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Research results of solid particle erosion resistance of 20GL steel with boriding

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Abstract. The paper presents the results of experimental studies of solid particle erosion resistance of 20GL structural steel samples with two different variants of surface modification based on the boriding process. Characteristics of modified layers such as depth, composition, microhardness were determined. Tests were carried out according to ASTM G76-13 standard at air-abrasive flow rate of 170 m/s, flow attack angles of 30º and 90°, sample surface temperature of 25ºC. It was found that both considered options of surface modification at an angle of attack of 90 ° flow do not worsen the abrasion resistance of 20GL steel samples, and at flow attack angle of 30 ° increase not less than 8 times. A change in the wear pattern of boriding samples with an increase in the angle of attack from 30° to 90° is noted. As after the boriding process surface embrittlement was observed, the angle of maximum wear for 20GL steel with boriding became equal to 90° in contrast to steel without treatment, where the maximum level of wear is observed at 30°. Thus, the change of fracture type from plastic to brittle was revealed, which should be taken into account in full-scale operation of the treated parts. The obtained results indicate that the process of boriding of pump parts made of 20GL steel will increase their solid particle erosion resistance and extend their overhaul period.

1. Introduction

During operation, functional surfaces of centrifugal pumps are subjected to various types of wear, such as mechanical, corrosion-mechanical, solid particle erosion, water- abrasive, etc. [1-4]. Change of relief of surfaces, and subsequently the form of the flow part due to wear becomes the cause of further destruction of parts or the whole unit.

Despite the previous experience in controlling various types of wear, including solid particle erosion, the problem of choosing materials and coatings for machine parts remains not completely solved and relevant. Due to its cost-effectiveness, cast iron, as well as carbon unalloyed and alloyed steels are the most widespread in pump engineering. Observations made under water abrasive conditions show that alloyed steels have greater solid particle erosion resistance than carbon steels [5-8]. To date there is a large number of studies of various methods of protection in the world, aimed at increasing the resistance of equipment elements to wear [9-12]. The main attention is focused on methods of passive protection, in particular modification of functional surfaces.

At present, such coating methods as gas-thermal spraying, physical and chemical vapor deposition, and electroplating are used to protect pump surfaces against wear [13-20]. The use of polymer coatings and epoxy resins is also becoming common. However, at the same time, the use of such a method as boriding is little known, which belongs to the category of diffusion coatings, when boron atoms are embedded in the lattice of the base metal, thereby forming iron borides [21]. Boriding has proven to be a relatively simple way to improve the wear resistance of structural steels due to the formation of a modified layer of a certain structure, phase composition and increased hardness [22].

In the present work, the task was to investigate the character of wear and to determine the solid particle erosion resistance of 20GL structural steel samples with two different variants of surface modification based on the boriding process.

2. Materials and methods

To carry out experimental studies we made samples of 20GL steel, which is widely used for the production of stator and flow parts of centrifugal multistage pumps operating under static and dynamic loads. Chemical composition of 20GL steel samples is given in table 1.

Table 1. Chemical composition of 20GL steel.

C (Carbon)	Si (Silicon)	Mn (Manganese)	P (Phosphorus)	S (Sulphur)	Fe (Iron)
0.15 – 0.25	0.2 – 0.4	1.2 – 1.6	< 0.4	< 0.4	others

Sample boriding was carried out in an STC 35/50 shaft furnace with external heating in a melt based on sodium tetraborate, sodium fluoride and sodium chloride salts [22]. Two technological processes were carried out which included the following stages:

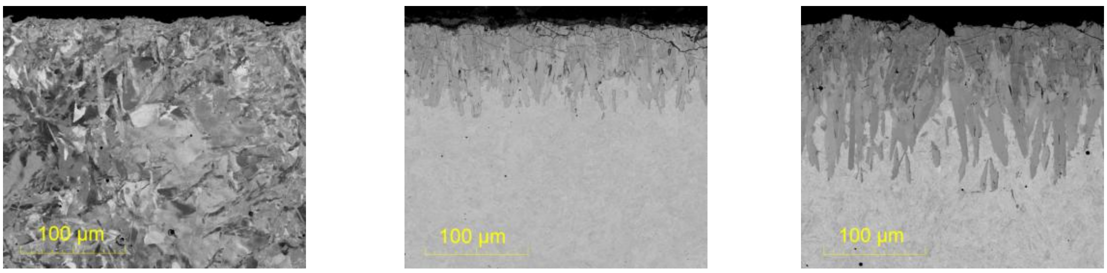
- heating and holding the samples at 350°C for 2 hours;
- holding samples in a boriding bath at 880°C for 3 (I type of boriding) and 6 hours (II type of boriding);
- hardening of samples in oil heated to 90°C.

To conduct research on the solid particle erosion resistance of the samples, an experimental stand of jet-abrasive type based on a sandblasting unit that simulates various conditions of interaction between solid particles and the surface of structural materials was used.

Air purified of impurities and moisture was used as a carrying agent in the test bench; the flow and sample surface temperature were maintained constant. Al_2O_3 particles (electrocorundum, average particle size 250-300 μm) were used as an abrasive material. At least three experimental samples were used to plot each dependence of solid particle erosion intensity on the test time. Experimental studies were carried out with test time increments of 15 minutes. After each test, the mass value of the sample was recorded and the mass loss from the sample over the test time relative to its initial mass was calculated. At the end of the tests, the relative resistance to solid particle erosion was assessed at a steady-state wear rate (total test time – 210 minutes).

3. Results and discussions

After two technological processes metallographic thin sections of 20GL steel samples with I and II type of boriding, as well as a sample of 20GL steel without surface modification were made. Images of thin sections are shown in Figure 1.



(a) (b) (c)

Figure 1. Cross-section of an uncoated 20GL steel sample (a), 20GL steel with boriding type I (b), 20GL steel with boriding type II (c).

As a result of the treatment of the surface of the samples a boride layer is obtained (on the surface the phase FeB and under it Fe_2B). The thickness of the layer after the boriding process of 3 hours was 80±5 μm, after boriding of 6 hours - 150±5 μm. From the images of the obtained thin sections shown in Figure 1, we can see that the boride layer has a needle-like structure.

As a result of a series of tests of 20GL steel samples without coating and with two types of boriding at air-abrasive flow rate S_{sp} = 170 m/s and different flow attack angles (α_{at} = 30°, 90°) kinetic curves of solid particle erosion process of the examined samples were obtained, and also the estimation of their solid particle erosion resistance in relation to 20GL steel without coating (see Figure 2) was carried out.

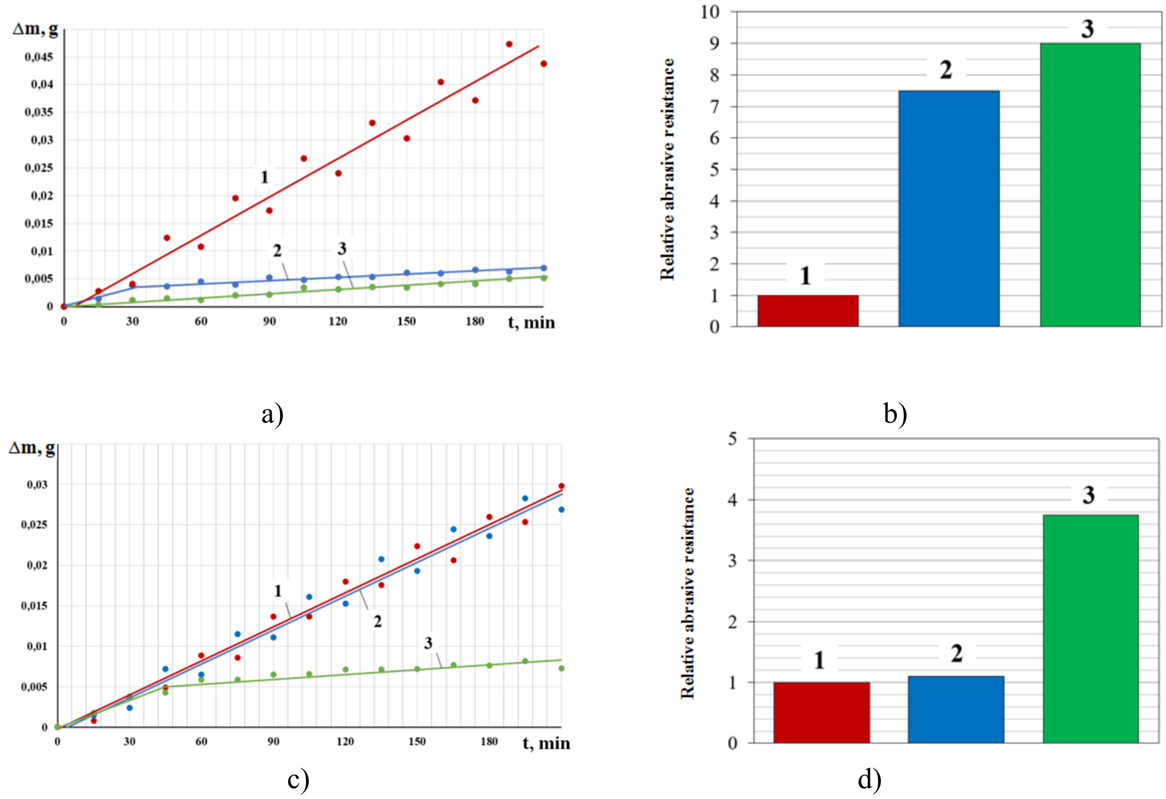


Figure 2. Solid particle erosion curves and relative abrasive resistance over an exposure time of 210 minutes of uncoated 20GL steel samples (1), with type I boriding (2), with type II boriding (3) at 30° (a, b) and 90° (c, d) flow attack angles.

It was found that both considered types of boriding at an flow attack angle of 90° do not worsen the solid particle erosion resistance of 20GL steel samples, and at an flow attack angle of 30° it increases not less than 8 times.

At the same time, it was noted that for 20GL steel wear process is more intense at flow attack angle of 30° than at 90°. This is explained by the fact that 20GL steel belongs to the plastic materials [23]. At tests of samples with boriding the opposite picture is revealed - the intensity of wear at an flow attack angle of 90 degrees is higher than at 30 degrees (see figure 3).

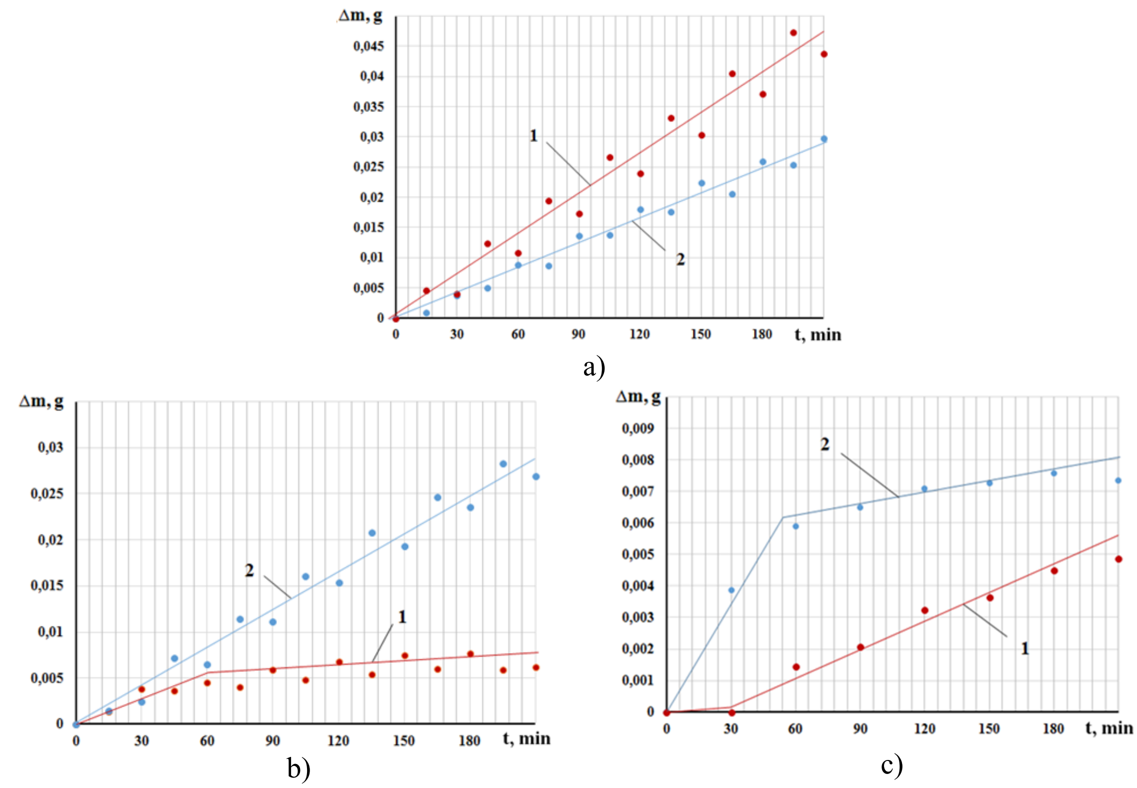


Figure 3. Solid particle erosion curves of uncoated 20GL steel (a), boriding type I (b), boriding type II (c) at 30° (1) and 90° (2).

This fact indicates a change in the type of wear with a change in the angle of attack - the emergence of the transition from ductile to brittle fracture. This is apparently due to the embrittlement of the 20GL steel surface after the boriding process. This fact is indirectly confirmed by the obtained results of measuring the microhardness of the boride layer: in the FeB phase 1800-2200 $HV_{0.1}$ and in the Fe_2B phase 1500-1800 $HV_{0.1}$.

Additionally solid particle erosion tests of 20GL steel samples with boriding type II (modified layer depth - 150 microns) were carried out, which by the results of the first two series of tests showed the best result on wear resistance. As a result of tests it was found out that at a velocity of air-abrasive flow S_{sp} = 170 m/s the wear time of boride layer to the main material at an flow attack angle of 30° was 870 minutes, and at an flow attack angle of 90° was 300 minutes (see figure 4).

The wear depth of 20GL steel samples without boriding, for exposure time equal to 210 minutes, at the same test parameters was equal to the corresponding values of the wear depth 250-300 microns, as for samples with boriding. This, in turn, means that at these parameters the use of boriding will increase the overhaul period of samples from 1.5 to 4 times. At the same time, in order to accurately predict the service life of pump parts subjected to solid particle erosion under real operating conditions, additional research is required that would allow transferring the data from laboratory experiments to real products.

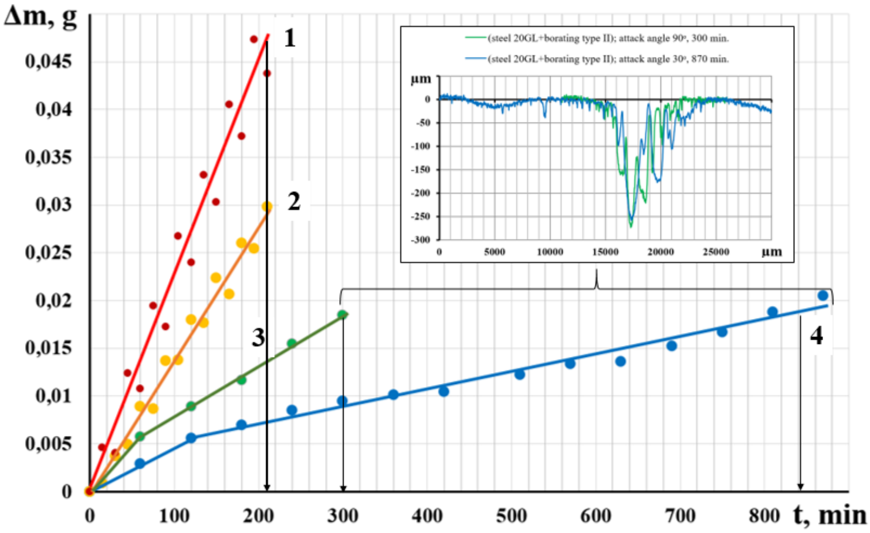
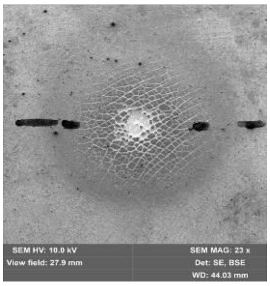
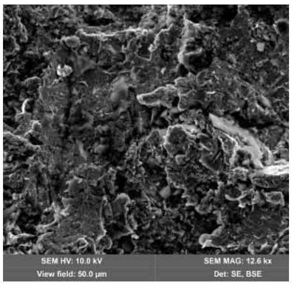


Figure 4. Results of additional solid particle erosion tests of 20GL steel samples (1 - 30°, 2 - 90°) and 20GL steel with boriding type II (3 - 90°, 4 - 30°) at different flow attack angles.

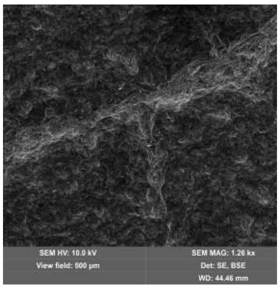
Figure 5 shows images of the surface topography of samples with boriding type II in the area of abrasive impact at flow attack angles of 30° and 90°, which clearly show both the destroyed boride layer and the surface of the base material.



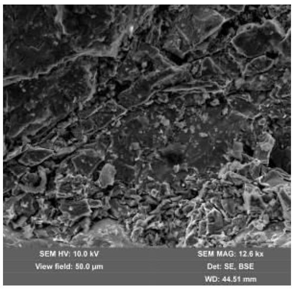
a)



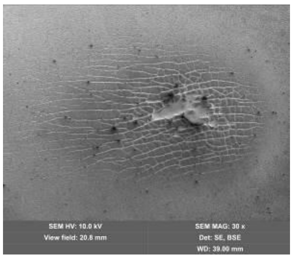
b)



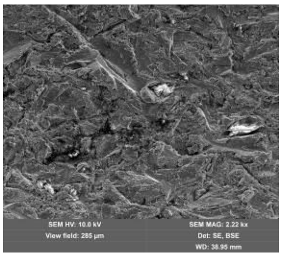
c)



d)



e)



f)

Figure 5. Surface images of 20GL steel samples with boriding type II at 90° (a, b, c, d) and 30° (e, f) after additional solid particle erosion tests.

In the central part of the impact spot at an angle of attack of 90°, surface pitting to the base metal is observed (Figure 5a). Microfractographic analysis of the central part shows the presence of a developed microrelief with traces of ductile-brittle fracture (Figure 5b). In the peripheral part of the impact spot, cracking of the surface layer is observed (Figure 5c), which has a brittle nature of fracture with the formation of a network of microcracks (Figure 5d).

The impact spot at a smaller angle of attack of 30° also has an area of pitting to the base metal in the central part (Figure 5e). At the same time, the microrelief of the central part of this spot differs from the corresponding part of the spot after impact at an angle of attack of 90°. In the case of direct exposure to air-abrasive flow (90°), a significant part of the energy is spent on plastic deformation and destruction of the surface. In the case of a lower angle of attack (30°), due to the reduced angle of attack and the impact impulse from the solid particles, part of the energy is spent on the micro-cutting of the surface, resulting in a change in the fracture character, and micro-cutting and scratching marks appear on the surface (Figure 5d). Brittle cracking of the surface layer is also observed in the peripheral part of the spot.

4. Summary

Obtained kinetic curves of solid particle erosion for both types of boriding at different angles of attack of the air-abrasive flow showed that at an angle of attack of 90° there is no decrease in solid particle erosion resistance of 20GL steel, and at an angle of attack of 30° an improvement in resistance of not less than 8 times is noted.

A change in the wear pattern of boriding samples with an increase in the angle of attack from 30° to 90° is noted. As after the boriding process surface embrittlement was observed, the angle of maximum wear for 20GL steel with boriding became equal to 90° in contrast to steel without treatment, where the maximum level of wear is observed at 30°. Thus, the change of fracture type from plastic to brittle was revealed, which should be taken into account in full-scale operation of the treated parts.

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