A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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LASER SURFACE MODIFICATION OF BOROCHROMIZING C45 STEEL

LASEROWA MODYFIKACJA BOROCHOROMOWANEJ STALI C45

In this study the test results for borochromized C45 steel after laser surface modification were presented. Influence of laser heat treatment on the microstructure and microhardness of surface layer was investigated. The process of borochromizing consisted of chromium plating followed by diffusion boronizing. The laser heat treatment (LHT) of multiple tracks in the helical line was carried out with CO_2 laser beam. The technological laser TRUMPF TLF 2600 Turbo CO_2 of the nominal power 2.6 kW was applied. Borochromizing was carried out with laser power density q = 41.40 kW/cm^2 and at laser beam scanning rate v = 0.67 m/min and v = 2.016 m/min. Measurements of microhardness were conducted using the Vickers' method and Zwick 3212 B hardness tester. Microstructure observations were performed by means of an optical microscope Metaval Carl Zeiss Jena and scanning electron microscope Tescan VEGA 5135. After laser heat treatment with re-melting a three-zone layer was obtained, which included: re-melted zone, heat affected zone and a core. Influence of laser treatment parameters on thickness of melted zone and microstructure of the surface layer was tested. The microhardness tested along the axis of track of the surface layer after laser modification was about 800-850 HV. The results of tests showed influence of laser power density and scanning rate on microstructure and properties of borochromized layers.
Keywords: chromium plating, diffusion boriding, laser heat treatment, microstructure, microhardness

W pracy przedstawiono wyniki badań borochromowanej stali C45 po laserowej modyfikacji. Badano wpływ laserowej obróbki cieplnej na mikrostrukturę i mikrotwardość warstwy wierzchniej. Proces borochromowania składał się z obróbki galwanicznej, następnie dyfuzyjnego borowania. Laserowa obróbka cieplna dla ścieżek wielokrotnych po linii śrubowej była wykonana przy użyciu lasera technologicznego CO_2 firmy TRUMPF TLF 2600 Turbo o mocy nominalnej 2,6 kW. Borochromowanie przeprowadzono przy użyciu gęstości mocy lasera q = 41,40 kW/cm^2 i prędkości skanowania wiązki laserowej v = 0,67 m/min oraz v = 2,016 m/min. Pomiar mikrotwardości wykonano metodą Vickersa na twardościomierzu Zwick 3212B. Natomiast badania mikrostruktury przeprowadzono przy użyciu mikroskopu Metaval produkcji Carl Zeiss Jena jak również skaningowego mikroskopu elektronowego Tescan VEGA 5135. Po laserowej obróbce cieplnej z przetopieniem otrzymana warstwa składała się z trzech stref: przetopionej, wpływu ciepła i rdzenia. Badano wpływ parametrów laserowej obróbki na grubość i mikrostrukturę strefy przetopionej. Mikrotwardość w osi ścieżki warstwy wierzchniej po laserowej modyfikacji wynosiła ok. 800-850 HV. Wyniki badań wykazały wpływ oddziaływania gęstości mocy lasera i prędkości posuwu na mikrostrukturę oraz właściwości warstw borochromowanych.

1. Introduction

Elements of the periodic system can be produced on metal alloys by depositing coatings (chromizing, nickelizing, copperizing, zinc plating) and diffusion methods, such as boriding, nitriding, carburizing, chromizing. Currently, many authors study the modifications of the surface layer aimed at obtaining beneficial properties (hardness [1-12], wear resistance [1, 2, 4-8], corrosion resistance [7]) and the structure free from imperfections (pores, cracks). Surface layer can be modified by various methods, among others: diffusing [11, 12], electroplating [1, 2, 8, 9], using beam of high energy (modification, alloying) [3, 5, 8, 9, 13, 14]. Chromium plating is a well-known and widely used process of galvanic treatment for various parts of machines (piston rings, dies, shafts). Diffusion boriding is a method of thermo-chemical treatment involving saturation of the steel surface layer with boron. As a result, boron-iron compounds called borides are formed: FeB and Fe_2B. The borides have a needle-like structure and average hardness up to 2000 HV. Among advantages of boride layers there are increased hardness, wear resistance, heat resistance to a temperature of 800°C and corrosion re-

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sistance in many acidic and alkaline solutions. The disadvantage of these layers is the brittleness within the subsurface zone (FeB) that manifests itself by spalling and peeling from the core. Boride layer is also characterized by high hardness gradient of the transition from the layer to the core [10-12]. The article [9] presents the influence of laser power density on structure and selected properties. This paper presents modification of the borochromized layer by means of CO_2 laser. The effect of laser scanning rate on the thickness of the melted zone, microstructure and microhardness were tested.

2. Experimental procedure

The tests were carried out on C45 steel of chemical composition 0.42% C, 0.72% Mn, 0.19% Si, 0.30% S, 0.008% P. The specimens were ring-shaped 20 mm in external diameter, 12 mm in internal diameter and 12 mm height. The process of borochromizing included chromium plating followed by diffusion boriding and heat treatment. The chromium layer was about 20 μm thick and its average microhardness was 850 HV0.05. The next stage of boriding treatment was performed at 950°C for 4 h. The boriding powder used in the gas-contact method contained: amorphous boron, KBF_4 as an activator and carbon black as a filler. After boriding samples were hardened from 850°C in water and tempered at 580°C for 1 h. After borochromizing a laser heat treatment for the chosen parameters was performed. For the laser heat treatment of borochromizing a technological laser TRUMPF TLF 2600 Turbo CO_2 with the nominal power 2.6 kW was used. It operated at the following parameters: power density q = 41.40 kW/cm^2, scanning rate v = 0.67 m/min and v = 2.016 m/min at a constant beam diameter d equal 2 mm. Laser tracks were arranged as multiple tracks produced in the shape of helical line, with the distance f = 0.5 mm/rev, where f is the width of the re-melted zone. Thus the determination of wear resistance was possible. Microstructure tests were performed using an optical microscope Metaval Carl Zeiss Jena with a camera 2300 3.0 MP and Live Motic Images Plus 2.0 Resolution software and scanning electron microscope Tescan VEGA 5135.

Metallographic observations of the microstructure were conducted on polished and etched cross-sections of the specimens using an optical microscope. Samples were etched in a solution including $CuSO_4$+ HCl + H_2O or 2% HNO_3. To determine microhardness profiles (Vickers method) ZWICK 3212 B hardness tester was used. The hardness tests were performed at a load of 0.1 kG.

3. Results and discussion

The layer produced in the two-step borochromizing process consists of a single zone, looking like iron borides. The thickness of the produced borochromized layer was about 70 μm. Microhardness of borochromized layers showed a mild gradient of hardness from surface to core. It was within the range of iron borides and was about 1400 HV [8]. Laser modification was carried out for borochromized layers. Microstructures after laser modification consisted of three zones: re-melted zone (MZ), heat affected zone (HAZ) and core (Fig. 1, 3).

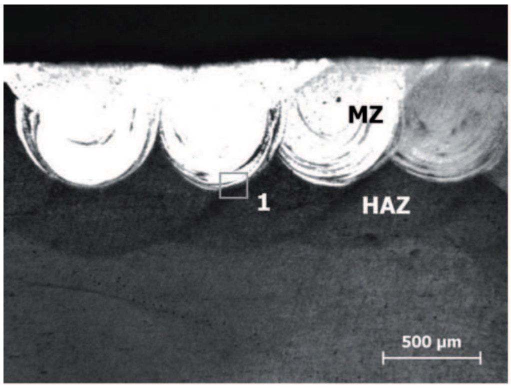

Fig. 1. Microstructure of C45 steel after borochromizing and LHT q = 41.40 kW/cm^2, v = 0.67 m/min; Reagent: solution 2% HNO_3

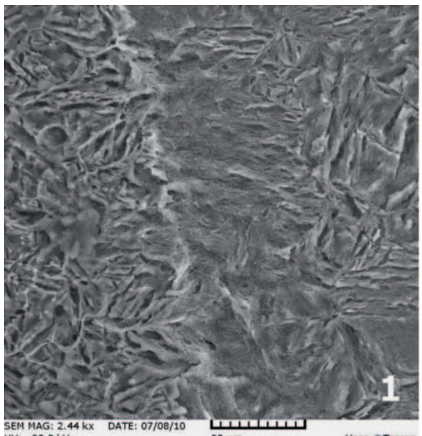

Fig. 2. Microstructure of C45 steel after borochromizing and LHT q = 41.40 kW/cm^2, v = 0.67 m/min; boundary MZ and HAZ; Reagent: solution $CuSO_4$+ HCl +H_2O

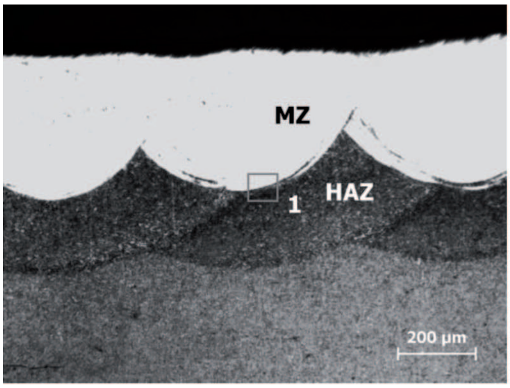

Fig. 3. Microstructure of C45 steel after borochromizing and LHT $q = 41.40\ kW/cm^2$, $v = 2.016$ m/min; Reagent: solution 2% HNO_3

As a result of re-melting, the borochromized layers were composed of the materials of surface layer and core. Observation of those layers proved the fluctuation of chemical composition in the melting pool. Applied spiral lead caused partial overlapping and contact of the re-melted zones and HAZ overlapping of the heat affected zones in the axle path of previously heat treated (Fig. 1, 3). Within the microstructure of the laser track a flat solidification front at the border of the melted zone and heat affected zone was observed. Flat solidification front transformed into column and dendritic crystals in the direction of carried away heat. Microstructure of the re-melted zone was composed of solid solution (Fig. 2) or eutectic borides (Fig. 4) with martensite. Heat affected

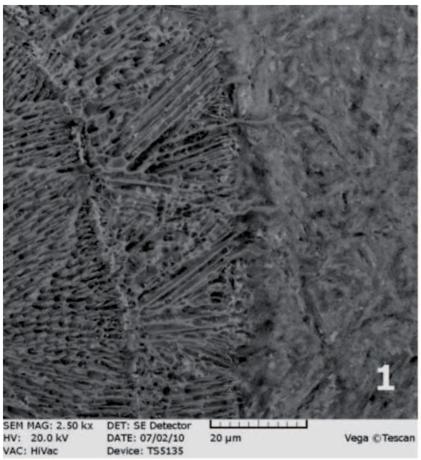

Fig. 4. Microstructure of C45 steel after borochromizing and LHT $q = 41.40\ kW/cm^2$, $v = 2.016$ m/min; boundary MZ and HAZ; Reagent: solution $CuSO_4$+ HCl +H_2O [9]

zone was composed of martensite needles. Microhardness tests of borochromized layers after laser modification are shown in Fig. 5. Microhardness was tested along the axis and at the interface of laser tracks. During the research constant power density and variable scanning rate of the laser beam were applied. It was found that relatively low scanning rate of the laser beam v = 0.67 m/min resulted in long solidification of the layer and slow cooling. For the power density $q = 41.40\ kW/cm^2$ and scanning rate v = 0.67 m/min, microhardness in the re-melted zone was about 600 HV, in heat affected zone reached 350 HV and decreased towards the core – 300 HV. For higher scanning rate v = 2.016 m/min, higher microhardness of approximately 850 HV was achieved in the re-melted zone. Measurements of microhardness along the axis and at the contact tracks for the parameters used were similar. Melted zone was four to six times thicker than the initial borochromized layer.

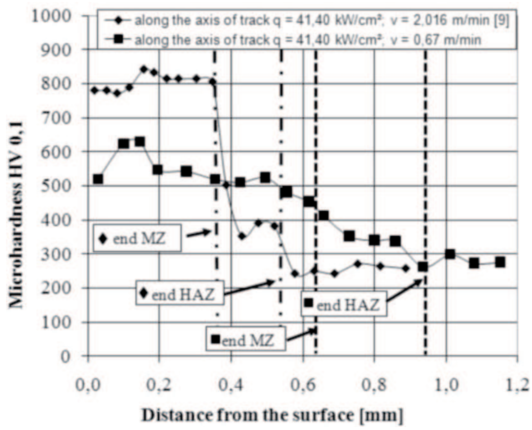

Fig. 5. Microhardness of C45 steel after borochromizing and LHT $q = 41.40\ kW/cm^2$, $v = 0.67$ m/min; and $q = 41.40\ kW/cm^2$, $v = 2.016$ m/min; measure along the axis of track

4. Conclusion

The microstructure, thickness and microhardness of layers produced in borochromizing process were similar to boride layers. As a result of the laser modification the borochromized layer included three zones: re-melted zone, heat affected zone and the core. The microstructure and dimensions of laser tracks depended on the scanning rate. After borochromizing and laser heat treatment the microstructure consisted of solid solution or boride eutectic with martensite. Decreasing of the scanning rate lead to increase of laser track dimensions, but decrease of microhardness in re-melted zone. The most advantageous microhardness, about 850 HV with scanning rate v = 2.016 m/min, was obtained.

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