Effect of electron beam processing on the characteristics of tool steels

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Abstract

One of the promising methods of energetic influences that have a significant impact on the structure, phase composition, physical and mechanical properties of metals and alloys is an electron beam processing (EBP). This method consists in treating the surface of the low– energy pulse high– current electron beams, providing adjustable over a wide range of energy density on the surface of the irradiated material. Ultrahigh heating speed to melting and subsequent cooling of a thin surface layer of material forms the limit temperature gradients. It is provides cooling of the surface layer due to heat transfer in the bulk material at a speed of 104..109 K/s, which can significantly improve the characteristics of the surface material. The electron beam treatment causes a change in the physicochemical properties of the metal surface layer that can be used to obtain protective and reinforcing coatings.

1 Materials and experimental technique

Investigation was carried out on 12Cr-V tool steel and speed steel R6M5 and R18. In this work it is used low-energy electron beam (20 KeV) [1], whereby hardened layer thickness of several tens of microns is heated by heat transfer. Using pulsed high-current electron beams with high-energy particles, it is possible to heat the surface layer of such thickness without heat transfer - as direct result of the energy of the electron beam. Experiments were conducted by electron-pulse treatment on the electron accelerator "Inus" (electron beam energy is $E \approx 230KeV$, the duration of the current pulse is $\leq 7mks$).
The phase state of metals was controlled by metallographic method using a microscope Axio-Observer-Z1-M after the appropriate chemical etching. The investigation of cross section structure was carried out on the optical microscope in the bright field. Quantitative phase relationship was determined by metallographic analysis with the help of random secant method.
Microhardness was determined using the Vickers method: measurements were carried out on a PMT-3 device with a load of $100g$.
To determine the main parameters of the surface roughness pertometr M1 was used in the study. This device is designed to determine the most frequently used characteristics according to the ISO 4287. The average roughness Ra is arithmetic average

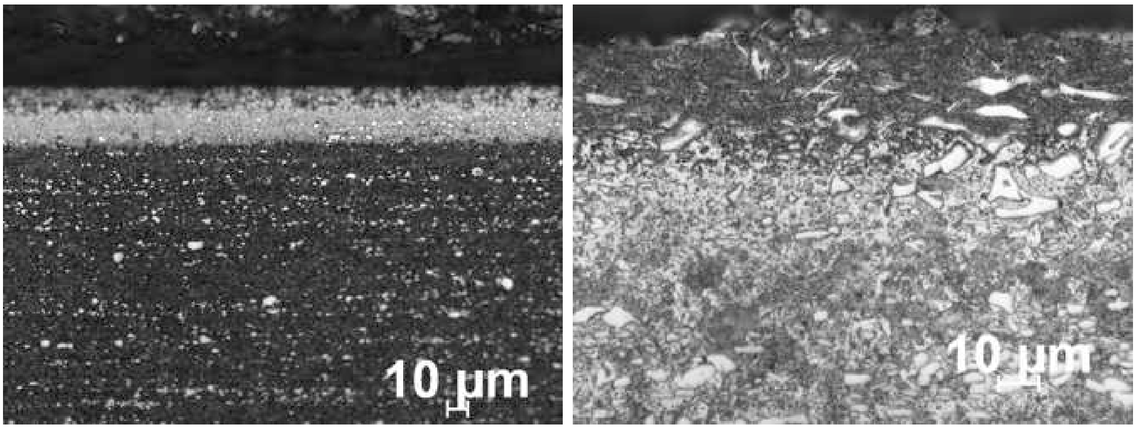
of all points of the roughness profile from the center line in the length of the assessment. The average height of roughness Rz is the arithmetic mean of the maximum protrusion height and the largest profile cavities. The greatest depth of roughness Rmax is the largest of the existing single roughness depths . The number of emissions per 1 cm Rpc is number of profile elements, which are sequentially intersect one upper and one lower section line.
Experimental conditions are shown in Table 1.

Table 1. Conditions of experiments

No	number of pulses	pulse energy	current density	pulse duration	tool steel
1		200 Mev			12Cr-V
2		200 Mev			12Cr-V
3	1	400 Mev			R18 quenched
4	1	400 Mev			R18 tempered
5	5	170 Kev	60 A/cm^2	$2\mu s$	R6M5
6	9	170 Kev	60 A/cm^2	$2\mu s$	R6M5
7	15	170 Kev	60 A/cm^2	$2\mu s$	R6M5

2 Results and discussion

The microstructure of the surface layer of steels after the EBP is shown in Figure 1.

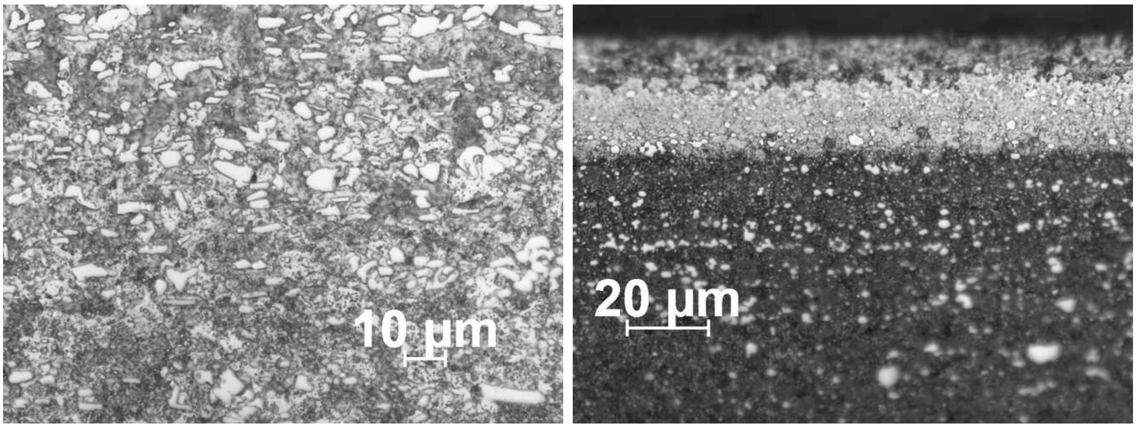


a b

Figure 1: The structure of the surface layer of steel samples after the electron beam treatment: a - R18 steel, b - 12Cr-Vsteel

On the submitted micrographs in tool steels it can be seen weakly etching light or dark layer with uniform distribution of fine carbides. This area in the result of impact pulses was subjected to rapid heating up to the quenched temperature and rapid cooling, resulting in the formation of fine-grained, but in some cases of the amorphous structure in the layer.

The microstructure in the center of the sample of tool steels is shown in Figure 2. It is a dark matrix with bright carbides, among which there are also large, sometimes they form clusters.



a b

Figure 2: Structure of tool steel specimens in the center of the cross section: a - 12Cr-Vsteel, b - R18

Microhardness in the surface layer of the samples was higher microhardness values of the basic metal, which indicates an increase in the hardness of the material after electron beam processing, i.e. improved strength properties. Microhardness measurement results are shown in Table 2. The thickness of the strengthened layer was $18 - 86$ microns (Table 3). The most significant hardening of the surface layer as compared to the steel base metal occurs in 12Cr-Vsteel - in 2.5 times. The surface layer of high-speed steels strengthened less - in $1 - 1,3$ times since its initial strength is much higher. At the same time, the maximum hardening observed in R18 steel – up to 9235 MPa.

Table 2. Values of microhardness

No	material	microhardness, MPa	
		layer	Basic metal
1	12Cr-V steel	3360 ± 10	1255 ± 10
2	R18 quenched steel	9235 ± 10	7015 ± 10
3	R6M5 steel - вҺЦ1	8390 ± 10	7016 ± 10
4	R6M5 steel - вҺЦ2	8640 ± 10	7480 ± 10
5	R6M5 steel - вҺЦ3	8005 ± 10	7702 ± 10

The results of the quantitative characteristics of the structure in the processed materials state (after EBP) are shown in Table 3. It can be seen that the maximum thickness layer is in steel R6M5 treated with the maximum number of pulses, and a minimum one is in steel R6M5 treated with a minimum number of pulses. The minimum grain size is in high speed steels - R18 and R6M5, so they have the maximum microhardness. Maximum carbide heterogeneity is observed in 12Cr-V steel (Figure 2 a) – 2 grade carbide heterogeneity according to standard.

Table 3 - Results of the quantitative characteristics of the steel structure.

Material	Layer thickness, μm	Grain size, μm	Carbide heterogeneity	
			Carbide size, μm	Carbide grade
R6M5 steel вҺЦ1	69.7 ± 0.2	7.1 ± 0.1	1.5 ± 0.1	1
R6M5 steel No 2	18.6 ± 0.2	3.2 ± 0.1	2.9 ± 0.1	1
R6M5 steel No 3	87.0 ± 0.2	3.6 ± 0.1	2.2 ± 0.1	1
R18 quenched steel	21.5 ± 0.2	2.0 ± 0.1	2.0 ± 0.1	1
R18 tempered steel	46.4 ± 0.2	1.6 ± 0.1	2.5 ± 0.1	1
12Cr-V steel No 4	31.3 ± 0.2	8.0 ± 0.1	2.0 ± 0.1	1
12Cr-V steel No 5	41.0 ± 0.2	8.6 ± 0.1	1.5 ± 0.1	2

Surface layer roughness of R6M5 steel after processing by EBP is higher than before the treatment (Table 4).

Table 4 - Results of the measurement of R6M5 steel surface roughness

N, pulses	condition	parameter			
		Ra, μm	Rz, μm	Rmax, μm	Rpc cm^{-1}
5	initial	0.1 ± 0.02	0.60 ± 0.02	0.85 ± 0.02	0.0 ± 1
	after EBP	2.9 ± 0.5	14.8 ± 1.8	18.5 ± 1.7	37 ± 4
9	initial	0.39 ± 0.02	3.79 ± 0.02	6.17 ± 0.02	48 ± 1
	after EBP	3.0 ± 0.5	14.2 ± 3.0	20.3 ± 3.1	27.7 ± 7
15	initial	0.12 ± 0.02	0.76 ± 0.02	0.90 ± 0.02	0.0 ± 1
	after EBP	3.9 ± 0.01	18.8 ± 0.9	26.1 ± 1.6	28 ± 6

After treatment by an electron beam regular relief of surface roughness is observed, which characterized by an increase of their number and height as compared with untreated surfaces. A more detailed analysis taking into account all characteristics shows that with increasing number of pulses the average roughness Ra and roughness depth Rmax increase. The average height roughness Rz is also maximum under the highest number of pulses. Regarding parameter Rpc – number of emissions per 1 cm, it is maximum with the minimum number of pulses.

3 Conclusion

1. The influence of electron beam processing on the quality of the surface layer of tool steels and the mechanical properties characteristics was carried out.

2. Changes of the structure of the material was revealed under EBP. There is a grain refinement and increase in microhardness. Electron beam processing of tool steels studied showed a significant improvement in the strength properties of the material.

3. The effect of the treatment of the electron beam on the geometry of the surface of the material was determined. The surface roughness of high-speed steel is strongly correlated with the number of pulses used in the processing, i.e. according to the selected treatment regime.

Acknowledgements

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References

[1] O.A. Gusev, Lazarenko A.B., Ivanov BA et al. The application of a pulsed electron beam for the heat treatment of metals // MiTOM, 9. -1984.- pp 95-100