Structure and properties of surface layers obtained by alloying of the hot work tool steels

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ABSTRACT

Purpose: The aim of the present work was to study the microstructure and properties produced after laser alloying of the 55NiCrMoV7 and X40CrMoV5-1 an alloy hot-work tool steels.
Design/methodology/approach: Structure investigation was performed using the light microscope Leica MEF4A supplied by Zeiss. Phase composition and crystallographic structure were determined by the X-ray diffraction method using the DRON 2.0. The measurements of microhardness have been performed using Shimadzu microhardness indenter equipped with electronic sensor that allows the direct readout of the hardness values.
Findings: The metallographic investigations on light microscope show that steel after laser remelting can be characterized by a dendrite structure. Metallographic examinations on the scanning microscope with the EDX attachment confirm the occurrence of the niobium carbides in the surface layer of the investigated steels.
Research limitations/implications: In order to evaluate with more detail the possibility of applying these surface layers in tools, further investigations should be concentrated on the determination of the thermal fatigue resistance of the layers.
Practical implications: The surface layer of the hot work steel alloyed with ceramic powder have good properties and make possibility for uses it in various technical and industrial applications.
Originality/value: The microstructure and properties of the surface layer of the 55NiCrMoV7 and X40CrMoV5-1 hot-work tool steels alloying with ceramic powder were compared.
Keywords: Surface treatment; Laser alloying and remelting; Hot work alloy tool steel; High power diode laser HPDL

1. Introduction

The investigations about surfacing-alloys reveal that the surface treatments and the surface coatings are very good in order to protect the dies against the thermal fatigue, and increase the life of the die too. In fact, the surface coatings increase the resistance to abrasion because it provides higher hardness, roughness and corrosion resistance. One of these treatments could be laser surface treatment, which allows modify the properties of the surface of the material without modifying the core of it. [1].

The 55NiCrMoV7 and X40CrMoV5-1 hot-work tool steels are one of the most used steels to make dies because of its good properties in thermal fatigue, corrosion and wear away resistance. That is why the hot-work tool steels are very used to cast aluminium, magnesium and their alloys [2,3].

Employment of the laser surface treatment is justified both from the economical point of view and because the laser treatment, in many cases, ensures obtaining better mechanical properties of the processed surfaces, e.g., teeth of gear wheels or cutting tools edges, which could not be attained using the conventional surface treatment methods [2]. The laser heat treatment includes operations which are conducted using the laser beam as the source of energy needed for heating the surface layer of the processed material, to change its structure for obtaining the
relevant mechanical, physical, or chemical properties, improving service life of the processed element. [3].

There is an opinion that laser manufacturing techniques belong to the most promising and efficient ones, for ensuring the development in many industry branches, and especially those in which materials processing dominates. Thanks to the very precise energy delivery laser radiation makes it possible to carry out the technological operations better or faster within the framework of the technologies known to date. It makes also possible introduction of the new technologies whose realisation is impossible when using the conventional power density. These kinds of treatments make a very low grain and homogenous microstructure at the surface with a very short HAZ (Heat Affected Zone), providing a higher solid solubility by the alloying elements. The resulting surface has very good mechanical properties because the steel is melting and cooling in a very short period of time (10⁸ – 10¹⁰ times faster than conventional moulding), giving rise to a composition, distribution of the alloying elements and microstructural changes [4-7].

Laser alloying of the surface layer of materials with alloying additions is a new method of the thermo-chemical treatment. Laser modification by the appropriate selection of the alloying elements and process parameters makes it possible to obtain the surface layers with the structure and parameters comparable to the high-alloy steels. The surface layer rich with the alloying elements is usually characteristic of the higher hardness than the substrate, higher fatigue strength, better tribological and anti-corrosion properties, at the simultaneously worse smoothness than the substrate before alloying.

Steels are the most often enriched materials, whereas elements increasing the abrasion and erosion wear resistance, heat- and corrosion resistance feature the alloying additives [8-10].

The alloying additions used in the laser alloying process are usually Co, Cr, Mn, Nb, Ni, Mo, V, W, superalloys, stellite, carbides, nitrides and borides. The structure and chemical composition of the surface layer created in the laser alloying process, as well as its physical properties are highly different from the base and alloying material. [5,7,8].

Currently the HPDL high power diode lasers feature the up-to-date energy source. They are used for the industry scale in materials engineering only from 1998. The HPDL (High Power Diode Laser) reaches up to 6 kW in the beam focus. The big advantage of these lasers is that they make possible obtaining rectangular, square, linear or circular shapes of the laser beam focus. They have the controlled energy distribution in the focus area with power density of up to 10⁷ W/cm², the high coefficient of radiation absorption, do not require guiding the laser beam by any complex optical systems causing energy loss in the range of 10-30%, they have the high energetic efficiency reaching 50%. Robotisation of the technological processes is easy; they are reliable and all-purpose, which makes them a very attractive tool in material engineering [11-15].

2. Investigation methodology

The 55NiCrMoV7 and X40CrMoV5-1 hot-work tool steels were used as materials for investigation. Chemical composition of the steels is given in Table 1. Test pieces were obtained from the vacuum melt. The material was delivered in the annealed state, from which cubicoid test pieces were cut out.

The test pieces were heated to the austenitizing temperature gradually, with holding at 650°C for 15 min for both steels. Next they were austenitized in the vacuum furnace at the temperature of 850°C for 30 min for 55NiCrMoV7 steel and at 1020°C for 15 min for X40CrMoV5-1 steel. Cooling was carried out in hot oil at the temperature of 110°C. The test pieces were tempered twice in the chamber furnace with the argon protective atmosphere in the temperature range of 550-600°C for 55NiCrMoV7 steel and 510-660°C for X40CrMoV5-1 steel. Test pieces were sand blasted and machined on a magnetic grinder after heat treatment. After that, powder layer of NbC bounded with the sodium glass inorganic binding agent 0.05 mm thick was put down onto the degreased specimen. Subsequently, the test pieces were melted with the Rofin DL 0.20 high power diode laser (HPDL), which technical specification is given in Table 2.

<table>
<thead>
<tr>
<th>Type of steel</th>
<th>Mean concentration of elements (wt) [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>X40CrMoV5-1</td>
<td>0.41</td>
</tr>
<tr>
<td>55NiCrMoV7</td>
<td>0.55</td>
</tr>
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</table>

Table 2.
Specification of the HPDL ROFIN DL 0.20 diode laser

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Wavelength of the laser radiation, nm</td>
<td>808 ±5</td>
</tr>
<tr>
<td>Maximum output power of the laser beam (continuous-wave), W</td>
<td>2300</td>
</tr>
<tr>
<td>Laser power range, W</td>
<td>100-2300</td>
</tr>
<tr>
<td>Focal length, mm</td>
<td>82/32</td>
</tr>
<tr>
<td>Laser spot size, mm</td>
<td>1.8×6.8</td>
</tr>
<tr>
<td>Range of the laser intensity, kW/cm³</td>
<td>0.8×36.5</td>
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</tbody>
</table>
Metallographic examination of the material structures after laser alloying of its surface layer was made on Leica MEF4A light microscope. Examination of spectrum of the pointwise chemical composition analysis was made on the OPTON DSM-940 scanning electron microscope with the Oxford EDS Link ISIS energy dispersive X-ray spectrometer with the 20 kV accelerating voltage.

3. Investigations results

The metallographic investigations on light microscope show surface layer having the remelted zone (RZ) and the heat affected zone (HAZ) (figure 1). The structure of the coagulated material after laser remelting can be characterized by a dendrite structure (figure 2). There is a clear relationship between the employed laser power and the dendrite size, namely with increasing laser power the dendrites are larger.

Metallographic examinations on the scanning microscope with the EDX attachment confirm the occurrence of the niobium carbides in the surface layer of the investigated steels (Figures 3 and 4). In remelted zone of steel 55NiCrMoV7 it was found out that the niobium occurs in the form of conglomerates. The X-ray qualitative analysis method confirm in all analysis cases the occurrence of the Fe and the niobium carbides phase in the surface layer of the investigated steels (Figure 5). The microhardnes of steel alloyed with ceramic powders for both steels growth with laser power beam.

The table 3 shows the microhardnes measurements results of the remelted surface for 1.2, 1.6, 2.0 and 2.3 kW laser power. Maximum microhardnes of steel alloyed with NbC ceramic powder occurred for 2.0 kW laser power beam.

Fig. 1. Surface layer of the steel after laser remelting, a) X40CrMoV5-1, b) 55NiCrMoV7 steels alloyed with the NbC ceramic powder, laser beam power 2.0 kW

Fig. 2. Dendrite microstructure of surface layer of the a) 55NiCrMoV7, b) X40CrMoV5-1 hot work steels alloyed with the NbC ceramic powder, laser power beam 2.0 kW

Fig. 3. Surface layer of the steel after laser remelting, a) 55NiCrMoV7 steel alloyed with the NbC ceramic powder, laser beam power 2.0 kW, b) spectrum of the pointwise chemical composition analysis

Fig. 4. Surface layer of the steel after laser remelting, a) X40CrMoV5-1 steel alloyed with the NbC ceramic powder, laser beam power 2.0 kW, b) spectrum of the pointwise chemical composition analysis
Fig. 5. X-ray diffraction pattern of the a) 55NiCrMoV7, b) X40CrMoV5-1 hot work steel alloyed with the NbC ceramic powder, laser power beam 2.0 kW

Table 3.
The results of microhardness test

<table>
<thead>
<tr>
<th>Type of steel</th>
<th>Laser power, kW</th>
<th>Microhardness, HV 0,05</th>
</tr>
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<tbody>
<tr>
<td>X40CrMoV5-1</td>
<td>1.2</td>
<td>519</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>562</td>
</tr>
<tr>
<td></td>
<td>2.0</td>
<td>559</td>
</tr>
<tr>
<td></td>
<td>2.3</td>
<td>633</td>
</tr>
<tr>
<td>55NiCrMoV7</td>
<td>1160</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>1123</td>
<td>1283</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1077</td>
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</table>

4. Conclusions

The carried out investigations allowed to state that due to the heat treatment and remelting of the 55NiCrMoV7 and X40CrMoV5-1 tool steel with the NbC powder it is possible to obtain the high quality of the surface layer with no cracks and defects and with hardness significantly higher than the substrate metal. Remelting experiments made it possible to demonstrate the effect of the HPDL high power diode laser alloying parameters on properties and structure of the tool steels.

References