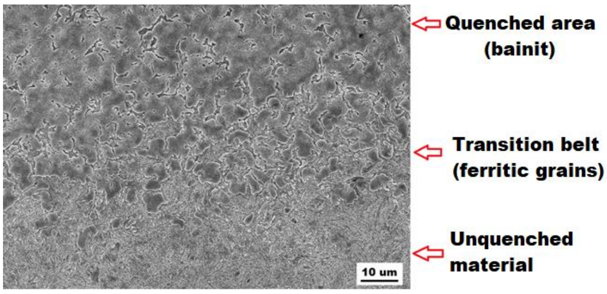

Figure 5. The transition area between fully quenched and unquenched material – 0 mm overlap of laser spots (SEM, InLens, HV 20 kV, Nital etchant)

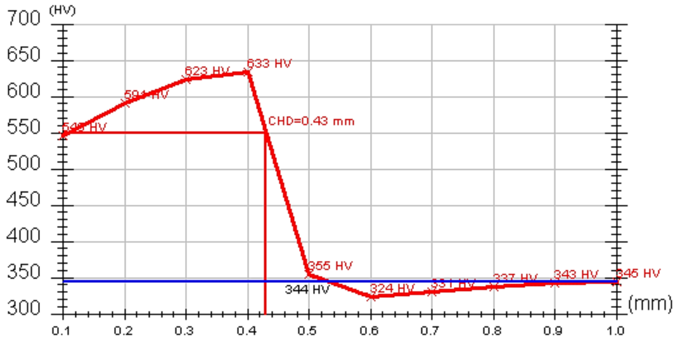

Figure 6. A record of hardness gradients of the fully quenched belt in the axis of laser spot – maximal depth of steel quenching is about 430 μm (test variant "0")

3.3 The overlap of 2 mm (+2)

When selecting the laser spot overlap of 2 mm (+2), the individual quenched tracks are still not overlapped, as shown in *Fig. 7*. The unquenched area between the individual quenching spots has a width of about 1 mm according to the image analysis of *Fig. 7*. The assumption that the hardening capability of 15142 sample is lower in comparison to the previously investigated materials [11, 12] was confirmed. The surface was completely quenched in the axis between the individual laser spots in the cases of 12050 and 19312 steels [11, 12]. The depth of these quenched belts was 413 μm for steel 12050 and 170 μm for steel 19312.

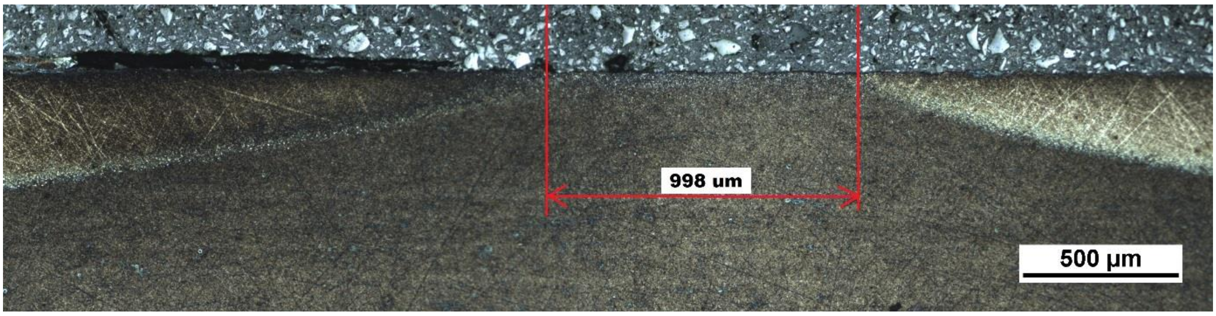

Figure 7. Quenched material – 2 mm overlap of laser spots (+2) – LOM, 50x, 3% Nital etchant

3.4 The overlap of 4 mm (+4)

Value selection of 4 mm (+4) shows some overlap, as it is visible from *Fig. 8*. However, this overlapped area was not quenched to martensite, but only to bainite state, as it was determined from the hardness gradient measurement (*Fig. 9*). The depth of bainitic area in the axis between the individual laser spots is about 140 µm. It can be summarized that the quenched belts overlapping starts at using the laser spots overlap of 4 mm (+4). On the other hand, the depth of the hardened material is too low at this overlap value. Therefore, the overlap higher than 4 mm is recommended for steel 1.7225 during square parts quenching.

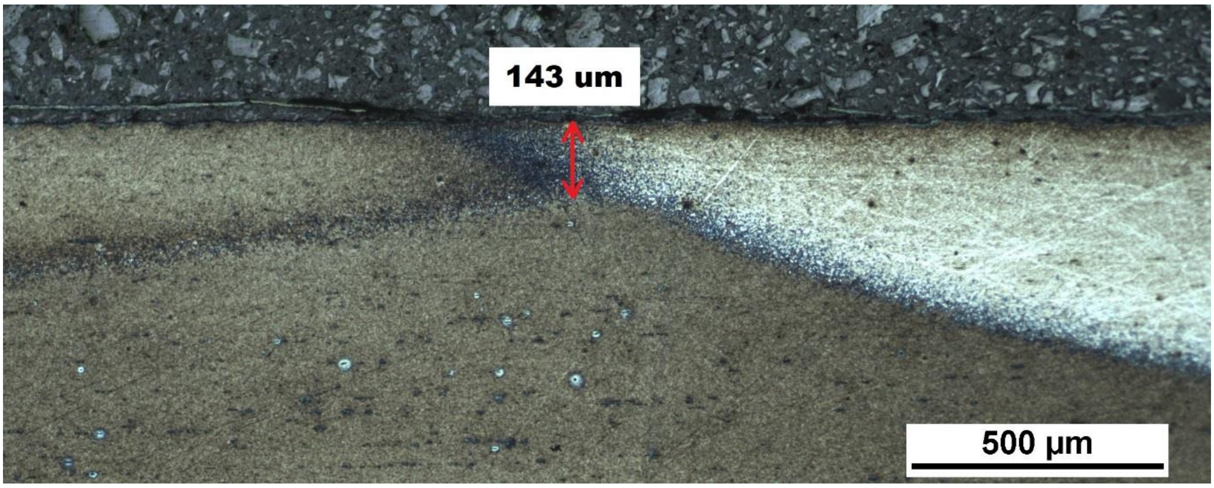

Figure 8. Quenched material – 4 mm overlap of laser spots (+4) – LOM, 50x, 3% Nital etchant

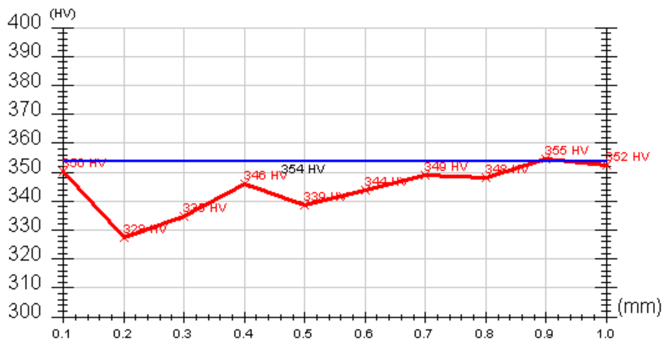

Figure 9. A record of hardness gradients in the axis between the quenched belts for variant +4

4 Conclusions

- A maximal depth of material hardening (in the axis of the laser spot) of 430 µm can be achieved for steel 1.7225 by laser quenching (hardening) using the test parameters.
- When selecting a laser spots overlap of 0 mm (0) or 2 mm (+2), the surface is not completely quenched. The unquenched belt in the axis between two laser spots has a width of 3.15 mm for variant "0" and 1 mm for variant "+2". The overlap was observed only in the case of "+4", however, the quenched depth in the axis between two laser spots was only 143 µm; moreover, this area was not created by martensite structure, but only the bainite.
- Hardening depths in the axis between the spots for each overlap variant and also for the previously tested materials [11, 12] are summarized in *Table 2*.

Table 2. The depth of the hardened layer in the axis between the spots for investigated steel 15142 (1.7225) and also for previously tested steels 12050 (1.1191) [12] and 19312 (1.2842) [11]

Overlap	**Hardening depth in the axis between the spots [µm]**		
	steel 15142 (1.7225)	steel 12050 (1.1191)	steel 19312 (1.2842)
0 mm	0	0	0
2 mm	0	413	170
4 mm	143 (only bainitic state)	896	580
Maximum depth of material hardenability at used laser parameters	430	1105	950

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