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INVESTIGATION OF SURFACE LAYER OF POLISHED HIGH-SPEED STEEL GRADE P6M5 USING X-RAYS

The purpose of this work is the experimental analysis of changes in the phase composition of heat-hardened high-speed steel grade P6M5 through the depth of polished layer.

The X-rays method for the phase composition of surface layers of tool steel gives information in average for depth 5 to 10 mkm. When solving this kind of problem by co-polishing of the thinnest layers with further radiography then introduce unknown structure impact index for the layer of polishing plastic flow that is not acceptable for our task. For stratified analysis of the phase composition of the product's thinnest layers one reccommends using a special method of radiography based on limiting the depth of radiation penetration into material appearing at changing the inclinations of sthe studied surface for steel sample to falling X-ray beam.

The outcome of this investigation is finding out the fact of high content of residual austenite in the thinnest (1-4 mm) surface layer of polished HSS P6M5. Moreover, the number of phases in a thin layer may be 50 - 60%, which undoubtedly can reduce surface hardness. Further research in this direction should be directed to analysis of the surface hardness and wear resistance of the surface layer of polished HSS.

It was determined that the phase composition of the thin surface layer of polished steel is virtually independent of the depth of grinding, and this in spite of the previously established dependence of the total thickness of the "white" layer on the depth of polishing.

Keywords: *X-ray analysis, austenite, polishing, lattice parameter, the width of the diffraction lines.*

Introduction

It is known [1] that when polishing heat-hardened high-speed steel, their thin surface layer has extremely high temperatures often exceeding the temperature of the critical points of the austenite phase. With rapid cooling of the austenite areas there immediately occurs hardened surface layer of steel and, as a consequence, a significant amount of fixed residual austenite. This is facilitated by the dissolution of dispersed carbide structure phase with intense layer's heating.

Due to the fact that the resistance of the instrument depends on the phase composition of the surface layers of steel [2], the information on the distribution of the residual austenite depth polished layer is of great interest. In the literature, the question was presented very little [1], especially for the analysis of very thin surface layers of depth 1 - 5 μm.

X-ray method for investigating the phase composition of the surface layers of tool steels gives the averaged information on a depth of 5 to 10 microns. And what phase composition of steel to a depth of 1 - 2 is not known. When solve this problem by the co-polishing method of thin layers followed by radiography, then introduce unknown factor affecting the structure of the layer of plastic flow of polishing, which is unacceptable for our task.

For stratified analysis of the phase composition of very thin layers of products is recommended to use a special method of radiography, based on the principle of limiting the depth of penetration of the radiation into the thickness of the material [3,4], resulting in variations in the inclinations of the sample surface to the incident X-ray beam.

Purpose
The purpose of this work is the experimental analysis of changes in the phase composition of thermally hardened high speed steel P6M5 to a depth of polished layer.

Investigation results
The investigation was performed on samples of steel P6M5 with a diameter of 25 mm and a thickness of 15 mm. Heat treatment of the samples was made under the optimum regimes of hardening, as in [5]. Surface polishing of the end surface of the samples was carried out to a depth EB25SM2K range from 0.02 to 0.10 mm in a single pass under the following constant conditions: speed range 19-20 m/s; traverse 0; table speed of 5 m/min.

In the first stage of research a microstructure of polished layer was studied. For this purpose there were prepared "oblique" thin sections, i.e. thin sections, inclined at an angle of $1.5\text{-}2.0^0$ to the surface of the samples investigated. This made it possible to "stretch" the polished layer for a considerable distance and, consequently, increase the scale of polished layer.

Figure 1 shows an example of the surface layer structure of the sample polished to a depth of 0.06 mm. Here one can see that the sample surface is the so-called "white layer", i.e. weak etching layer consisting of martensite, residual austenite and carbides. This layer has a considerable extension in the depth of the sample and a significant structural heterogeneity. These zones of "white layer" were found in all samples, with no exceptions.

Radiographic examination of samples was performed on a diffractometer DRON - 3M in an iron-filtered radiation.

Fig. 1. Microstructure of "oblique" thin section from the sample surface (left edge) to its center, polishing depth is 0.06 mm

The amount of residual austenite in the layer was determined as described in [5]. Furthermore, the position of diffraction lines and austenite martensite phase was used to calculate lattice parameters of the phases and the width of the diffraction lines was measured using known methods [6].

To estimate the phase composition and phase parameters they used angled X-ray photography, in which the sample with its investigated surface was bent by an angle of 10 to 50^0, making it possible to change the X-ray penetration depth into the surface layer of the sample. Figure 2a shows a diagram of X ray diffraction patterns and the typical view of the diffraction patterns for the low and high angles of a meeting of the beam to the surface of the samples.
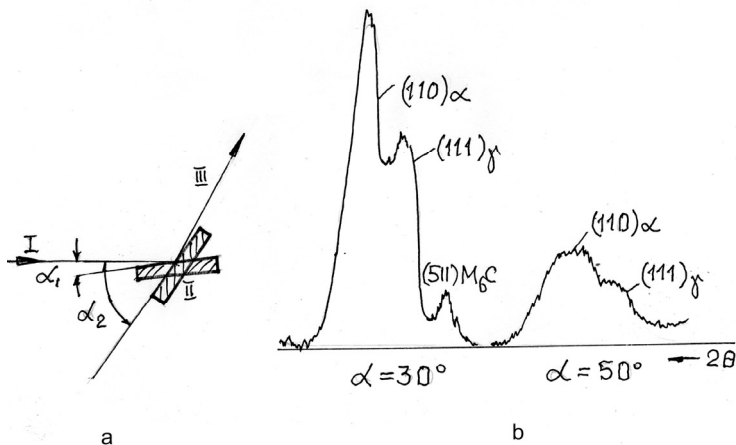

Fig. 2. Scheme of angled X-ray photography of the samples made by diffractometer (a) and typical diffraction lines of martensite, austenite and carbide phases for different touching angles of the tested surface with X-ray (α)

To assess the depth of the layer, which gives information about the phase composition and parameters of a solid compounds they used known methods [3,4]. The depth of the information zone X is defined by the formula:

$$X = U_x \bullet sin\alpha \; / \; 2\mu, \tag{1}$$

where U_x – index, depending on the value chosen for that area of intensity of the scattered rays, which provides receiving the information from layer – X;

α – inclination angle of the sample surface to incident X-ray;

μ – linear index of diminution of X-rays.

For 75% of the intensity of the scattered rays by a layer, U_x value according to data available in the references [3,4], is equal to 1.39.

Considering the complexity of the chemical composition of the investigated steel (Fe·W·Mo, Cr·VC), the μ coefficient is calculated by the formula [3,4]:

$$\mu = \sum \mu_i^* \bullet \rho_i \bullet c_i, \tag{2}$$

where μ_i^* – mass coefficient of radiation diminution by a chemical element the composition of the steel;

ρ_i – the density of the chemical element;

c_i – mass share of chemical element in steel composition.

Calculation of Equation 2 for steel P6M5 provided a value of linear coefficient of X-ray diminution by iron anode as 1075 cm^{-1}. Hence, depth of information zone (X) in the formula 1 for the angles α = 10; 20; 30; 40 and 50^0 will have values equal respectively to 1.02; 2.0; 2.95; 3.82 and 4.6 microns.

Thus, the chosen method of X-ray analysis allows to perform investigation of near-surface layers of the finest polished steel structure.

As it is seen from Figure 1b, a deviation from the focus angle of Bragg -Brentano leads to geometrical broadening of diffraction lines and reducing their intensity. To account this instrumental broadening of the lines it was used samples' survey with reference substance (aluminum powder) and without it in this work.

Results of studying the surface layers of polished high-speed steel P6M5 layer are shown in Table 1.

It is obvious that closer to the polished surface of the sample the amount of residual austenite increases in the layer and increases its lattice parameter. This shows extremely high temperatures of contact zone metal-abrasive, when carbides are rapidly dissolved in a thin surface layer and austenite is saturated with the alloying elements. This is evident by the increased lattice parameter of the residual austenite.

The amount of residual austentite (A$_{res}$), the parameters of its crystal lattice (a$_\gamma$) and martensite (a$_\alpha$), the width of the diffraction lines of austenitic and martensitic phases (B$_{\gamma\alpha}$) of thin layers of polished steel P6M5

Polishing depth, mm	Layer depth X, microns	A$_{res}$, % $\pm 3\%$	$a_\alpha, \kappa X$	$a_\gamma, \kappa X$	$B_\alpha,$ mrad	$B_\gamma,$ mrad
1	2	3	4	5	6	7
0.02	1.02	60	2.949	3.674	17.2	12.4
	2.00	52	2.933	3.671	17.2	10.5
	2.95	52	2.928	3.666	16.3	12.0
	3.82	44	2.915	3.639	17.1	14.6
	4.06	37	2.900	3.620	16.0	14.1
0.04	1.02	50	2.912	3.649	17.4	15.0
	2.00	43	2.918	3.661	16.8	13.4
	2.95	38	2.930	3.648	17.0	16.1
	3.82	37	2.921	3.651	15.7	15.2
	4.06	28	2.880	3.611	18.7	15.6
0.06	1.02	48	2.900	3.640	16.4	10.6
	2.00	39	2.899	3.643	16.0	12.1
	2.95	35	2.890	3.631	15.8	13.0
	3.82	36	2.897	3.652	16.0	15.1
	4.06	36	2.910	3.619	17.1	12.9
0.10	1.02	59	2.916	3.650	16.5	11.5
	2.00	52	2.891	3.620	15.6	13.6
	2.95	45	2.910	3.640	18.1	15.1
	3.82	44	2.890	3.633	17.3	14.6
	4.06	41	2.897	3.640	17.4	15.0

At the same time the lattice parameter increases as well in the martensite phase, that shows an increase of carbon content in this phase. The width of the diffraction lines of both phases in layers varies slightly, and this demonstrates the strong hardening work both for the martensite and austenite phases of the surface layer.

The data in Table 1 also shows that the phase composition of a thin surface layer of polished steel is virtually independent on the depth of polishing, and this in spite of the installed earlier [5] the dependence of the total thickness of the "white" layer to the depth of polishing.

Conclusions

The result of this study is finding out a high content of residual austenite in the thinnest (1.4 mm) surface layer of polished high-speed steel P6M5. Moreover, the number of phases in a thin layer may be 50-60%, which undoubtedly reduce surface hardness.

Further research in this direction should be directed to analysis of the surface hardness and wear resistance of near surface layer of polished HSS.

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Ершов В.М., Коробко Т.Б. Исследование поверхностного слоя шлифо-ванной быстрорежущей стали Р6М5 рентгеновским методом.

Приведены результаты рентгенографического анализа микронных по-верхностных слоев шлифованной быстрорежущей стали Р6М5. На первом этапе исследования были изучены микроструктуры шлифованного слоя на дифрактометре в железном фильтрованном излучении после упрочнения с углом наклона поверхности образца от 10 до 50⁰, что давало возможность изменять глубину проникновения рентгеновских лучей в поверхностный слой образца. Глубину информационной зоны X определяли по соответствующим формулам с учетом сложного химического состава, что позволило произве-сти исследование тончайших приповерхностных слоев шлифованной струк-туры исследуемой стали. Обнаружено заметное увеличение количества ос-таточного аустенита в приповерхностных слоях быстрорежущей стали Р6М5 для всех режимов шлифования, что несомненно должно привести к снижению твердости поверхностного слоя.

Ключевые слова: рентгеновский анализ, аустенит, шлифование, пара-метр кристаллической решетки, ширина дифракционной линии.

Єршов В.М., Коробко Т.Б. Дослідження поверхневого шару шліфованої швидкорізальної сталі Р6М5 рентгенівським методом.

Наведено результати рентгенографічного аналізу мікронних поверхневих шарів шліфованої швидкорізальної сталі Р6М5. На першому етапі дослідження були вивчені мікроструктури шліфованого шару на дифрактометрі в залізному фільтрованому випромінюванні після зміцнення з кутом нахилу поверхні зразка від 10 до 50^0, що давало можливість змінювати глибину проникнення рентгенівських променів в поверхневий шар зразка. Глибину інформаційної зони Х визначали за відповідними формулами з урахуванням складного хімічного складу, що дозволило зробити дослідження найтонших приповерхневих шарів шліфованої структури досліджуваної сталі. Виявлено помітне збільшення кількості залишкового аустеніту в приповерхневих шарах швидкорізальної сталі Р6М5 для всіх режимів шліфування, що безсумнівно повинно привести до зниження твердості поверхневого шару.

Ключові слова: _рентгенівський аналіз, аустеніт, шліфування, параметр кристалічної решітки, ширина дифракційної лінії._

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