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INVESTIGATION OF THE HARDNESS OF 65G STEEL AFTER ELECTROFRICTION TREATMENT

ЭЛЕКТРОФРИКЦИЯЛЫҚ ӨҢДЕУДЕН КЕЙІНГІ 65Г БОЛАТЫНЫҢ ҚАТТЫЛЫҒЫН ЗЕРТТЕУ

ИССЛЕДОВАНИЕ ТВЕРДОСТИ СТАЛИ 65Г ПОСЛЕ ЭЛЕКТРОФРИКЦИОННОЙ ОБРАБОТКИ

Abstract. *The results of research on the influence of the speed of electrofriction treatment on the structure and microhardness of steel 65G are presented. The structure-phase state of steel 65G before and after electrofriction treatment was studied by X-ray phase analysis and scanning electron microscopy. The Vickers indentation method was used to study the distribution of microhardness values along the depth of the modified layer of steel 65G depending on the speed of electrofriction treatment. It has been shown experimentally that during electrofriction treatment of 65G steel at the depth of the hardened zone a structure with high microhardness is formed with the thickness of the hardened layer from 1.2 to 1.8 mm depending on the speed of treatment. The results of the study showed that the speed of electrofrictional treatment affects the thickness of the treated layer, and the distribution of microhardness values along the depth of steel 65G has the same pattern. It is established that the microhardness of the hardened layer after electrofriction treatment at a fixed current strength of 300 A reaches the value of 830* $HV_{0.3}$*. The increase in the microhardness of steel 65G after electrofriction treatment is associated with the formation of martensite with carbide particles* Fe_3C *and* Fe_7C_3*.*

Keywords: *electrofriction technology; surface hardening; 65G steel; hardness; structure.*

Аңдатпа. *Электрфрикциялық өңдеу жылдамдығының 65Г болатының құрылымы мен микроқаттылығына әсері бойынша зерттеу нәтижелері келтірілген. Электрфрикциялық өңдеуге дейінгі және кейінгі 65Г болатының құрылымдық-фазалық күйі рентген-фазалық талдау және сканерлеуші электронды микроскопия әдістерімен зерттелді. Виккерс бойынша индентту әдісімен электрфрикциялық өңдеу жылдамдығына байланысты модификацияланған 65Г болат қабатының тереңдігі бойынша микроқаттылық мәнінің таралуы зерттелді. 65Г болатты электрофрикциялық өңдеу кезінде қатайтылған аймақтың тереңдігі бойынша өңдеу жылдамдығына байланысты жоғары микроқаттылығы және қатайтылған қабаттың қалыңдығы 1,2-ден 1,8 мм-ге дейін болатын құрылым қалыптасады. Зерттеу нәтижелері электрофрикциялық өңдеу жылдамдығы өңделетін қабаттың қалыңдығына әсер ететінін және 65Г болаттың тереңдігі бойынша микроқаттылық мәндерінің таралуы бірдей сипатта болатынын көрсетті. 300А тұрақты ток күші бар электрофрикциялық өңдеуден кейін қатайтылған қабаттың микроқаттылығы 830 HV0.3 мәніне жететіні анықталды. Электрофрикциялық өңдеуден кейін 65Г Болаттың микроқаттылығының жоғарылауы* Fe_3C *және* Fe_7C_3 *карбидті бөлшектері бар мартенситтің пайда болуымен байланысты.*

Түйін сөздер: *электрфрикциялық технология; беттік шынықтыру; 65Г болаты; қаттылық; құрылым.*

Аннотация. *Приведены результаты исследований по влиянию скорости электрофрикционной обработки на структуру и микротвердость стали 65Г. Структурно-фазовое состояния стали 65Г до и после электрофрикционной обработки изучались методами рентгенофазового анализа и сканирующей электронной микроскопии. Методом индентирования по Виккерсу исследована распределение значения микротвердости по глубине модифицированного слоя стали 65Г в зависимости от скорости электрофрикционной обработки. Экспериментально показано, что при электрофрикционной обработке стали 65Г по глубине упрочненной зоны формируется структура с высокой микротвердостью толщиной упрочненного слоя от 1,2 до 1,8 мм в зависимости от скорости обработки. Результаты исследования показали, что скорость электрофрикционной обработки влияет на толщину обрабатываемого слоя, а распределение значения микротвердости по глубине стали 65Г имеет одинаковый характер. Установлено, что микротвердость упрочненного слоя после электрофрикционной обработки при фиксированной силе тока 300 А достигает значение 830* $HV_{0.3}$. *Увеличение микротвердости стали 65Г после электрофрикционной обработки связано с формированием мартенсита с карбидными частицами* Fe_3C *и* Fe_7C_3.

Ключевые слова: *электрофрикционная технология; поверхностная закалка; сталь 65Г; твердость; структура.*

Introduction. The tillage tools of agricultural machinery are classified as wearing parts and are replaced with new products as they wear out [1-3]. Increasing their serviceability is an important task of agricultural machine-building and repair production. The principal solution of the problem is to use resource-saving hardening technologies, which will allow improving operational characteristics of critical parts of tillage machines. That is why the material science direction of new developments for parts of agricultural machinery is the most important one.

To increase the wear resistance of working surfaces of agricultural machinery tools, plasma [4-6] and electrode cladding, as well as baking by HFC (high-frequency current) of wear-resistant powders are used. One of the methods of hardening and restoration of ploughshares, which has wide application, is electric arc cladding (cladding reinforcement) [7-9]. These methods are accompanied by heating of the surfaced product, which causes its thermal leaks and hardness reduction. The cladding layer does not provide sharpening of the tool blade during its wear, and the thin (0.7-1.5 mm) layer baked by HFC as a result of wear is destroyed. The high cost of cladding materials and electric energy as well as the necessity of solving the problem of the tool blade sharpening during its wear has determined the necessity of the development of the electrofriction technology (EFT) hardening.

Electrofriction technology is based on the joint melting of the surfaces of the cast iron electrode and the surface of the tillage tool, by introducing the energy of low-voltage electric arcs and cooling with water. Implementation of treatment under a layer of water provides rapid hardening and eliminates heating and tempering of structures of preheat-treated steel sample (product too). The same condition is also responsible for the environmental friendliness of the process. A non-hazardous welding voltage and the friction of the electrode surfaces against the tool are used to form the arcs. Friction provides the necessary electrical resistance. EFT was first suggested by A.A. Abinder in the 40's and is up-to-date now [10]; electrofriction cutting is a type of machining where the workpiece is subjected to mechanical, thermal and electric influence simultaneously. EFT is carried out by contact of a fast-rotating electrode-tool with a product, as well as by supplying electric current of high density to the contact zone: electromechanical processing [11-13] and electrifriction hardening [14,15].

Bogdanovich P.N. and his co-authors used the technology of electrofriction hardening as an experimental method for processing knives of cutting drum of forage harvesters. The effectiveness of using high-strength cast iron in the structures of knives of the cutting drum of forage harvesters is considered. The results of testing the wear resistance of hardened specimens showed that the electrifriction method of hardening, depending on the test mode, increased the wear resistance of specimens in 1.1-1.5 times, the thickness of the hardening zone was 400 μm [14]. However, the thickness of the hardening zone (thermal effect) refers to the reserves for increasing the adhesion wear resistance of tillage tools and requires additional research to expand the possibility of electrifriction treatment. It is worth mentioning that the strength of the material should be 1500-1800 MPa, and the impact toughness should correspond to the values not less than 0.8-1.0 MJ/m^2 for today's conditions of soil processing [16]. To reduce the intensity of abrasive wear it is necessary to provide the maximum possible surface hardness 60-65 HRC. Such values of strength, impact toughness and hardness are not provided by traditional technologies (hardening + tempering) for parts of L53 and 65G steels (exchangeable parts of plow bodies) [17,18].

The prerequisite for the research of the electrofriction technology of hardening of structural 65G steel is the development of affordable, cost-effective and efficient technology to increase the operating characteristics of tillage tools, which helps to reduce costs when performing agricultural works. The purpose of the present research was to study the effect of electrofriction treatment speed on the hardness of 65G steel.

Materials and methods of research. Figure 1 shows a diagram of the installation for EFT hardening of flat products with a disk electrode. Friction of the electrode against the product is accompanied by formation and rupture of electric contact between them. The contact between the product and the electrode is carried out by a layer of coolant (water), which causes heating until the contacting surfaces are melted.

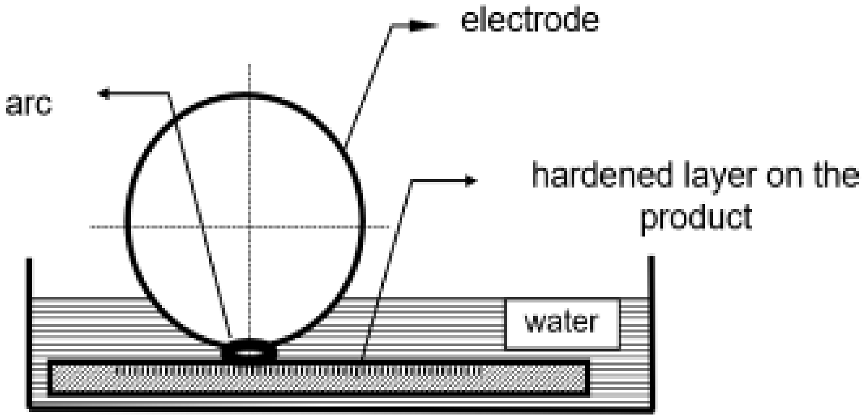


Figure 1. Schematic diagram of a device for electrofriction hardening technology

The machined surface of the product is melted and the melt is alloyed with the elements included in the electrode or in the coolant. Periodic interruption of the electrical contact, with an increase in the interelectrode gap, creates conditions for rapid cooling of the alloyed in the melt product surface. Cooling rate reaches 10^4 - 10^5 °C/s. Cast-iron disk was used as an electrode at EFT. The electrode was included into electric circuit with an anode and isolated from the unit structure. The electric current was limited in the range of 300 A. The voltage of electric current was 44 V. Experiments on hardening were carried out on a sample of structural steel 65G (0.65%C, 1%Mn) GOST 14959-79. The electrode rotation speed was 90 rpm, the samples of 65G steel were moved at a speed of 0.83 rpm, 1.33 rpm, and 2 rpm.

The microstructure of the investigated samples was studied on scanning electron microscope JSM-6390LV and on metallographic microscope ALTAMI-MET-5C. X-ray phase analysis of the studied samples was performed on X-pert PRO diffractometer in CuKα radiation. The diffractograms were decoded using the diffractometer software XPert High Score. Roughness was evaluated using a model 130 profilometer. The microhardness of the formed coatings was determined by Vickers method on a METOLAB 502 microhardness tester at an indenter load of 3 N and dwell time at this load of 10 seconds. To obtain reliable values of the indices, measurements were made in at least 5 points with subsequent statistical processing of the results. To clarify the phase composition and structure of the obtained layers after electrofriction treatment, mechanical treatment (grinding and polishing) and chemical treatment (etching) of the sample surface in 5% ethyl alcohol-based HNO_3 solution were carried out.

Results and discussion. During the experiment, the following was monitored: hardness and thickness of hardening layer of 65G steel (Figure 2). The different configuration of the layer is obtained depending on the distortions in the clamping of the machined sample. In the machining regime with a low sample displacement rate of 0.83 rpm, the possibility of formation of microcracks parallel to the boundaries with the substrate was noted (Figure 2a, shown by arrow).

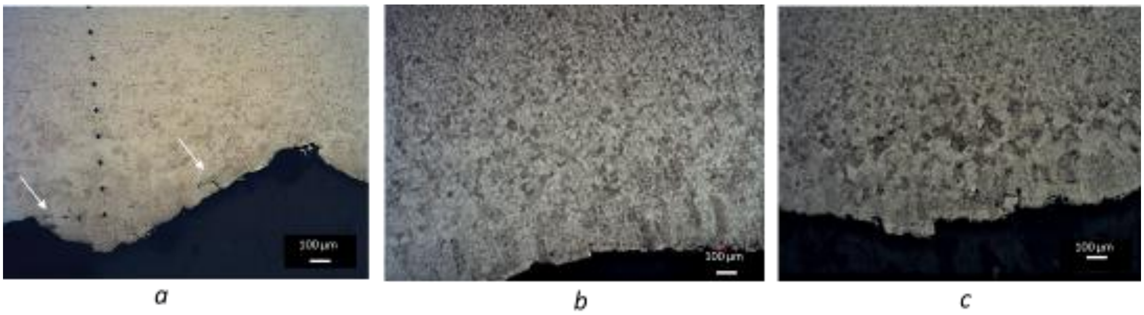


Figure 2. Hardened 65G steel layer by electrofriction treatment at speeds: 0.83 rpm (a), 1.33 rpm (b), 2 rpm (c)

The primary cause of cracking in surface hardening, as in conventional hardening, is internal stresses. However, crack formation conditions, their type and size during quenching have their characteristic peculiarities. Their essence is the following. As only a thin surface layer of steel is exposed to heating, during subsequent rapid cooling it will tend to shrink in volume, but the cold layer of metal underneath will prevent this. As a result, tensile stresses will occur in the surface layer. The unevenness of cooling contributes to the occurrence of micro-cracks. The unevenness of cooling decreases when the part is rotated at a higher speed.

A layer was formed in the hardened layer of the sample up to 1.8 mm deep, which provided more than a threefold increase in microhardness compared to the original structure, 65G steel (Figure 3). The microhardness of 65G steel before EFT treatment was approximately 280 $HV_{0.3}$. After EFT, the hardness of the rapidly hardened layer reaches a value of 830 $HV_{0.3}$.

Depending on the speed at which the sample is moved relative to the electrodes, the thickness of the hardened layer can vary from 1.2 to 1.8 mm. The surface layer of 65G steel shows a transition zone with a thickness of 0.2-0.3 mm when processed at 1.33 rpm and 2 rpm. Such regularity is typical for most methods of hardening materials by concentrated energy flows, for example, plasma treatment of the surface layer of steel parts [4]. The high hardness obtained as a result of EFT hardening is explained by superhigh heating and cooling rates, which are unattainable using traditional methods of heat treatment. Thus, the results of the study showed that during EFT treatment the speed of the sample movement relative to the rotating electrode affects the thickness of the treated layer, and the distribution of microhardness values over the depth of steel 65G has the same character. This indirectly indicates the absence of structural changes and significant changes in the phase composition depending on the speed of movement of the treated sample during EFT treatment. On this basis, further study was carried out on the sample treated by EFT at a speed of 1.33 rpm.

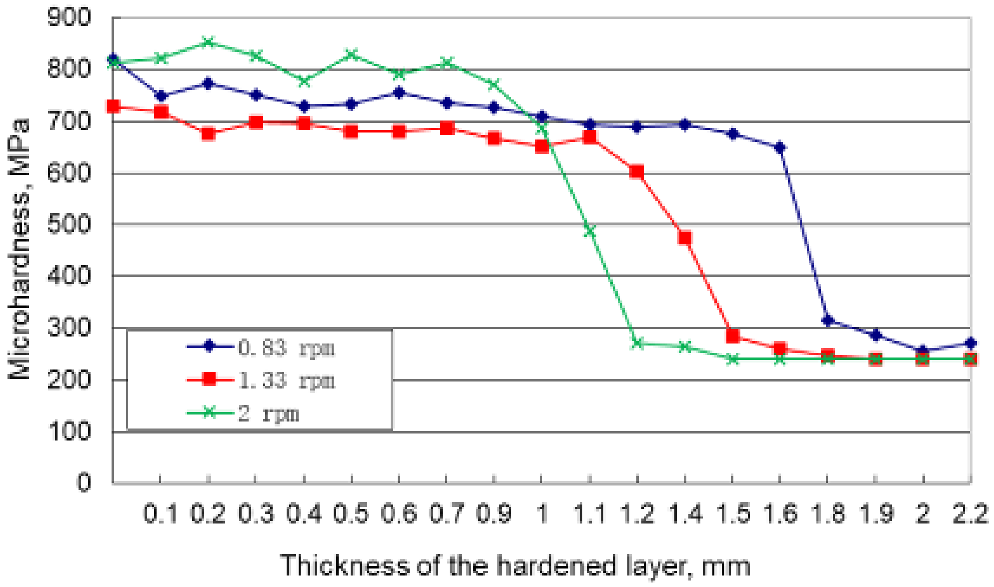
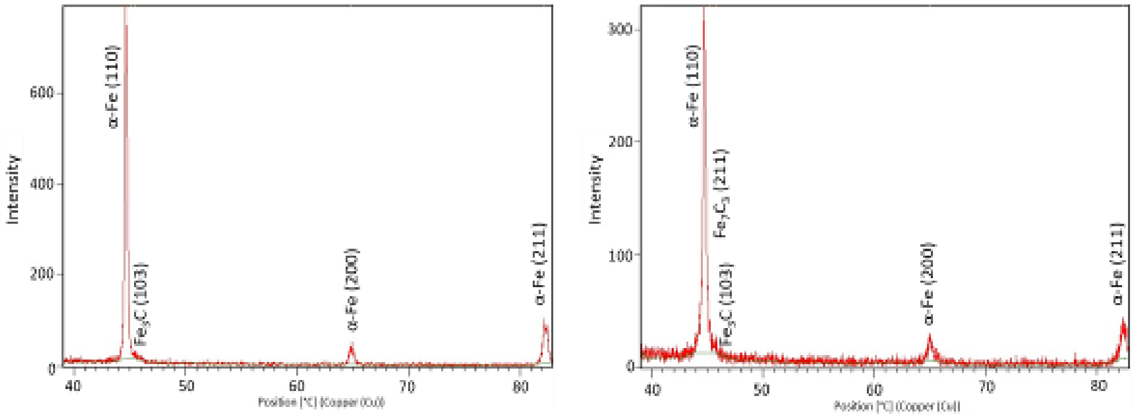


Figure 3. Results of hardness measurement of 65G steel after electrofriction hardening

Figure 4 shows X-ray diffractograms of 65G steel before and after EFT treatment. X-ray phase analysis showed that in the initial state (after standard heat treatment in the delivery state) in the structure of 65G steel there are α-phase and cementite. After EFT treatment the appearance of diffraction line (211) of Fe_7C_3 carbide is observed. Thus, it can be established that the modified layer of 65G steel consists of α-phase with carbides - Fe_3C and Fe_7C_3.



a b

Figure 4. Diffractograms of 65G steel samples: (a) before treatment; (b) after EFT treatment

The initial microstructure of steel 65G before EFT treatment was plate-plate pearlite and ferrite (Figure 5, a). After EFT treatment, the structure of 65G steel is significantly pulverized and a martensitic structure is formed. The ferrite around the original pearlite groups was partially dissolved and significantly reduced and presented a broken shape. The original pearlite group represented martensite. (Figure 5, b). The fine-grained martensite structure formed after EFT treatment contributes to the increase of microhardness of 65G steel.

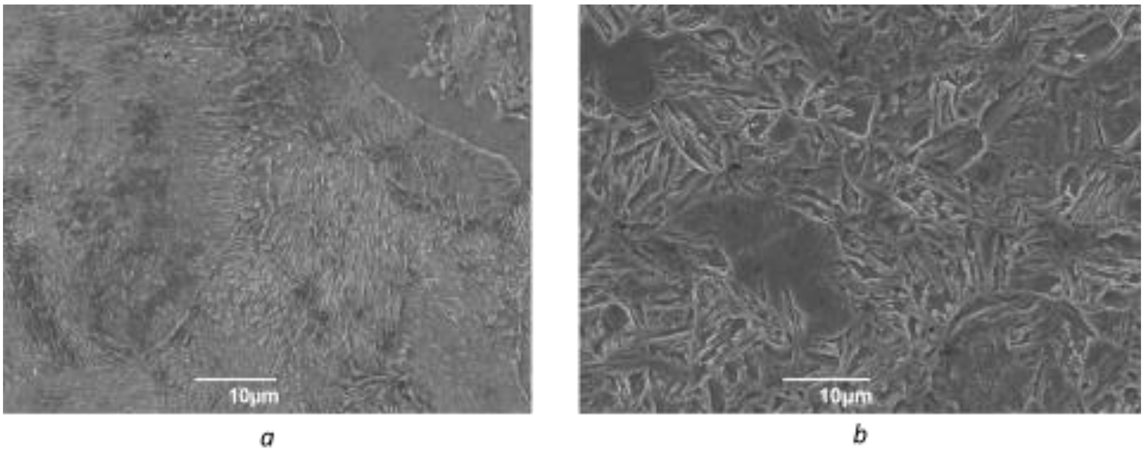


Figure 5. Microstructure of 65G steel: (a) before treatment; (b) after EFT treatment

Conclusion. Electrofriction technology is based on joint melting of the surfaces of the cast iron electrode and the surface of the machined material, by introducing the energy of low-voltage electric arcs and cooling with water. It is established that the microhardness of steel 65G after electrofriction treatment at a fixed current strength of 300 A increases 3-4 times compared to the initial state. The increase in microhardness of steel 65G after electrofriction treatment is associated with the formation of martensite with carbide particles Fe3C and Fe7C3. The study of microhardness distribution of the treated surfaces by depth showed the presence in them, a harder surface layer and a less hard layer lying under it, the length of which differs depending on the speed of electrofriction treatment. Depending on the speed of electrofriction treatment, the thickness of the hardened layer of steel 65G can vary from 1.2 to 1.8 mm, and the thickness of the transition zone is 0.2-0.3 mm. At the low speed treatment mode of 0.83 rpm, microcracks are formed at the paral-lateral boundaries with the substrate. Occurrence of microcracks is promoted by non-uniformity of cooling, which decreases at machining of parts with high speed. The results of the conducted research allow us to conclude that electrofriction technology can be used for hardening of 65G steel.

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