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Laser surface modification of carburized and borocarburized 15CrNi6 steel

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Abstract

The paper presents the results of laser heat treatment (LHT) of carburized and borocarburized 15CrNi6 low-carbon steel. Laser tracks were arranged by CO_2 laser beam as multiple tracks formed in the shape of a helical line. The microstructure and properties of these diffusion layers were compared with those obtained after through-hardening. The microstructure after carburizing and LHT consists of adjacent characteristic zones: re-melted zone (coarse-grained martensite), carburized layer with heat affected zone (fine acicular martensite), carburized layer without heat treatment and the substrate (ferrite and pearlite). The highest measured microhardness (about 820 HV) was observed in re-melted and heat affected zones. The increase of distance from the surface was accompanied by a gradual decrease of microhardness up to 400 HV beneath the HAZ and up to 250 HV in the core of steel. The carburized layer after LHT exhibited a higher resistance to frictional wear compared to a carburized layer after through-hardening. The microstructure after borocarburizing and LHT consists of the following characteristic zones: iron borides of laser-modified morphology (FeB and Fe_2B), carburized layer with heat affected zone (martensite and alloyed cementite), carburized layer without heat treatment and the substrate (ferrite and pearlite). The highest microhardness was obtained in the iron boride zone. The microhardness of FeB boride extended up to 2200 HV and for the Fe_2B boride up to about 1300–1600 HV. With increased distance from the surface, the microhardness gradually decreases to 800 HV in HAZ, 400–450 HV in the carburized layer without heat treatment and to 250 HV in low-carbon substrate. The iron borides after LHT assume a globular shape, which leads to a lower texture and porosity of the borided layers. The increased resistance to friction wear of the borocarburized layers is certified in comparison with the borided layer after conventional heat treatment (through-hardening).

Keywords: Carburizing; Borocarburizing; Laser heat treatment; Microstructure; Microhardness; Wear resistance

1. Introduction

Laser transformation hardening is a well-established technique for heat treating steel surfaces [1,2]. Laser surface modification is very often applied after carburizing or boriding [3–7]. Boriding generally results in the formation of a FeB and Fe_2B needle-like microstructure at the surface. The layers thus obtained, because of the iron borides, show a high hardness (about 2000 HV) at the surface and improved wear and corrosion resistance. The

Table 1
Chemical composition of the low-carbon steel (wt.%)

Material	C	Cr	Ni	Mn	Si	P	S
15CrNi6	0.15	1.69	1.53	0.57	0.22	0.035	0.035

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Table 2
The parameters of the thermochemical processes—non-LHT specimens

Type of process	Carburizing	Boriding			
	C_p (% C)	Temp. (°C)	Time (h)	Temp. (°C)	Time (h)
Boriding	–	–	–	950	3
Borocarburizing	1.20	930	4	950	3
Carburizing	1.20	930	4	–	–

main disadvantage of boriding is the brittleness of the borided layers, especially the FeB boride [8–10]. There are several factors that cause the brittleness of borided layers. One is a large hardness gradient existing between the borided layer and the substrate. The carburizing process carried out before boriding can lessen the brittleness of boride layers. A two-step treatment (boriding after precarburizing) as a thermochemical treatment of steel is practically applied because of its many advantageous properties [11–17]. This diffusion process is termed borocarburizing. The hardness gradient between the iron borides and carburized substrate is reduced [11–16]. Similarly, a positive influence in this regard has been attained with the use of laser heat treatment (LHT) after boriding [5–7,14].

In this paper, the results of laser surface modification of a carburized and borocarburized 15CrNi6 low-carbon steel have been analyzed. The characterization of the microstructure, microhardness and wear resistance has been carried out. In the present study, laser tracks were arranged as multiple tracks produced in the shape of a helical line. Thus the determination of wear resistance was possible.

2. Experimental

The chemical composition of the low-carbon steel used for these experiments is presented in Table 1. The specimens in the shape of rings of about 20 mm OD, 12 mm ID and 12 mm high were prepared.

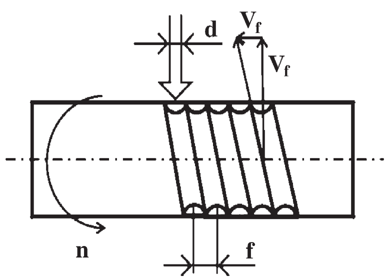

Fig. 1. The method of multiple tracks producing: d—laser beam diameter (d=2 mm), v_f—rate of feed, v_l—scanning rate, n—rotational speed, f—distance from track to track.

Table 3
The parameters of the thermochemical and LHT processes

Type of process	Carburizing			Boriding		LHT	
	C_p (% C)	Temp. (°C)	Time (h)	Time (h)	Temp. (°C)	P (kW)	v_l (m/min)
Borocarburizing	1.20	930	3	3	950	0.78	2.88
Carburizing	0.80	930	3.5	–	–	1.56	2.88

The carburized layers have been formed in controlled carburizing atmosphere at 930 °C (1203 K). The arrangements used were described in a previous paper [11]. An atmosphere of a fixed composition (cracked methanol with propane–butane gas) was used. The carbon potential C_p was controlled by means of a dew-point measuring system and by carburizing pure Fe–C foils until equilibrium with the atmosphere was obtained. The carbon content in a pure Fe–C alloy corresponds to the carbon potential of the atmosphere. The specimens were carburized at different carbon potentials (0.8% or 1.2% C) for times of 3, 3.5 or 4 h. After carburizing, the specimens were slowly cooled in the carburizing atmosphere.

Gas boriding was carried out by means of the apparatus described in the paper [11]. A gas mixture of hydrogen and BCl_3 (up to 5 vol.%) was applied at a flow rate of 50 l/h. The process was performed at a temperature of 950 °C (1223 K) for 3 h.

Some of the carburized, borided and borocarburized samples were typically heat treated in the normal through-hardened condition. These samples were put into the furnace, heated to temperature 950 °C (1223 K) within 10 min, held at temperature for 15 min and quenched in oil at 60 °C (333 K). After hardening, these specimens were tempered at 150 °C (423 K). The parameters of the thermochemical treatment of these specimens are presented in Table 2.

Additionally, after carburizing and borocarburizing, laser heat treatment (LHT) was performed with a TRUMPF TLF 2600 Turbo CO_2 laser at a nominal power 2.6 kW operated at the following parameters:

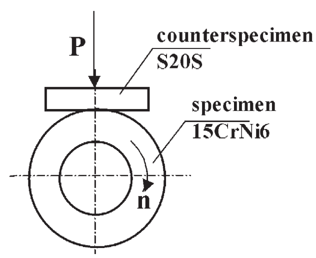

Fig. 2. Scheme of wear (P=147 N, rotational speed n=250 min^{-1}).