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Crystallisation mechanism of laser alloyed gradient layer on tool steel

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ABSTRACT

Purpose: The objective of the present work was to study the modification of the microstructure of hot-work tool steel X40CrMoV5-1 during the surface modifying by means of laser technology.
Design/methodology/approach: The structural mechanism of surface layer development was determined and the effect of alloying parameters and thickness of paste layer applied onto the steel surface on structure refinement and influence of these factors on the crystallisation mechanism of surface layer was studied.
Findings: Development of the surface layer was observed in which one can distinguish the remelted zone, heat-affected zone and the transient zone. The fine grained, dendritic structure occurs in the remelted and alloyed zone with the crystallization direction connected with the dynamical heat abstraction from the laser beam influence zone. The X40CrMoV5-1 conventionally heat treated steel was used as reference material.
Practical implications: Laser surface modification has the important cognitive significance and gives grounds to the practical employment of these technologies for forming the surfaces of new tools and regeneration of the used ones.
Originality/value: The outcome of the research is an investigation showing the structural mechanisms accompanying laser alloying.
Keywords: Heat treatment; Laser; Tool materials; Wear resistance

1. Introduction

The hot-work steel X40CrMoV5-1 is 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 steel X40CrMoV5-1 is very used to cast aluminium, magnesium and their alloys. 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, toughness and corrosion resistance [1-6].

One of this treatments could be laser surface treatment, which allows modify the properties of the surface of the material without modifying the core of it. 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 ($10^4 - 10^5$ times faster than conventional moulding), giving rise to a composition, distribution of the alloying elements and microstructural changes [7,8]. When laser is used to modify the surface of some steel, the final result depends on some variables. The reflectivity of the surface influences on the effect produced by the heating because of the

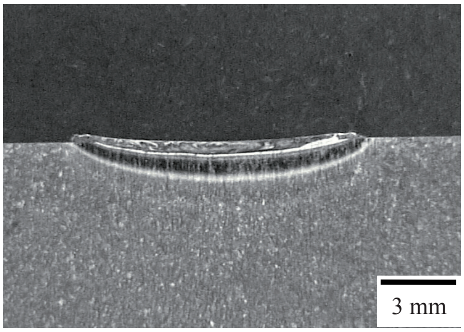

Fig. 1. Steel surface layer after alloying with parameters: scanning rate – 0.5 m/min, beam power – 1.5 kW, WC coating thickness – 0.11 mm

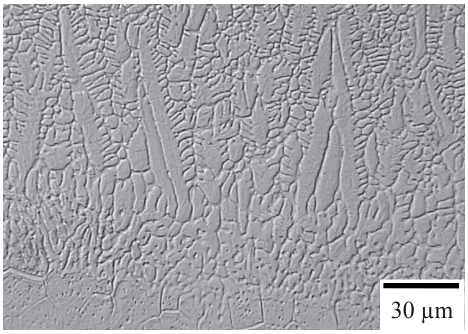

Fig. 2. Boundary of the remelted steel surface layer after alloying with parameters: scanning rate – 0.5 m/min, beam power – 1.5 kW, WC coating thickness – 0.11 mm

absorption of the laser radiation. And this reflectivity depends on the surface finish, kind of coating and oxidation state. If we were alloying the surface and the elements of the coating dissolved on the melting steel, it would be chemical, microstructural and properties changes of the laser melting zone [9-15].

The goal of the work is fundamental understanding of crystallisation mechanism of laser alloyed tool steel and determine the technical and technological conditions for alloying the surface layer of the X40CrMoV5-1 hot work alloyed tool steel with the high power diode laser, and of the relationship between the parameters of laser treatment and the properties of the surface layer which increase the exploitation durability of hot- work tools [4-6, 15]

2. Investigation procedure

The experiments were made on specimens made from the X40CrMoV5-1 alloy hot work tool steel. The specimens were austenitized on the salt bath furnace and tempered in the chamber furnace in the protective atmosphere – argon. The specimens were gradually heated to the austenitizing temperature with the isothermic stops at 650 and 850°C for 15 min. Further they were austenized for 30 min at the temperature of 1060°C and cooled in hot oil. The specimens were tempered twice for 2 hours at the temperature of 510°C after quenching. Next, powder layers of the WC tungsten carbide of two different thicknesses of 0.06 mm and 0.11 mm bounded with the inorganic binding agent were put down onto the degreased specimens. Specimens of the X40CrMoV5-1 steel fixed in a turntable were remelted with the Rofin DL 020 high power laser beam (HPDL). The multimode energy distribution was used. It was found out in the preliminary investigations that the maximum feed rate at which the process is stable is 0.5 m.min. Further experiments were carried out at the constant remelting rate, changing the laser beam power in the 0.5-2.5 kW range during remelting the surface layer of the test pieces, and in the 0.5-1.9 kW range during alloying the test pieces.

The research of the structure as well as the measurement of the thickness of proper zones of the surface layer were also conducted by comparison with transverse microsections in the Opton DSM 940 scanning microscope at the magnification of 1000 and 5000x. Diffraction and chemical composition examinations in micro-areas and of the thin foil structures were made on the JEOL 200CX transmission electron microscope at the accelerating voltage of 200 kV, equipped with the Oxford EDS LINK ISIS X-ray energy dispersive spectrometer and on the TESLA BS 540 electron microscope at the accelerating voltage of 120 kV. Thin foils were made from lamellae diced on the electro-discharge machine from the test pieces for the structural examinations, from which disks with 3.2 mm O.D. were cut out, next mechanically thinned and ion polished in the electrolyte on the Struers TENUPOL-2 electrolytical polishing device and on the Gatan 691 ion polishing device. The diffraction patterns from the transmission electron microscope were solved using the computer program. Analysis of the crystallographic relationships occurring between the phases identified in the diffraction patterns from thin foils was made using the stereographic projections.

3. Discussion of the investigation results

Experiments of remelting and alloying with tungsten carbide the X40CrMoV5-1 hot-work alloy tool steel indicate to the clear influence of the remelting and alloying processes' parameters, especially of the laser beam power, on the bead face shape (Figs. 1,2). Treatment in the analysed laser power range ensures the regular and flat face shape, without undercuts and with the relatively good surface smoothness. Quick crystallization leads to structure diversification in the remelted zone transverse section. Mixing of materials proceeds according to various mechanisms, depending on the employed treatment parameters. Capillary lines are not connected and the remelting structure is relatively homogeneous at low energy values of the laser impact on the material. The capillary lines swirl occurs along with the laser power increase (Fig. 1), as they begin to link. The remelting bottom is still flat, however slight waviness appears in surface (Fig. 2). Occurrences of the remelted- and heat affected zones have been confirmed in the surface layer of the investigated steel, whose thickness depends on the employed laser treatment parameters (Figs. 1,2). Columnar crystals developing in the remelted layer under such dynamical crystallization conditions are oriented in the direction of the maximum temperature gradient and – simultaneously – orientation of the privileged growth <100> is maintained, characteristic of materials with the regular structure. Growth of crystals in directions <110> and <111> is also possible, which leads often to sudden change of the crystals

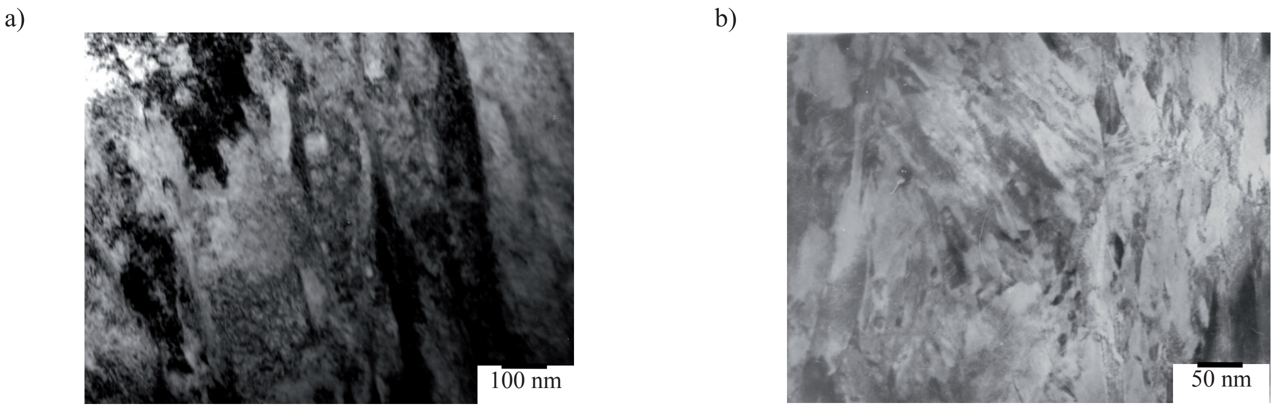

Fig. 3. Thin foil structure from the X40CrMoV5-1 steel a) quenched at 1060°C and tempered at 510°C, b) after remelting with parameters: scanning rate – 0.5 m/min, beam power – 1.4 kW

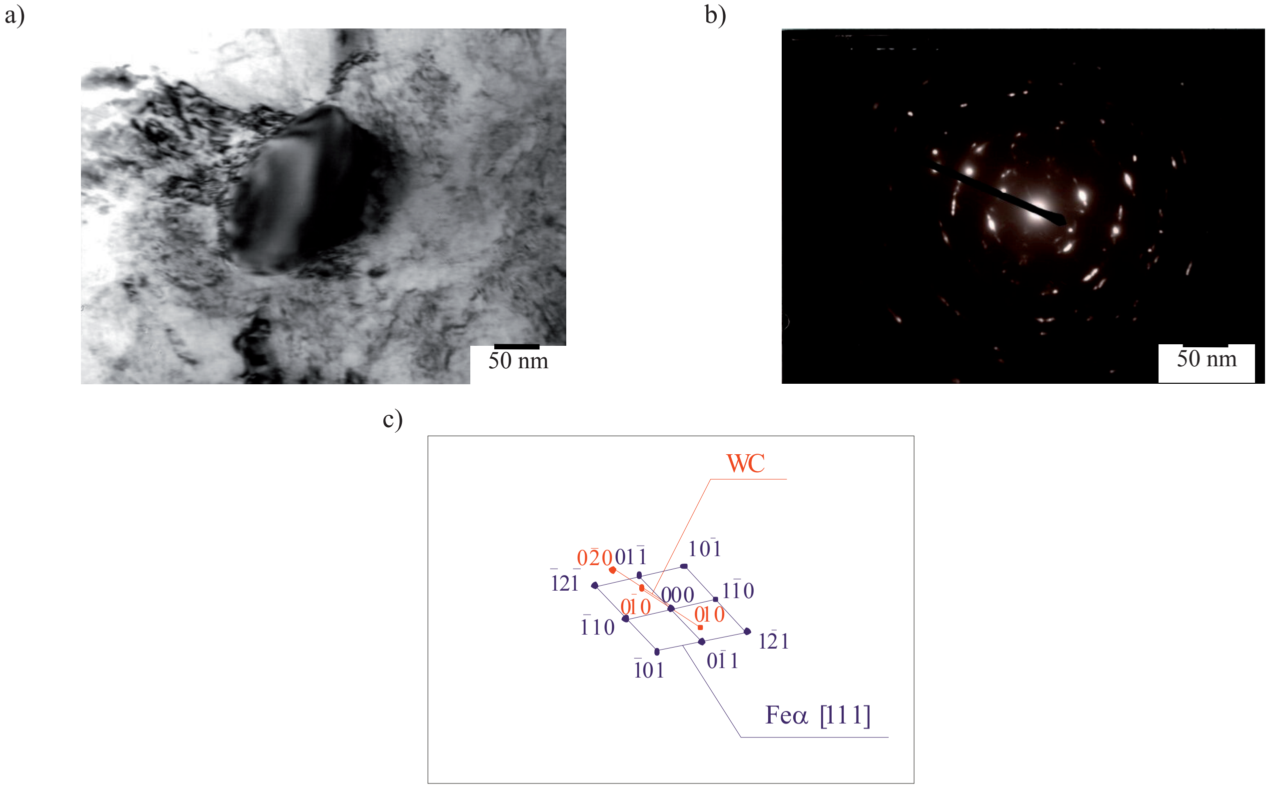

Fig. 4. Thin foil structure from the X40CrMoV5-1 steel after alloying with parameters: scanning rate – 0.5 m/min, beam power – 1.3 kW, WC coating thickness – 0.11 mm, a) light field image, b) diffraction pattern from the area as in figure a, c) solution of the diffraction pattern from figure b

growth direction. Possibility of re-nucleation on the partially melted dendrite arms, occurring due to concentration superfusion is an explanation of the sudden change of crystals growth direction from the <100> orientation. Carbide clusters appear in the central area of the remelted zone, arranged in the characteristic swirls, caused by the convection motion of the material in the liquid state. Size of the crystals depends on the remelting process parameters, and especially on the remelting rate and volume of the remelted material, and also on the non-remelted volume of the heat abstracting material. Solidification rate grows along with shortening of the time period of the laser beam impact on the material and with the increase of the treated material volume, and the obtained crystalline structure is more refined. This is the reason for the ultra-fast phase transformations influencing the structural mechanism of forming the surface layers subjected to laser modification. The austenite grain size has an essential effect on the martensitic transformation, and grain boundaries feature the privileged location of the martensitic transformation initiation. Atoms at grain boundaries participate in the martensitic transformation to a less degree because of their weaker bonding with the crystal lattice. Also the crystalline structure defects migrating to the grain boundaries – dislocations – decrease the probability of martensite origination inside the austenite grains. Grain boundaries, except the low-angle ones, feature also obstacles to the martensite lathes' growth, due to the grain crystalline continuity loss (Fig. 3). It is most often the lathe martensite in the hot-work tool steels; and several martensite packets separated with the wide-angle boundaries originate within one austenite grain (Figs. 3,4). The martensite lathes in the particular packets are separated with the low-angle- or twin boundaries. Therefore, development of the lathe martensite is dominated by slip shear, therefore the martensite lathes are characteristic of the big dislocation density. Twinned areas occur only locally in the martensite of this type. Results of examinations of thin foils on the transmission electron microscope indicate that the remelted zone structure is characteristic of the significant refinement of the martensite with the martensite lathes' length several times smaller than of the ones of the martensite developed during the conventional quenching (Figs. 3,4). Particles of tungsten carbide and the increased tungsten concentration, forming the superfine eutectics, occur in steel alloyed with tungsten carbide. The increased tungsten concentration in the remelted layer results from the tungsten portion in the alloying powder, tungsten carbide melting temperature, and its solubility in the solid solution.

4. Conclusions

It was found out, basing on the research carried out, that it is feasible to develop the surface layers on the X40CrMoV5-1 hot-work tool steel by remelting and alloying with the tungsten carbide using the high power diode laser (HPDL). The structure of material solidifying after laser remelting is characteristic of the diversified morphology connected with the repeated changes of the crystals' growth direction, from the small dendrites, whose principal axes are oriented in accordance with the heat removal directions at the boundary between the solid and liquid phases, clusters of carbides arranged in accordance with the swirls caused by the metallic liquid convection motion, and partially non-remelted WC conglomerates as the alloying material in the central area of the remelted zone, to the fine equiaxial grains in the subsurface zone. The very fast heat removal from the remelting zone by the material core with the much bigger thermal capacity, decides the martensitic transformation of the austenite originated due to crystallization, and the lathe martensite developed in this process, partially twinned, is characteristic of the significant refinement of the martensite with the martensite lathes' length several times smaller than of the ones of the martensite developed during the conventional quenching. Laser remelting and alloying with the tungsten carbide results in refinement of the structure in the entire laser power range and in diversification of the grain size in the particular surface layer zones. The research results indicate to the feasibility and purposefulness of the practical use of remelting and alloying with the tungsten carbide using the high power diode laser, e.g., for making new tools or for regeneration of the used ones from the X40CrMoV5-1 hot-work tool steel.

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