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Surface modification of the X40CrMoV5-1 steel by laser alloying and PVD coatings deposition

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ABSTRACT

Purpose: The paper presents the influence of alloying with NbC powder by the use of a high-power diode laser and TiAlN, AlSiCrN and TiCN gradient coatings deposition by PVD process on microstructure and hardness of the X40CrMoV5-1 steel surface layer.
Design/methodology/approach: Microstructure was characterised using optical metallography, scanning and transmission electron microscopy.
Findings: In the effect of laser alloying with powders of carbide NbC occurs size reduction of microstructure as well as dispersion hardening through fused in but partially dissolved carbides and consolidation through enrichment of surface layer in alloying additions coming from dissolving carbides. The structure of the PVD coatings consisted of fine crystallites while their average size fitted within the range of 15-50 nm, depending on the coating type. The coatings demonstrated columnar structure.
Research limitations/implications: It is necessary to continue the research to determine alloying parameters for demanded properties of hot work tool steels surface layers. Further investigations should be concentrated on the determination of the thermal fatigue resistance of the layers.
Practical implications: Good properties of the PVD coatings and the laser treatment make these layers suitable for various technical and industrial applications.
Originality/value: Laser alloying by using different carbide powders and HPDL laser is a new way to improve the structure and mechanical properties of the hot work tool steels.
Keywords: Hot work tool steel; Laser treatment; PVD coatings; Microstructure

1. Introduction

Laser alloying of the surface layer of materials is a part of new technology of the thermo-chemical treatment. Laser modification by the appropriate selection of the alloying elements and process parameters makes possible to obtain the surface layers with the structure and parameters comparable to the high-alloy steels. This type of surface treatment is used for improvement 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. Laser treatment is characteristic of the contact less operation, selectivity, and possibility of full automation of the process [1-4]. A laser alloying technique can be used for obtaining thin surface layers in order to increase its wear-resistance. In laser surface alloying the high energy of a laser beam is used to alloy the surface of a material with another material. The properties of the alloyed layer depend on its preparation, e.g. laser beam power, traverse speed, feeding method and the amount of the alloying material [5-8].

Fast development of the PVD processes has offered the potential of the specific coatings properties on an industrial scale, not limited only to coat tool materials but also in other application domains [9-11]. Mechanical properties of hard coatings deposited with the PVD technique depend to a great extent on their structure. The X-ray diffraction examinations (XRD), examinations on the transmission electron microscope (TEM), and on the scanning electron microscope (SEM) make it possible to determine thoroughly the essential details of the crystalline structure of the coatings [12-13].

2. Investigation methodology

The examinations have been made on the specimens of hot work tool steel X40CrMoV5-1 deposited in the PVD process with hard TiCN, AlSiCrN, TiCN gradient coatings. The process of the coatings' deposition has been made in the device based on the cathodic arc evaporation (CAE) method. The deposition conditions was presented in [14]. Alloying of surface layers with NbC powder were made using the high-power diode laser ROFIN DL 020 in the laser power range from 1.2 kW to 2.3 kW. Experimental methodology was presented in [2, 14-15].

3. Investigations results

Laser alloying of surface layer of investigated steel in the whole range of used laser power, causes size reduction of dendritic microstructure with the direction of crystallization consistent with the direction of heat carrying away from the zone of impact of laser beam. The structure of the material solidifying after laser remelting is diversified, which is dependant on the solidification rate of the investigated steels. Occurrence of structure with big dendrites was revealed in areas on the boundary of the solid and liquid phases (Fig. 1). In the effect of laser alloying with powders of carbide NbC occurs size reduction of microstructure as well as dispersion hardening through fused in but partially dissolved carbides and consolidation through enrichment of surface layer in alloying additions coming from dissolving carbides. Introduced particles of carbides and in part remain undissolved, creating conglomerates being a result of fusion of undissolved powder grains into molten metal base (Fig. 2).

The investigation gradient coatings deposited by PVD techniques show columnar structure which may be considered as compatible with the Thornton model (I zone), only in case of TiCN the cross-section morphology is dense (Fig. 3). Fractographic examinations of the investigated steel specimens with the TiAlN and TiCN coatings deposited onto their surface show a sharp transition zone between the substrate and the coatings.

On the basis of the investigations made of thin foil, which was performed by surface layer of the hot work tool steel alloyed with niobium carbide it was found that a warp superficial layer is a part of lathe martensite about major thickness of dislocations after alloying in the scanning electron microscopy. The slats of this martensite are a very expensive and about an irregular shape. Moreover, they are twinning to a large extent. There are located small carbides a type of M_7C_3. There is retained major thickness of dislocations in slats of martensite, some slats are in part twinned (Fig. 4).

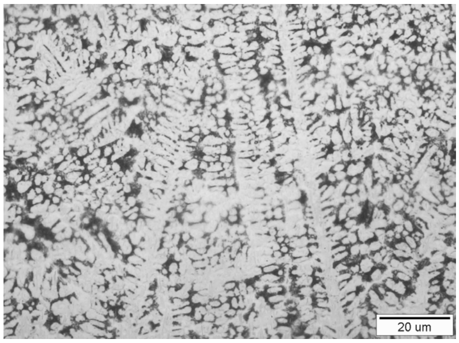

Fig. 1. Central zone of the remelting surface layer of X40CrMoV5-1 steel after alloying with NbC, power range 1.2 kW

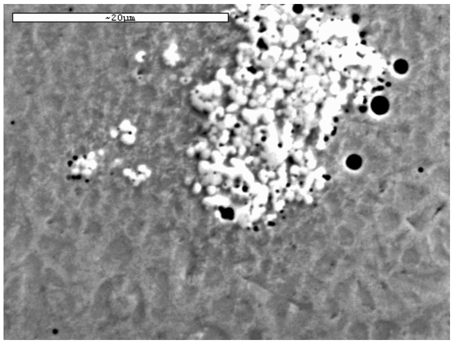

Fig. 2. Surface layer of the X40CrMoV5-1 steel alloyed with the NbC powder, power range 2.0 kW, (SEM)

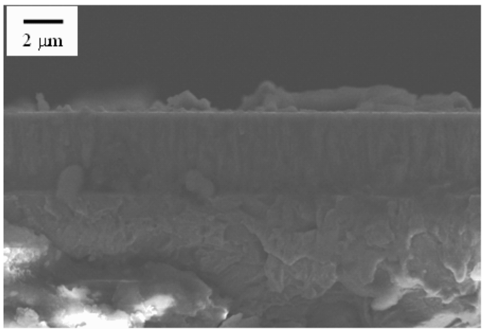

Fig. 3. Fracture of the TiAlN coating deposited onto the X40CrMoV5-1 steel substrate

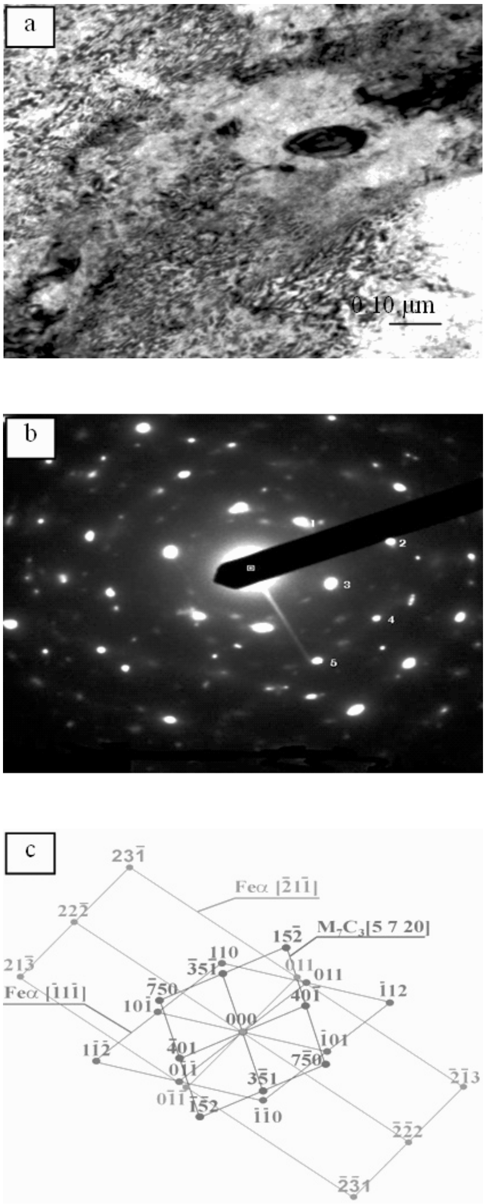

Fig. 4. Structure of the thin foil of X40CrMoV5-1 steel, after alloying NbC, power of bunch laser 1.6 kW: a) a picture in a bright area, a diffraction pattern of area as fig. a), a solution of diffraction pattern from fig. b)

TEM investigations of the coatings (Fig. 5) show fine crystallites with average size about 15-50 nm depending on the kind of the coating. Generally, there are no premises that might suggest the epitaxial growth of the examined coatings. In case of the CrAlSiN coating some large grains are observed and from SAED pattern evident epitaxy is deduced, resulting from larger crystals. Several large grains were observed in the CrAlSiN coating and the possibility of epitaxy due to the presence of large crystalites may be deduced upon examination of the SAED pattern.

It was observed that increase of the laser power causes inundation of a bigger amount of niobium carbide; hardness for the native material after heat treatment is about 2.0 GPa, whereas after alloying with NbC it is about 2.4 GPa. The deposition of the PVD coatings onto the specimens causes the growth of hardness of the surface layer rainging from 29.9 to 32.8 GPa. The highest hardness i.e. 32.8 GPa was noted in the TiAlN coating, while the lowest, i.e. 29.9 GPa is characteristic for the TiCN coating (Table 1).

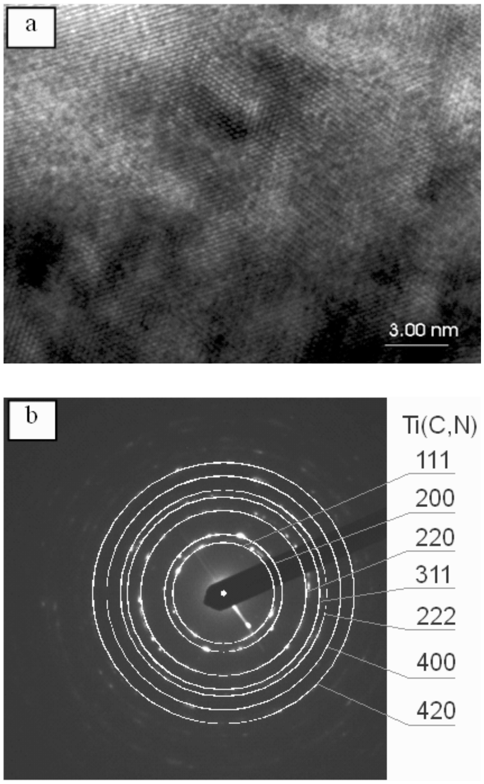

Fig. 5. a) Structure of the thin foil from the TiCN coating deposited onto the hot work tool steel X40CrMoV5-1, b) diffraction pattern from the area as in figure a) and solution of the diffraction pattern

Table 1
Hardness test results for the surface layer alloyed by HPDL high-power diode laser with the NbC and after PVD coating deposited process

X40CrMoV5-1 conventional heat treated	2.0 GPa
X40CrMoV5-1 alloyed with NbC	
1.2 kW	2.1 GPa
1.6 kW	2.1 GPa
2.0 kW	2.2 GPa
2.3 kW	2.4 GPa
X40CrMoV5-1 after PVD coating deposited process	
TiCN	29.9 GPa
AlSiCrN	32.1 GPa
TiAlN	32.8 GPa

4. Conclusions

Investigations presented in this paper include comparison between alloying of the X40CrMoV5-1 hot work tool steel surface layer by NbC carbide using the high-power diode laser HPDL and PVD coating deposition process. Laser alloying tests of the X40CrMoV5-1 steel surface layer with the NbC powder revealed that with the correctly selected alloying parameters, like scanning rate, laser power, and gas protection method, it is possible to obtain the flat remelting face with no cracks. There is the increase in the hardness of the surface layers in relation to the output material. Surface layer obtained due to laser modification is characteristic of different properties than the native material.

The compact structure of the PVD gradient coatings without any visible delamination was observed in the scanning electron microscope. The investigated coatings show columnar structure, which may be considered compatible with the Thornton model (zone I). Upon examination of the thin films obtained from TiAlN and TiCN coatings, it was found that the coatings were composed of fine crystallites.

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