SURFACE ENGINEERING OF SLIDER VALVES OF FLUID POWER MOTORS MADE OF TOOL STEELS BY USING BORIDING SATURATION MIXTURE

V.M. Konstantinov, V.G. Dashkevich, A.V. Kovalchuk
Belorussian national technical university, Minsk, Belarus

The technique for producing compact boride layers for the effective hardening of slider valves of fluid-power motors and distributives valve of Belarusian origin made of tool steel has been designed. The effect of temperature and time parameters in boriding powder saturation mixture on the thickness and phase composition of the diffusion layers and the morphology of the upper boriding layer and the intermediate layer on steels У8А (C80W1) and 9ХС (90CrSi) has been researched. Furthermore, the impact of boriding on the dimensional accuracy of slider valves has been investigated.
Keywords: boriding, phase boundary, frangibility, shear stress, collapse load, dimensional accuracy.

INTRODUCTION

One of the most effective methods to enhance the resistance of steel articles under the conditions of boundary friction and abrasive wear is the engineering of their surface with the use of boriding [1, 2]. Boriding can be performed in the powder or gaseous medium, in the salt melt, etc. depending on the geometry and the quantity of detail parts. The boriding methods mentioned above have both advantages and disadvantages for different conditions of use. Due to a number of characteristics, the boriding of steelwork in the powder medium is considered to be one of the most efficient [3–5]. Powder saturation boriding mixtures of the "Besto" trade mark were used in CIS industries in previous decades [6]. The process of surface thermodiffusion alloying by boron from the mentioned powder mixtures was acknowledged to ensure high technical and economic performance and the stability of steelwork characteristics. The saturation mixture "besto-bor" does not yield to the ones of the same type developed by the companies BotTech GmbH (Germany), Worldwide Alloy Surfacing Inc. (USA) in respect of their effectiveness in the boriding process, and the cost of such treatment does not exceed the cost of liquid boriding. Boride layer thickness changes from 50 μm to 400 μm depending on the purpose and the manufacturing parameters of the process, and microhardness can reach 22 GPa. Saturation powder mixture reuse ratios can come up to 4…6 times.

In this study, research was conducted into the boriding of steels У8А and 9ХС used for the manufacturing of the slider valve detail parts of fluid-power motors and distributive valves of Belarusian origin in the saturation powder medium "Besto". The dependence of boride layer thickness on the temperature and the time of exposure were established, the frangibility of the borated layer defined by shear stress was estimated, and the impact of double-phase boriding in the powder medium on the change of the size and the roughness of the surface of steel specimens У8А and 9ХС was stated.

MATERIALS AND METHODS

The slider valves are made of steels У8А (GOST) (table1) and 9ХС (GOST) (table 2) and are used in fluid-power motors and distributive valves of Belarusian origin. The operation conditions of slider valves can be characterized as semifluid sliding friction in combination with contact-abrasive wear by wear products. Maximum unit load does not exceed 100...120 MPa, and the sliding speed does not exceed 0,2 m/s. The original structure of slider valves is equilibrium, obtained by annealing. The hardness of the slider valves made of steel 9ХС was 200 HB, the ones made of steel У8А – 185 HB.

Table 1. The chemical composition of steel У8А in wt. %.

C	Si	Mn	Ni	S	P	Cr	Cu
0,75…0,84	0,17…0,33	0,17…0,28	≤0,25	≤0,018	≤0,025	≤0,2	≤0,25

Table 2. The chemical composition of steel 9ХС in wt. %.

C	Si	Mn	Ni	S	P	Cr	Mo	W	V	Ti	Cu
0,85…0,95	1,2…1,6	0,3…0,6	≤0,4	≤0,03	≤0,03	0,95…1,25	≤0,2	≤0,2	≤0,15	≤0,03	≤ 0,3

Diffusion saturation was carried out in the powder medium in sealed containers at temperatures from 1120 to 1220 K for 1...4 hours with preliminary isothermal exposure at 1020 K for 1 hour. The heating rate was secured not to exceed 200 K/h and the cooling rate – 100 K/h in order to reduce buckling.

The microstructure was inspected with Neophot-2 microscope; standard metallographic agents were used to reveal the structure. The frangibility of the borated layer was estimated according to the method [7]. Microhardness was measured using the indentation test with the DuraScan (Austria) instrument. The detail parts dimensions after boriding were estimated with the YATO YT-72305 micrometer. In particular, the slider valve surface with the nominal dimension of $6_{-0,12}$ mm (12 quality class) was measured.

RESULTS AND DISCUSSION

As a result of boriding in the powder medium "besto bor" diffusion layers on steel У8А with the microhardness of 16300...17800 MPa and on steel 9ХС with the microhardness of 16500...18000 MPa were formed. It is stated that the obtained thickness of the boride layer on steel У8А exceeds the one on steel 9ХС, and the difference in layer thickness lies within 20 microns. It is explained in a greater degree by the presence of chromium in steel 9ХС, and in a lesser degree by the presence of silicon and a great quantity of carbon. At the same time Si slightly increases the overall thickness of the diffusion layer as it facilitates the formation of the clearly marked section of α-solid solution.

It is stated that the morphology of the diffusion layers formed under different conditions differs slightly, but they equally retain the conventional "sawtooth" structure of the boride zone, which is represented on the surface by prismatic formed protuberances. Perlite-structure areas remain in the space between the protuberances on steel У8А, and the quantity of borocementite is insignificant. At the same time the transition zone on steel 9ХС is more developed and is represented by the globular inclusions of borocementite in the upper boriding layer and an interlayer at the boundaries of perlite grains.

The degree of frangibility of the boride layers defined by shear stress at the phase boundary was estimated and the thickness of the boride layer and the shear stress related to the temperature and time of exposure were shown (Fig. 1). On the basis of the results of the study the boriding conditions ensuring the least degree of frangibility with boride layer thickness not less than 100 μm were chosen for slider valves hardening. It is proved that the boride layers formed as a result of the saturation process at 1220 K for 1 hour with preliminary isothermal exposure at 1020 K for 1 hour are the least frangible on steel У8А, and the boride layers formed at 1220 K for 1 hour and 1170 K for 2 hours with preliminary isothermal exposure at 1020 K on are the least frangible on steel 9ХС. Such boride layers are the least probable to crack and have a relatively high rate of shear stress. The core reason for it is, apparently, the thickness of the boride layer and the pattern of residual stresses and their peak value related to it, as the boride layers formed under different conditions are of practically the same microhardness and have the same FeB/Fe$_2$B-phase ratio.

As seen on the diagram (Fig.1), saturation temperature decrease or time of exposure increase is followed for the steels in question by the decrease in shear stress at the phase boundary, i.e. under the given conditions boride layers optimum in thickness and phase ratio are formed, and according to the author's data [2] such layers exist to every steel.

It should be noted that if boriding is carried out under different conditions, spontaneous shelling of the boride layer is observed on a number of occasions. Figure 2 shows two distinctive forms of such destruction. In the first case the surface gets covered by a net of microcracks (Fig. 2a). The indentation test results in the formation of a fracture nucleus with radial cracks spreading from the center. Such destruction is caused primarily by the forming stressed state of the detail part. In the second case there occurs the spontaneous spalling of the boride layer, its flaking with the formation of craters on the surface (Fig. 2b).
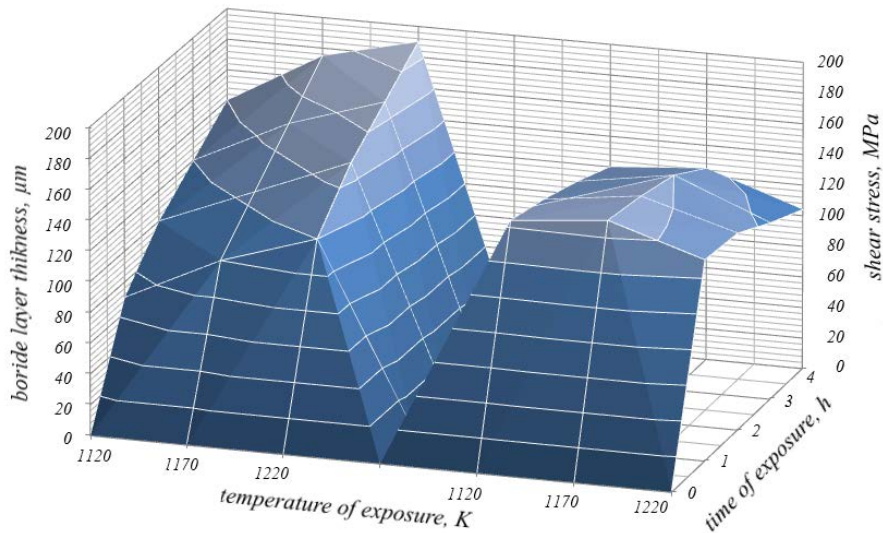
a)
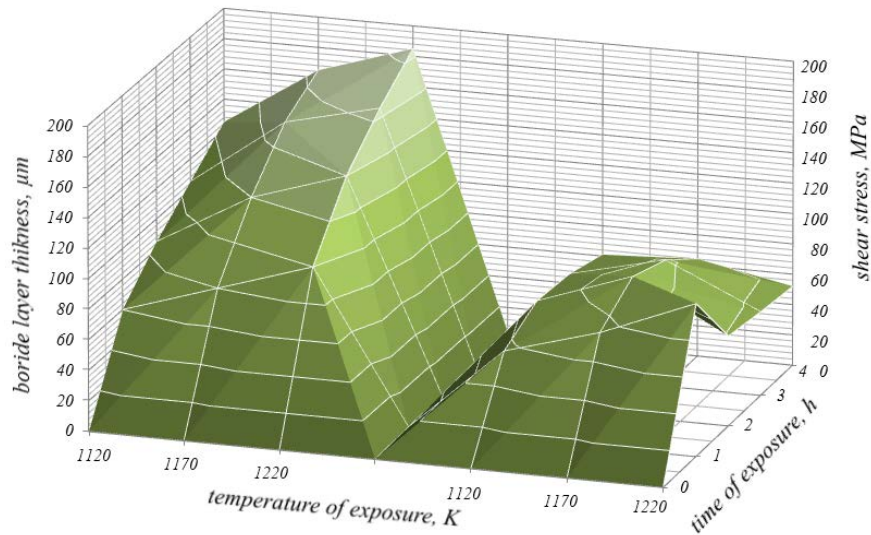
b)

Fig. 1. The dependence of boride layer thickness and shear stress at the phase boundary on the temperature and time of exposure (a) for steel У8А and (b) for steel 9ХС.

At the same time the high-boron phase tends to peel off. According to our observations, this destruction is typical of steels with the increased concentration of Si and Mn. It is explained by the fact that if there is more than 2 wt. % Si contained in the steel, graphite interlayer can be formed in the upper boriding layer [8] because of C and Si cross diffusion, and, consequently, ferrite is formed in adjacent volumes, which contributes to the increased spalling of the diffusion layer.
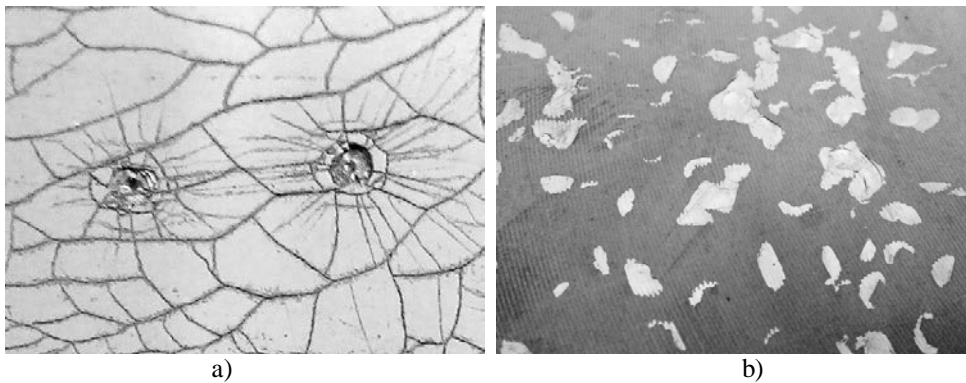
a)   b)

Fig. 2. The image of defective boride layer surface: a) in the form of a net of microcracks; b) with chipped flake-like fragments.

3

The results of the measuring of the checkpoints on the slider valves showed that the dimensional increment is uniform on all the surfaces, except for the sections with curved surface of less than 5 mm radius, where the layer growth progresses more actively. Parallelism and flatness errors remain within the tolerance limits. It is stated that 25...43 % of the boride layer thickness grows outwards with the detail part configuration increment (Fig. 3).
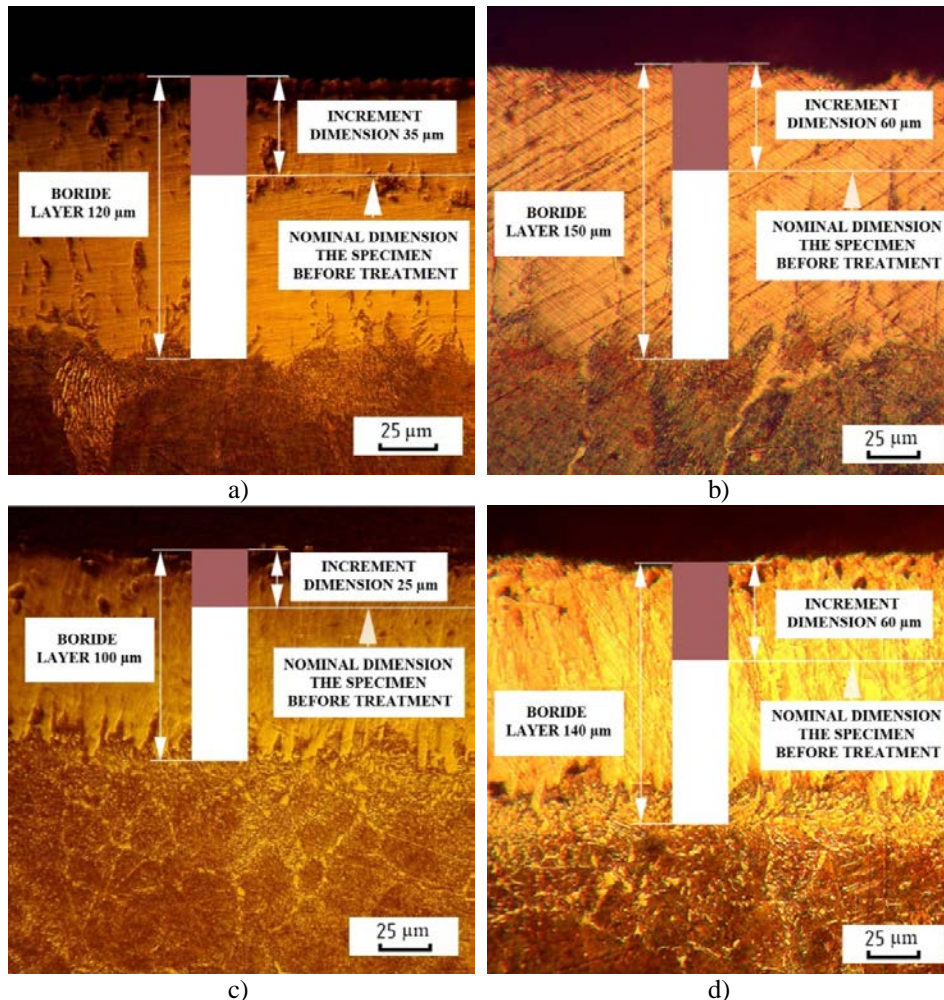

Fig. 3. Microstructure of the borated specimens of steels У8А (a and b) and 9ХС (c and d) after boriding at 1220 K for 1 hour (a and c) and 2 hours (b and d) with preliminary isothermal exposure at 1020 K for 1 hour.

In contrast to the results of the studies [9], in which the decrease in the boride layer part growing outwards and the decrease in the increment of the dimensions of the hypo eutectoid steel specimen with the increase of exposure time were stated, our findings indicate the increase in the dimensional increment of steel specimens У8А and 9ХС and the increase in the portion of the layer part growing outwards. It can be attributed to the higher degree of dispersion of the components of the saturation mixture in use as well as a larger proportion of carbon in steels У8А and 9ХС, which restricts the diffusion of boron into the basis and presupposes more continued redistribution of carbon and its increased concentration in the transition zone [10].

Thus, when the diffusion layer reaches 100 μm and 150 μm the increase in the nominal dimensions of the detail parts by 25...30 μm on every side should be expected (with the exposure time of 1 hour). Therefore, for including boriding into slider valves treatment process the construction documentation needs to be corrected with allowance for the change in the linear dimensions of the detail parts caused by boriding. It should be noted that an increase in the dimension of the bores takes place. Consequently, the nominal dimension of the central fitment bore of the slider valves under the saturation conditions in question decreased by 50 μm and was 19,95 mm instead if 20,0 mm (Fig. 4).
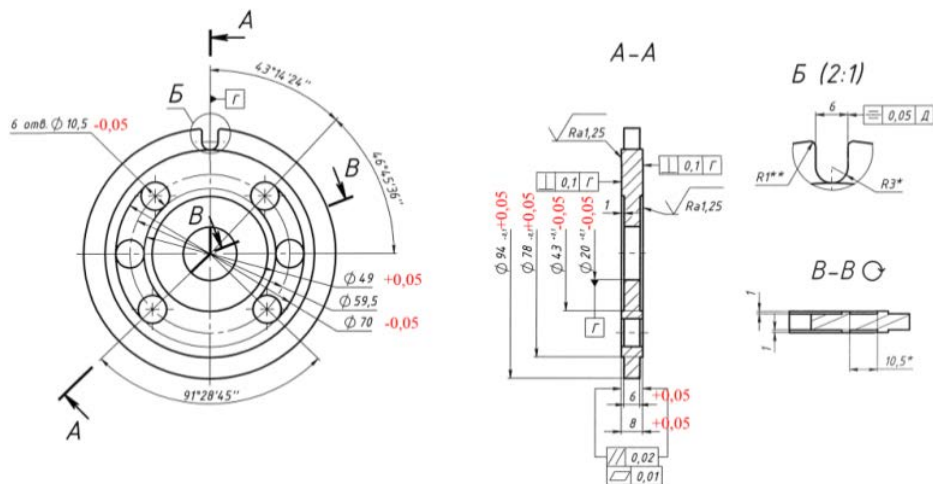
4

Figure 4. The dimensional change of the slider valve in relation to the nominal value.

No significant difference in dimensional increment kinetics by means of boride layer on steels У8А and 9ХС is observed, the average speed of increment within the time interval in question ranges from 20 μm/h to 30 μm/h. However, some influence of the type of steel base material on the allocation of boride layer parts growing outwards and inwards is observed (Fig. 3a, 3c). This can be explained by the difference in the overall thickness of boride layers on the steels as well as by the time spent on the diffusion redistribution of the alloying elements in steel 9ХС and the change of the parameters of boron diffusion and iron ascending diffusion.

The degree of the surface roughness of the slider valves after the boriding process remains at the initial level with the initial roughness Ra ≤ 1,0…1,25, but it decreases by 1...2 degrees with the initial roughness Ra ≤ 0,25…0,32.

To forecast the influence of boriding on the mechanical properties of detail parts we should take into account the scaling factor – the ratio of boride layer thickness to the detail part thickness. In general, boriding reduces the ultimate strength σ_u, the yield strength σ_y, the percent elongation δ and the impact toughness of steel, but this influence is insignificant if the scaling factor value for double-phase boride layers is under 0,016 [2]. The influence of the boride layer on σ_u, σ_y, δ and the impact toughness of the detail parts can be neglected as under the chosen conditions the scaling factor value for borated slider valves made of steels У8А and 9ХС is within the limits of 0,12...0,16. At the same time the boride layer will enhance the ultimate compressive strength of the slider valves σ_c by means of the high value of σ_c at the level of 2000...2500 MPa of the borides themselves. The thickness of boride layers does not exceed 150 μm, therefore as a result of slow cooling of the detail parts after boriding their endurance strength σ_{-1} should increase by 20...25 % as compared with the initial state [2, 5].

CONCLUSIONS

Research was conducted into the boriding of steels У8А and 9ХС used for the manufacturing of slider valve detail parts of fluid-power motors and distributive valves of Belarusian origin in the saturation powder medium "Besto". The dependence of boride layer thickness and shear stress at the phase boundary on the temperature and the time of exposure were established for the steels in question.

The control of the temperature and time parameters of boriding process can lead to the changes in the stress state of the borated layer on steel which will promote the decrease in its frangibility defined by shear stress at the phase boundary. The least frangible of the examined boride layers are the ones formed as a result of saturation process at 1220 K for 1 hour with preliminary isothermal exposure at 1020 K for 1 hour for steel У8А; at 1220 K for 1 hour and at 1170 K for 2 hours with preliminary isothermal exposure at 1020 K for steel 9ХС. Boride layer thickness optimal for the given steels and the pattern of residual stresses and their peak value are most probably of the greatest significance.

The influence of boriding on the dimensional changes of steel specimens У8А and 9ХС was analyzed and the fact that boriding leads to the uniform dimensional increment while the time of exposure can be different was found out. If the boride layers thickness is 100...150 μm the dimensional increment forms 25...43 % of the boride layer thickness. The dimensional increment is uniform on all the surfaces, except for sections with curved surface of less than 5 mm radius, where the layer growth progresses more actively.

The technique for the hardening of the slider valves made of steels У8А and 9ХС was proposed which makes it possible to obtain relatively not frangible boride layers with the value of thickness up to 150 μm and the value of microhardness up to 18 GPa, with the scaling factor ensuring the decrease in the ultimate compressive strength and the endurance strength of detail parts. The use of the technique requires the correction of the construction documentation with allowance for the dimensional increment of the borated detail parts determined for each of the steel grades.

REFERENCES

[1] E.J.Mittemeijer, M.A.J.Somers. Thermochemical Surface Engineering of Steels: Improving Materials Performance: 2d ed. Elsevier, 2014. 816 p.

[2] Krukovich M.G., Prusakov B.A., Sizov I.G. Plastichnost borirovannyh sloev. FIZMATLIT, 2010, 384 p. (in Russian).

[3] K.G.Budinski. Friction, Wear, and Erosion Atlas. CRC Press, 2013. – 309 p.

[4] X.Hea , X.Huaping , M.F.Ozaydina , K.Balzuweitb , H.Lianga. Low-temperature boriding of high-carbon steel. Surface and Coatings Technology, 2015, Vol. 263, P. 21–26. DOI:10.1016/j.surfcoat.2014.12.071

[5] F.I.Panteleenko , V.P.Lialiakin , V.P.Ivanov , V.M.Konstantinov. Restoration of machine parts: Handbook. "Mashinostroenie", 2013, 672 p.

[6] BESTO – Mode of access: http://besto.by/vidy-obrabotok/borirovanie. Date of access: 08.08.2015.

[7] P.K.Grigorov , B.B.Kathanov. Povyshenie nadezhnosti i dolgovechnosti detakey mashin: Metodika opredeleniya hrupkosti borirovannogo sloya. 1972, Vol. 16, P. 97–98. (in Russian).

[8] B.Matijevic. Evaluation of boride layer growth on carbon steel surfaces. Metal science and Heat treatment, 2014, Vol. 56, № 5-6, P. 269–273. DOI: 10.1007/s11041-014-9744-7

[9] L.A.Kurkina , Yu.P.Kharaev. Influence of temperature of diffusion saturation on the size of samples of steel at borating. Basic Problems of Material Science (BPMS)), 2014, Vol. 11, No.2, P. 201–205.

[10] S.Şahin. Effects of boronizing process on the surface roughness and dimensions of AISI 1020, AISI 1040 and AISI 2714. Journal of Materils processing Technology, 2009, Vol. 209, № 4, P. 1736–1741. DOI:10.1016/j.jmatprotec.2008.04.040

[11] V.I. Matkovich. Boron and Refractory Borides. New York: Springer Science & Business Media, 2012. – 656 p.

Author for contacts:
Full Prof., Grand PhD in engineering sciences Valery M. Konstantinov, Head of the Department of Material Science in mechanical engineering, Belorussian national technical university, Minsk, Belarus.
Phone: +375 29 6388827, Fax +375 17 2928185, E-mail: v_m_konst@mail.ru.