

Effect of Glow Discharge Treatment on the Depth and Degree of Structural Phase Modification of Tool Steel Products

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Abstract. The structure and phase composition of 1.1625, 1.2080 and 1.3343 tool steels (DIN) were studied and the research results are presented. The glow discharge treatment is shown to lead to dissolution and redistribution of the carbide phase, a change in the degree of crystal lattice distortion of the matrix phase, and a decrease in the residual austenite in the surface layer to a depth of 80 μm , which results in a 15% to 30% increase in the microhardness of the surface layers of materials.

1. Introduction

The surface layer is known to have a significant effect on the performance of products, and as a consequence, one of the modern world trends, especially in mechanical engineering, is to develop methods for increasing the wear resistance of surface layers of critical parts operating under conditions of tribomechanical and tribochemical effect.

The research was carried out as part of the *Physical Materials Science, New Materials and Technologies* State Program of Scientific Research of the Republic of Belarus, and its results show that treatment by glow discharge ignited in the atmosphere of residual atmospheric gases is one of the promising methods of increasing wear resistance of surfaces of the products made of metals and their alloys due to the structural phase modification of the surface layer [1 – 4].

2. Purpose and object of the research, and experiment description

The purpose of the research was to establish the effect of glow discharge treatment on the depth of structural phase modification of tool steels.

Samples of the following steels were selected as the object of research:

- 1.1625 steel (DIN), commercially melted. The samples were quenched in water at temperatures from 790° C (holding time: 1 h 30 min) followed by tempering at 250° C during 2 h;
- 1.2080 steel (DIN), commercially melted, quenched in oil at temperatures from 970° C (holding time: 1 h 30 min) followed by tempering at 180° C during 1.5 h;
- 1.3343 steel (DIN), commercially melted, quenched in oil at temperatures from 1,220° C (holding time: 1 h 30 min) followed by threefold tempering at 560° C during 2 h.

To study the dynamics of the process, the samples were subjected to glow discharge treatment during 30 min using three modes: mode No. 1 - combustion voltage 1,000 V, current density 0.125 mA/m²;



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mode No. 2 - combustion voltage 2,000 V, current density 0.250 mA/m²; mode No. 3 - combustion voltage 3,000 V, current density 0.375 mA/m².

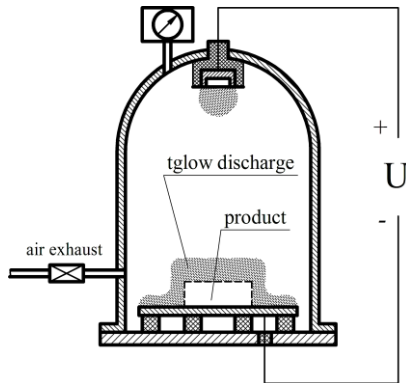


Figure 1. Schematic of the installation for modifying treatment.

3. Research methodology

In the research, an electron microscopic analysis of the surface layer of samples was conducted using a Tescan VEGA 2SBA scanning electron microscope equipped with an unexposed secondary electron detector, as well as an X-ray structural analysis of the metal phase composition using an automated X-ray system on the basis of a DRON-3M diffractometer with the application of monochromatic $\text{Co}_{\text{K}\alpha}$ - radiation. A durometric analysis of the surface layer was carried out using a Zwick Roell ZHV 1M hardness tester.

4. Research results and discussion

The electron microscopic analysis revealed that the structure of 1.1625 steel before glow discharge treatment is a classic martensitic structure with carbide inclusions of alloying elements up to 5 μm in size. The glow discharge treatment results in dissolution and redistribution of the carbide phase in the surface layer 60 to 65 microns deep (Figure 2)

Based on the X-ray diffraction analysis, it was found that in its initial state, 1.1625 steel contains martensite, retained austenite $\gamma\text{-Fe}$, as well as inclusions in the form of iron carbides (Fe_3C) (Figure 3). The crystal lattice parameter is close to the crystal lattice parameter of ferrite, which indicates an insignificant concentration of defects in the crystal lattice which are typical for martensite in steels (Table 1).

The glow-discharge treatment of 1.1625 steel with different combustion parameters does not result in a qualitative change in their phase composition (Figure 3). At the same time, after the treatment in mode No. 1, a decrease in the lattice parameter and an increase in the physical broadening of diffraction lines of the α -phase are recorded, which is due to an increase in the density of dislocations in the surface layer as a result of the treatment.

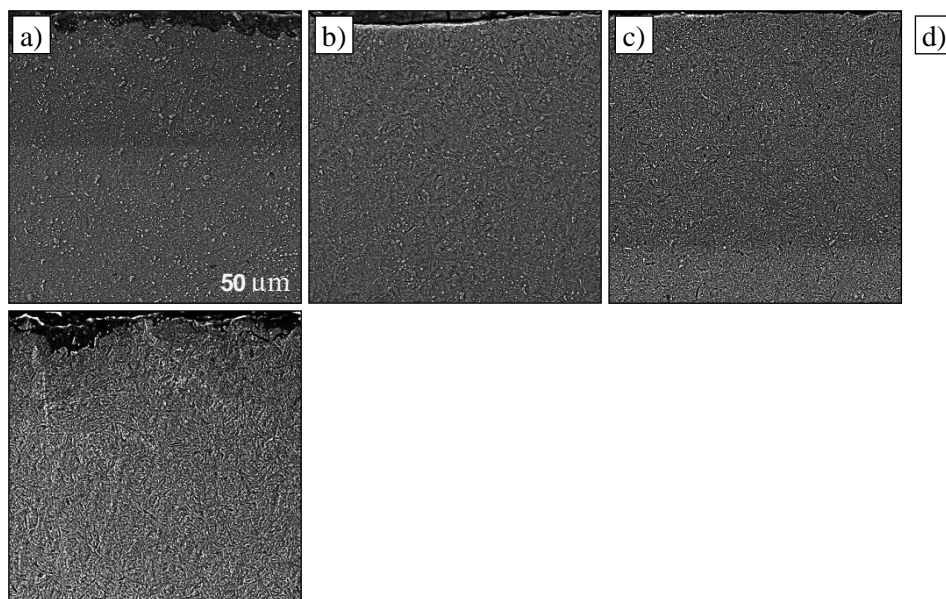


Figure 2. The structure of U8 steel: a – before processing; b – after processing mode 1; c – after processing mode 2; d – after processing mode 3.

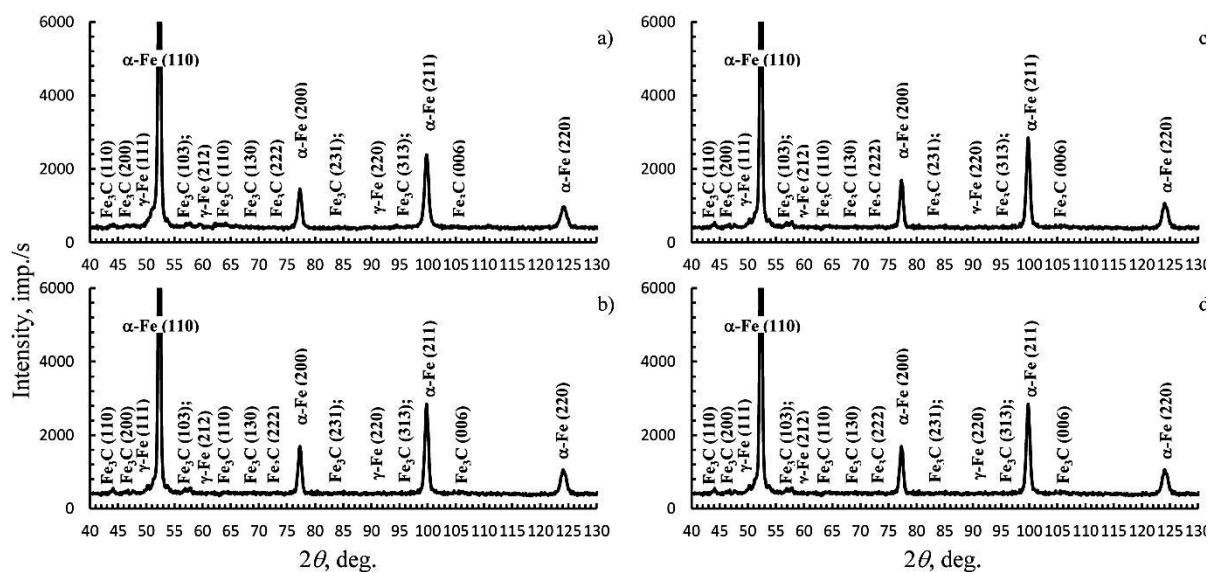


Figure 3. Fragments of X-ray diffraction patterns of 1.1625 steel: a – before processing; b – after processing mode 1; c – after processing mode 2; d – after processing mode 3.

Table 1. Phase composition, amount of retained austenite (A), crystal lattice parameter a , physical broadening β of diffraction lines and dislocation density ρ .

Sample	Phase composition	Amount of A, %	$a_{\alpha\text{-Fe}}$, nm		β_{110} , 10^{-3} rad	β_{220} , 10^{-3} rad	ρ , cm^{-2}
			experiment	standard [5]			
initial state	$\alpha\text{-Fe}$, Fe_3C , $\gamma\text{-Fe}$	5.7	0.28622	0.28664	5.24	22.14	$2.8 \cdot 10^1$

mode No.1	α -Fe, Fe ₃ C, γ -Fe	4.1	0.28619	7.04	24.98	$5.1 \cdot 10^1$ ₁
mode No.2	α -Fe, Fe ₃ C, γ -Fe	4.8	0.28623	5.26	19.51	$2.8 \cdot 10^1$ ₁
mode No.3	α -Fe, Fe ₃ C, γ -Fe	4.4	0.28624	5.24	21.96	$2.8 \cdot 10^1$ ₁

Prior to the glow discharge treatment, the surface layers of both 1.2080 steel and 1.1625 steel have a classical hardened martensite structure with carbide inclusions in the form of plates. The glow discharge treatment causes dissolution and redistribution of the carbide phase in the surface layer 80 to 85 μm deep (Figure 4).

The analysis of fragments of 1.2080 steel diffraction patterns (Figure 5) revealed that the glow discharge treatment of 1.2080 steel does not result in a qualitative change in their phase composition (Figure 4). At the same time, an increase in the lattice parameter of the α -phase is recorded after the glow discharge treatment, which is due to an increase in the concentration of interstitial atoms in the martensitic phase. The processing also leads to a decrease in the values of physical broadening of the α -phase diffraction lines, which is due to a decrease in the density of defects during the processing (Table 2).

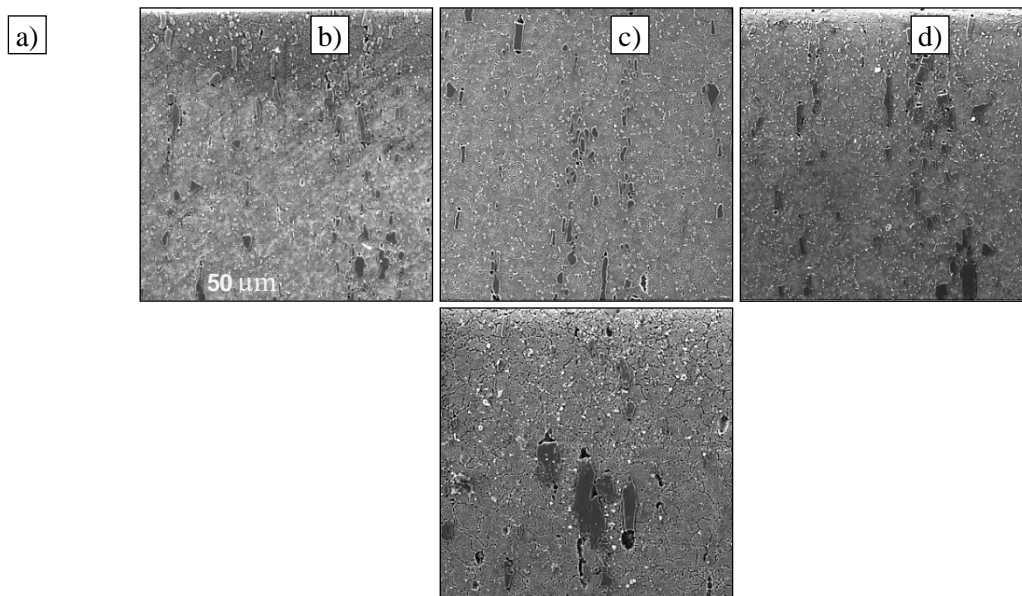


Figure 4. The structure of 1.2080 steel: a – before processing; b – after processing mode 1; c – after processing mode 2; d – after processing mode 3.

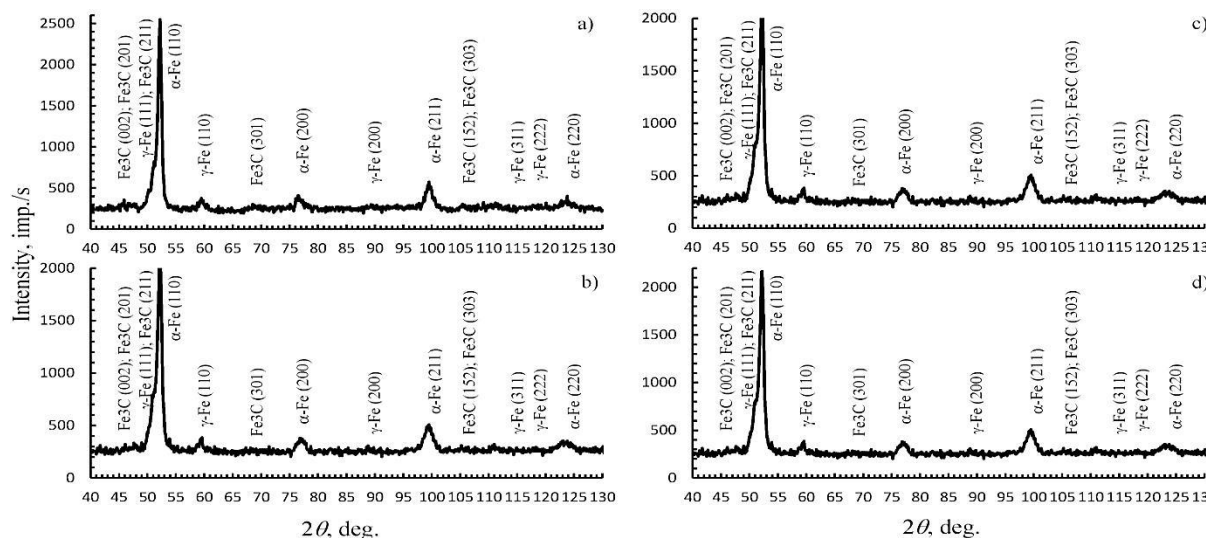


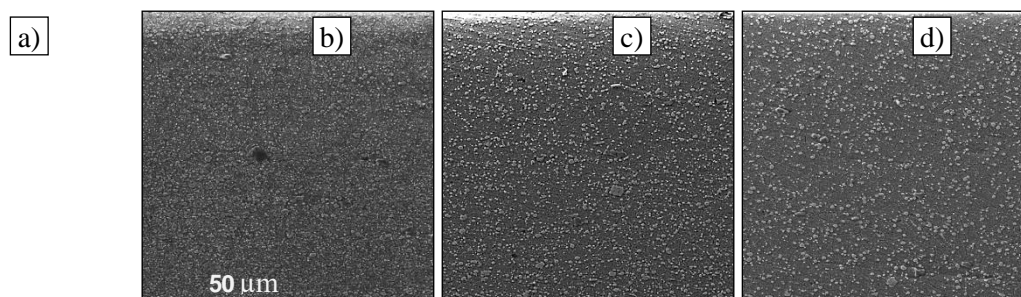
Figure 5. Fragments of X-ray diffraction patterns of 1.2080 steel: a – before processing; b – after processing mode 1; c – after processing mode 2; d – after processing mode 3.

Table 2. Phase composition, amount of retained austenite (A), crystal lattice parameter a , physical broadening β of diffraction lines and dislocation density ρ .

Sample	Phase composition	Amount of A, %	$a_{\alpha\text{-Fe}}$, nm		β_{110} , 10^{-3} rad	β_{220} , 10^{-3} rad	ρ , cm^{-2}
			experiment	standard [5]			
initial state	α , γ , M_3C	33.7	0.28734		14.1	72.8	$2.1 \cdot 10^{12}$
mode No. 1	α , γ , M_3C	34.1	0.28742	0.28664	18.0	100.6	$3.4 \cdot 10^{12}$
mode No. 2	α , γ , M_3C	31.1	0.28737		16.5	60.0	$2.9 \cdot 10^{12}$
mode No. 3	α , γ , M_3C	31.4	0.28745		18.0	71.8	$3.5 \cdot 10^{12}$

The structure of high-speed 1.3343 steel before it was subjected to glow discharge treatment, as well as the structure of the previous steels, corresponds to quenched martensite with finely dispersed carbide inclusions. The glow discharge treatment leads to dissolution and redistribution of the carbide phase in the surface layer 70 to 75 μm deep. This effect is most pronounced when processing in mode No. 3 (Figure 6).

The X-ray structural analysis of the surface of samples made of 1.3343 steel (Figure 7) showed that processing does not cause a change in the phase composition of steel. All steel samples under study include $\alpha\text{-Fe}$, M_6C carbide and VC carbide (Table 3).



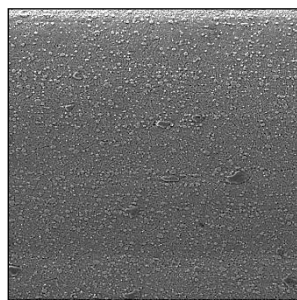


Figure 6. The structure of 1.3343 steel: a – before processing; b – after processing mode 1; c – after processing mode 2; d – after processing mode 3.

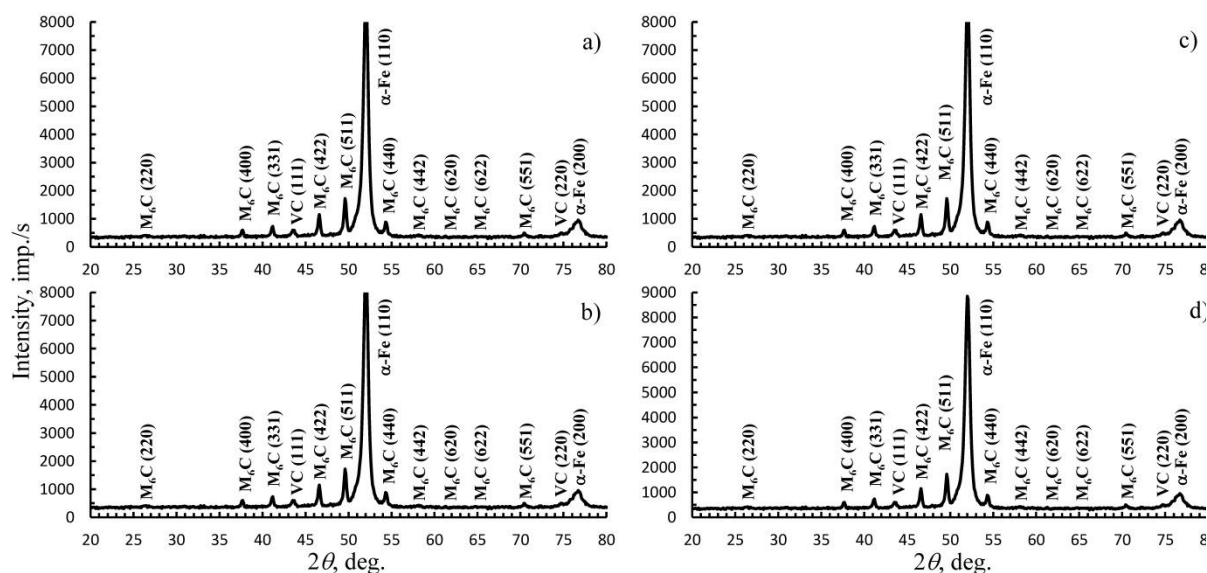


Figure 7. Fragments of X-ray diffraction patterns of 1.3343 steel: a – before processing; b – after processing mode 1; c – after processing mode 2; d – after processing mode 3.

The recorded broadening β of the diffraction lines is proportional to $\tan\theta$, which indicates that the broadening observed is mainly due to a high density of randomly distributed dislocations. Lower values of the physical broadening of the α -Fe diffraction line (220) recorded for the samples subjected to glow discharge in processing modes 2 and 3, indicate a decrease in the dislocation density in the surface layer of the 1.3343 steel samples.

Table 3. Lattice parameter a and physical broadening β of α -Fe diffraction lines.

Sample	a, nm		β_{110} , 10^{-3} rad	β_{220} , 10^{-3} rad
	experiment	standard [5]		
initial state	0.2882		15.5	75.1
mode No. 1	0.2880	0.28664	15.1	76.4
mode No. 2	0.2880		15.7	64.9
mode No. 3	0.2882		15.1	57.5

At the same time, the processing of samples in mode 3 leads to a significant increase in the physical broadening of the diffraction line (511) of M_6C carbide ($\beta_{511} = 10.3 \cdot 10^{-3}$) as compared to unexposed samples ($\beta_{511} = 6.4 \cdot 10^{-3}$), which is the evidence of the dissolution of carbide particles during processing.

As a result of the glow discharge treatment, a 15 – 30% change in the microhardness of the surface layers of materials is observed, in addition to structural changes. The results of the durometric analysis are shown in Figure 8.

The results shown in Fig. 2–7 are evidence that the data of the electron microscopic and durometric analyses correlate sufficiently well with each other and allow for a conclusion that the depth of the modified layer of tool steel products subjected to glow discharge processing depends significantly on the presence of alloying elements in them affecting the electrophysical properties, namely, the specific resistance.

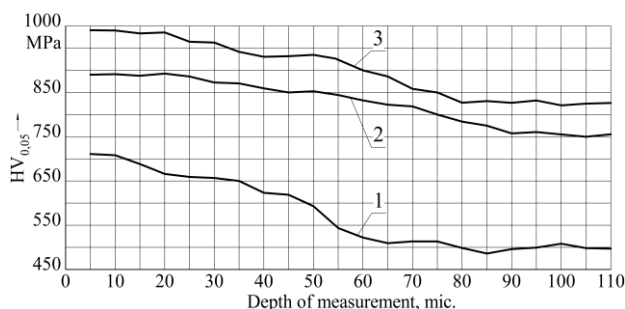


Figure 8. Microhardness of the surface layer through the depth after glow discharge treatment: 1 – 1.1625 steel; 2 – 1.2080 steel; 3 – 1.3343 steel.

5. Conclusions

The glow discharge treatment of tool steels leads to the dissolution and redistribution of the carbide phase, the change in the degree of crystal lattice distortion of the matrix phase, and the decrease in retained austenite due to the polymorphic transformation $\gamma\text{-Fe} \rightarrow \alpha\text{-Fe}$ in the surface layer to a depth of 80 μm . These changes, in their turn, ensure a 15 – 30% increase in the microhardness of the surface layers of materials.

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