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MICROSTRUCTURE AND WEAR RESISTANCE OF THE LASER HARDENED PM TOOL STEEL VANADIS 6

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Abstract. Laser hardening of previously unhardened PM tool steel Vanadis 6 was studied. It was found that the best combination of properties was achieved, applying the laser beam of 700 W and the scan speed of 300 mm/min. In this case, the microhardness values ranged from 330 to 540 HV0.3 and case depth from 7.3 to 7.8 mm, volumetric wear equalled to 2.4 mm^3, what is, however, 2 times larger wear than that of conventionally hardened steel. This result can be explained by the large amount of retained austenite.
Key words: laser hardening, tool steel, abrasive wear resistance, austenization

1. INTRODUCTION

Laser hardening has several benefits over conventional hardening, including minimal distortion of the parts, opportunity to harden specific areas, absence of the quenchant, etc [1]. In the case of laser hardening, it is possible to improve hardness, strength, wear, fatique and lubricant properties of the mateial's surface, while desirable bulk properties, such as toughness and ductility, remain the same [2]. All this makes laser hardening an attractive and perspective process for treatment of tool steels. This paper focuses on laser hardening of PM tool steel Vanadis 6, which is used for stamping and forming of hardly treated materials [3]. Conventional heat treatment and accompanying routines, such as sub-zero treatment, nitriding and nitrocarburizing [4], are complicated and expensive in comparison with the laser hardening, what makes it a perspective technology. According to [5], lower interaction times, thus lower scan speeds allow to obtain deeper hardened layer. In contrast, higher scan speed and power density result in bigger hardness values due to the faster cooling rate, however, the hardened zone's depth decreases. Thus the aim of this study is to clarify the influence of parameters of laser hardening – laser beam power and scan speed – onto the hardness, hardened zone's depth and abrasive wear resistance of the above-mentioned tool steel.

2. EXPERIMENTAL

2.1 Preparation of the specimens

The chemical composition of tool steel Vanadis 6 is brought in Table 1. Specimens of the size 50 × 25 × 10 mm were machined and polished up to the surface roughness of Ra = 0.8 μm. Steel was used in the annealed condition.

2.2 Laser hardening

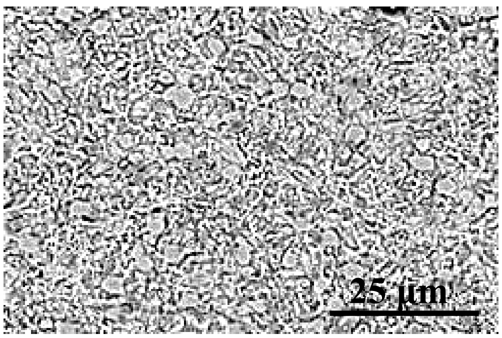
For the current experiment, the Haas HL4006D 4 kW Nd:YAG laser with the wavelength of 1064 nm was used. The perpendicular section of the laser beam had the dimensions of 8 × 5 mm. The consumption of the shield gas (argon) was 20 l/min. The overlapping was 50 %.

Steel grade	C, %	Si, %	Mn, %	Cr, %	Mo, %	V, %
Vanadis 6	2.1	1.0	0.4	6.8	1.5	5.4

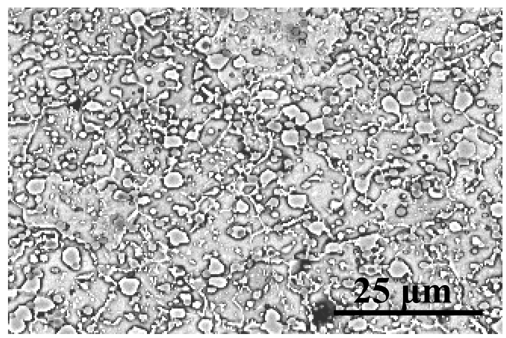
Table 1. Chemical composition of the PM tool steel Vanadis 6 [4].

Number of the experiment	Laser beam power, W	Scan speed, mm/min
1	350	300
2	525	450
3	350	600
4	700	300
5	700	600

Table 2. Parameters of laser hardening.



a)



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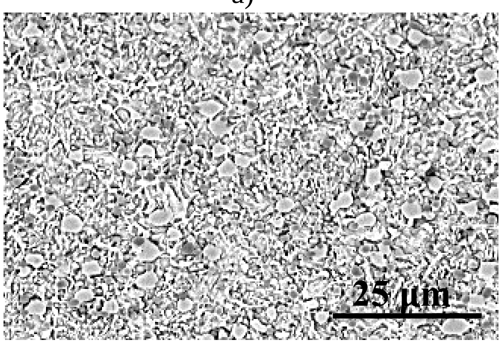

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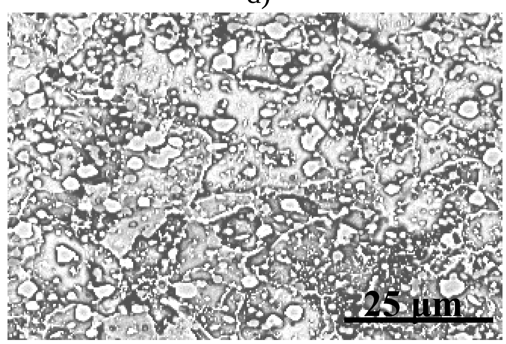

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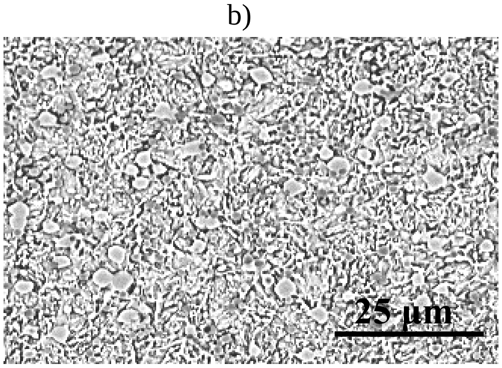

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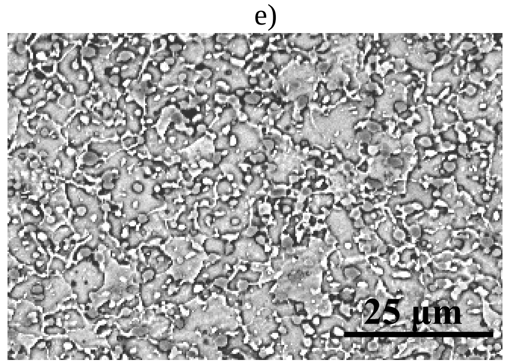

f)

Fig. 1. SEM pictures the cross-sections of laser hardened steel Vanadis 6: a) 700 W, 300 mm/min; b) 700 W, 600 mm/min; c) 525 W, 450 mm/min; d) 350 W, 300 mm/min, e) 350 W, 600 mm/min, f) initial microstructure.

The parameters of laser hardening are brought at Table 2. The scheme of laser hardening is brought elsewhere [6,7].

2.3 Obtained data evaluation

Cross-sections of the specimens were polished, etched with nital and studied by the scanning electron microscope (SEM) EVO MA15 (Carl Zeiss) in order to reveal the changes in the microstructure. Energy dispersive spectroscopy (EDS) was applied to find out the distribution of chemical elements in the specimen's cross-section.

Buehler Micromet 2001 microhardness tester was used to measure the Vickers microhardness HV 0.3 at the cross-section of the specimens perpendicular to the surface. In-depth measurements were carried out three times at each specimen's cross-section in order to find out the variation in the depths of the heat-treated zone.

Abrasive wear resistance was studied by the block-on-ring (rubber wheel) method according to the standard ASTM G 65-94, and was estimated by the volumetric wear. The diameter of the ring was 228.6 mm, the applied force equalled to 222 N, speed of rotation was 200.8 l/min (linear velocity 2.4 m/s). Mass of the quartz sand, applied in the experiment, was 0.84 kg, with the feed rate of 280 g per minute. Fraction of the sand was 0.1 – 0.3 mm, hardness of the quartz sand, measured at the polished cross-section, was in the range of 800 – 1100 HV0.05. Wear scars were studied under the optical microscope (OM) Axiovert 25 (Carl Zeiss).

3. RESULTS AND DISCUSSION

3.1 Microstructure

Fig. 1 illustrates the microstructure of the laser hardened Vanadis 6 at different parameters' sets. As it can be seen in Fig 1., a), the unhardened structure of Vanadis 6 consists of carbides, embedded in a ferrite matrix [7,8]. Neither melting nor heat-affected zone (HAZ) have been found at the micrographs.

As it can be observed, no changes in the microstructure can be seen in the specimen, hardened at the laser beam power value of 350 W, e.g. no quenching structures can be seen, as well as no carbide particles are dissolved in this case.

Concerning the changes in microstructures of specimens, hardened at laser beam power values, higher than 350 W, the structure of the hardened steel can be characterized as martensitic-trostitic, with the embedded carbide particles, whereas small carbide particles have dissolved in the metal matrix. Small dark areas of probably retained austenite can also be observed. No secondary carbides could be found, what means that melting temperature has been reached in none of the experiments.

The observed martensite must be the tempered martensite, forming from retained austenite due to overlapping of the laser passes. Trostite must have the same nature, as the tempered martensite.

It also can be observed, that the size of martensitic lamells decreases with the growth of the scan speed, what is, in general, in correspondence with [5], as the structure with fine grains must have a higher hardness.

3.2 Chemical composition

For specimens, hardened at laser beam power values of 350 W, no changes in the elements' distribution were discovered. For specimens, treated at laser beam power values higher than 350 W, a slight increase in V and Mo peak intensities can be seen. This can be explained by the dissolution of V and Mo containing carbides, which was observed during the microstructural studies. In the case of laser beam power value, equal to 700 W, less intense peaks were discovered for specimens, treated at the scan speed of 600 mm/min, what can be explained by less

Laser beam power, W	Scan speed, mm/min	Microhardness range of HZ, HV0.3	Microhardness range of HAZ, HV0.3	Depth of the HTZ, mm	Depth of the HTZ, mm	Depth of the HAZ, mm
350	300	270 – 280	240 – 280	–	–	–
350	600	270 – 280	240 – 280	–	–	–
525	450	445 – 575	325 – 440	5.1 – 7.3	2.1 – 6.2	1.0 – 2.9
700	600	445 – 605	330 – 445	1.9 – 7	0.0 – 3.1	1.9 – 3.9
700	300	430 – 560	330 – 420	7.3 – 7.8	4.0 – 6.5	1.0 – 3.3

Microhardness of unhardened specimens – 270 – 320 HV0.3.
Microhardness values of conventionally hardened [4] specimens – 775 HV0.3.

Table 3. Microhardness values and depths of heat-treated zones of laser hardened specimens.

time and thus smaller dissolution rate of the carbide particles.
No change in intensity of Cr peaks was registered, what can indirectly confirm the existence of the retained austenite in the structure, as Cr promotes the formation of ferrite in the structure.

3.3. Microhardness

Microharndess intervals and heat-treated zones' depths, obtained for different sets of laser hardening parameters, are brought at Table 3.
As it can be seen, no hardening effect was observed in the case of laser beam power value of 350 W. It can also be observed that two zones – hardened zone (HZ) and heat-affected zone (HAZ) – can be distinguished in the heat-treated zone (HTZ) according to the results of the microhardness measurements. As it can be observed, the microhardness values in HAZ are similar for all hardening conditions. The microhardness values in HZ vary slightly, whereas they grow in direct proportion to the scan speed values, what corresponds well with [5]. A slight drop of microhardness could be observed in the all the hardened specimens with the increase in distance from the hardened surface.
As no precipitation of secondary carbides was observed, it can be assumed that increase in the microhardness values in comparison with the unhardened condition occurs at the expense of quenching of the initial metal matrix. As formerly it was proved that no remarkable dilution of carbides, especially chromium ones, occurs during treatment, it may be concluded that no significant saturation of the forming martensite takes place, and its hardness thus mainly depends on the grain size, not on the bigger deformation of crystal lattice, caused by alloying elements' dilution, and accompanying effects. In addition to the presence of the retained austenite, this can explain the difference in microhardness values of laser hardened specimens and conventionally hardened ones.
Dramatic differences in the depths of the heat-treated zones of specimens can be explained by two effects: back tempering [1] and insufficient austenization time, e.g. forming austenite isn't saturated with alloying elements, whereas the second seems to be dominating, as if back tempering was the principle affecting factor, the smallest hardened zone's depth would be in the case of 700 W and 300 mm/min, but now the situation is vice-a-versa.

3.4 Abrasive wear resistance

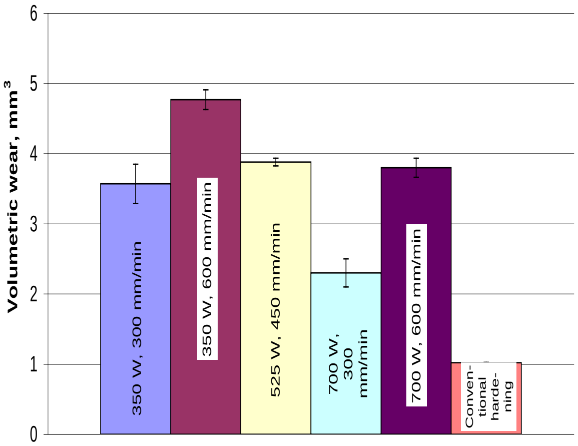

Fig. 2. Abrasive wear resistance of laser hardened steel Vanadis 6.

As it can be seen from Fig. 2, three hardening parameters' sets, namely 350 W and 300 mm/min, 525 W and 450 mm/min, 700 W and 600 mm/min show similar wear resistance, which is approximately 1.5 – 1.7 times lower than wear resistance, corresponding with 700 W and 300 mm/min. This fact can be explained by the different completeness of austenization of different surface areas of the specimens and thus different wear resistance of these surface areas.

The study of wear scars, which is illustrated by Fig. 3, witnesses that the prevailing wear mechanism for the specimens a) – d) is microcutting, accompanied by oxidation of the surface during the wear process. It also can be seen that some areas show bigger wear, and scratches are more evident there, what is in correspondence with the previous assumption.

In the case of 700 W and 300 mm/min, the dominating wear mechanism is microcutting, the amount of oxide and contribution of the oxidation wear is minor. In addition to that, it can be observed that fewer carbide particles are extracted from the substrate in comparison with specimens, treated at other

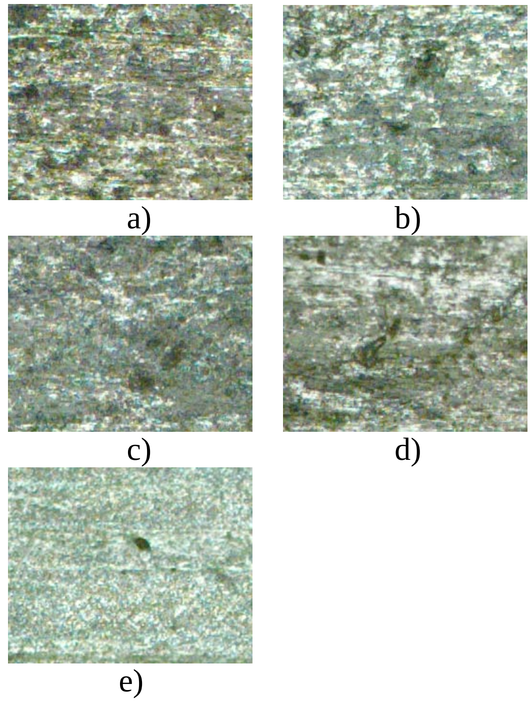

Fig. 3. Wear scars of laser hardened steel Vanadis 6, × 40: a – 350 W, 600 mm/min; b – 350 W, 300 mm/min; c – 525 W, 450 mm/min; d – 700 W, 600 mm/min; e – 700 W, 300 mm/min.

hardening parameters' sets. This can be explained by a more uniform rate of austenization and thus more uniform surface structure.

4. CONCLUSIONS

1. An inhomogeneous structure, consisting of tempered martensite, trostite, carbide grains and most probably retained austenite forms after laser hardening of tool steel Vanadis 6.
2. The microhardness values and the depth of the hardened zone, as well as variation of the last, depend primarily on the scan speed and for the second time on laser beam power value.
3. No remarkable diffusion of alloying elements has been discovered, the

microhardness of the structure was mainly influenced by the grain size.

4. Biggest wear resistance was shown by the specimens, hardened at 700 W and 300 mm/min parameters' set, what provided the most uniform surface structure.

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7. ADDITIONAL DATA

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