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Using Dynamic Pre-activation of Steel Surfaces for Nitriding Intensification

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Abstract. The article considers the possibility of pre-activation of the steel surface before nitriding. A complex dynamic method of material activation with a high-speed flow of powder particles (super deep penetration) was used. To exclude the influence of alloying elements, low-carbon steel (2% wt. C) was chosen as the initial material. Powders of NaF (> 250 μm) and Pb (<200 μm) were used as material of powder flow. Research of samples structure revealed the penetration of Pb particles through the depth of samples with the formation of channel elements and the absence of NaF powder traces. Microhardness measurements have shown that using of NaF powder leads to activation of the nitriding process and to increase of hardness of the resulting nitrided layer, while using of Pb powder leads to inhibition of diffusion activity and decrease in the hardness of the nitrided layer. Application of too coarse fraction of NaF resulted in particles sticking to the surface of the sample that reduced the thickness of the nitrided layer. The necessity of using a finer-dispersed fraction of NaF in the future is shown.

Keywords: super-deep penetration, SDP, nitriding, intensification, powders, dynamic loading.

I. INTRODUCTION

Nowadays it has been accumulated vast experience of steel hardening by the different types and methods of chemical and heat treatment. Traditional nitriding allows to form relatively thin, uniformly distributed nitride layers during long processing period. However, production of wear-resistant diffusion layers with a unique morphology and intensification of the process of low-temperature nitrogen saturation of surface layers is an actual scientific problem [1].

Traditional nitriding technologies are characterized by low productivity because of long period of saturation of the surface layer material. One of the reasons that lead to premature failure of the hardened parts is uneven wear of the surface. It's explained, for example, by physical-mechanical and chemical heterogeneity of the diffusion layer after nitriding and the formation of brittle phases therein. Use of traditional nitriding technologies with a sufficiently high degree of probability leads to the formation of an uneven layer with a reduced concentration of saturable substance, low and inhomogeneous hardness of the surface layer, and the appearance of defective areas.

Nitriding intensification can be achieved by variation of some technological parameters in order to reduce duration of preliminary heat treatment [2]-[3]. Such methods of nitriding intensification are only partial solutions of the problem. Many researchers see a fundamental solution to the problem in the fundamental reorganization of the cycle itself. Developments aimed at surface modification using variable electromagnetic fields of different ranges, as well as using a pulsating discharge look promising. Application of ion-plasma processes in chemical-thermal treatment allows to intensify the process [4]. However, they also have a number of shortcomings.

Effective methods of preparing the surface for coating are complex dynamic operations of the matrix steel activation before nitriding [1]. Therefore, alloying technology for metals and alloys in solid state in the mode of super-deep penetration (SDP) by the flow of powder particles is promising. The specificity of this treatment is an achievement of impulse of high pressure in the range of very short intervals. During SDP process powder particles work as needles and the fibers are formed in metal matrix under dynamic interaction between powder particles and matrix material [5]-[6]. Dynamic loading of surfaces by powder streams may ensure the intensification of subsequent nitriding and increase the wear resistance of the resulting layer.

At SDP process flow of powder particles (strikers) move in a volume of the metal body. Behind the strikers in a dense "quasi-liquid" plasma channel cavities are formed, which can slam under the effect of background pressures. Slamming of microcavities under the action of high pressure to a point can lead to energy density $\geq 10^{15}$ J/m^3. In this case matrix crystal lattice is destroyed with high speed [7], and the matrix material changes from a solid state to a dense plasma, i.e. a dynamic phase transition is realized. Under the influence of this high pressure the cores of material may stick together, i.e. automodel process of inertial confinement fusion [7]-[8] can be realized.

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Until now, a common understanding of process of particles penetration at SDP was not found what led many research groups continue working in this direction [9]-[10]. The phenomenon of interaction of cosmic dust particles (diameter less than 100 microns) with the spacecrafts observed in the near-Earth environment. The SDP process is used to determine the possible damages of spacecrafts with flows of cosmic dust and for control systems testing [11]-[12].

II. MATERIALS AND METHODS

Dynamic processing in SDP mode was carried out in the following conditions : particles speed 300-1000 m/s, exposure time ≈ 100 microseconds, material of billets: low-carbon steel (0.2% C), material of strikers - various fractions of SiC powders - 3-100 microns, and Pb - ≤ 200 microns with addition of powder activator NaF >250 microns.

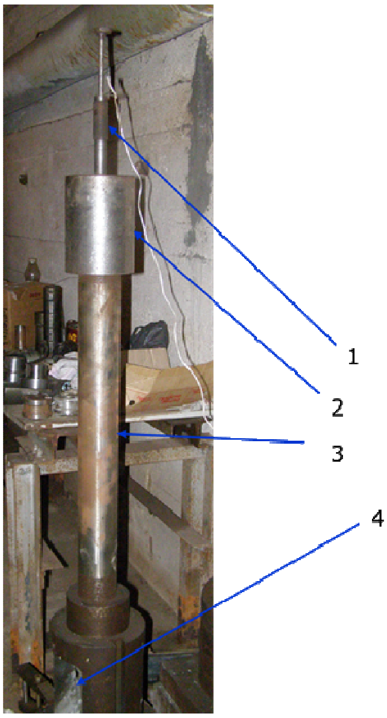


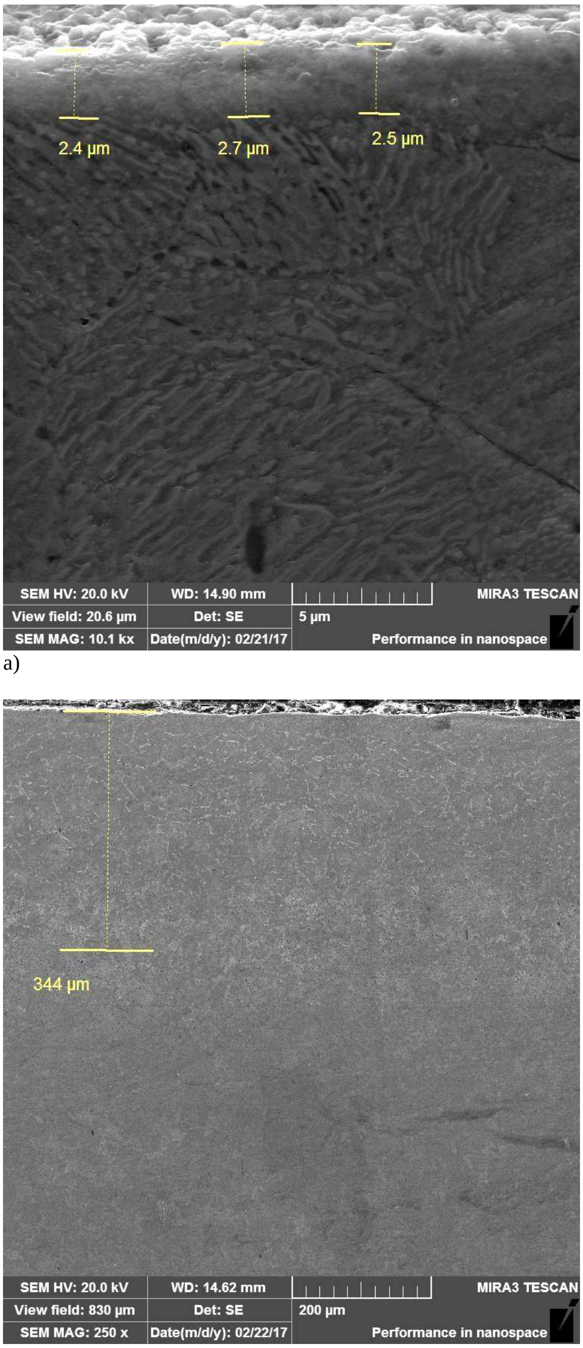
Fig. 1. Indoor cannon accelerator: 1-detonator, 2- explosive chamber, 3 – barrel, 4 – body of sample holder.

The low-temperature nitriding process was carried out in a powder medium at a temperature 560 °C for 10 hours, in containers with a sealing fused shutter. For a low-temperature nitriding the following powder composition (% wt.) was used: $C_6N_6FeK_4$ 20-30%, charcoal 5-10%, $NaHCO_3$ 5-10%, inert filler 50-70%. A shaft electric furnace with selitic heaters was used for the process.

The samples preparation technique includes cutting, polishing and etching in 4% nitric acid. Structures were studied by TESCAN MIRA3 SEM, microhardness was measured by micro durometer PMT-3.

III. RESULTS AND DISCUSSION

To eliminate the influence of alloying elements, low-carbon steel with 0.2% wt. C was used as an initial material. After nitriding, a nitride layer with a thickness of 2.5 µm and a transition zone of 350 µm were formed in the initial steel (Fig. 2).



a)

b)

Fig. 2. Nitride (a) and transition layer (b) on the initial 0.2%C steel.

As a result of the high-energy impact in the SDP mode, activation or inhibition of the matrix material can be realized at different depths. To control the process of preliminary solid-phase doping in the mode of super-deep penetration (SDP), the introduction of chemical elements, which are certainly absent in the matrix steel, is used. In the low-carbon steel Pb powder was used as a marker of the penetration process. The traces of processing (channel elements) are observed on steel samples after activation by Pb powder (Fig. 3). The nitrided layer is shown on Fig. 4.

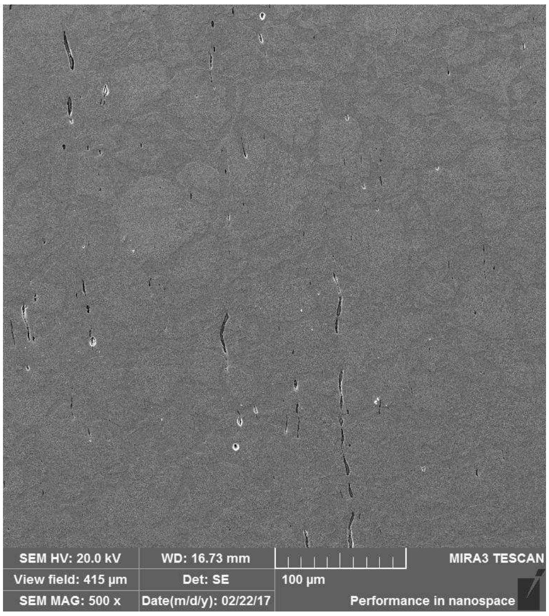


Fig. 3. The structure of low-carbon steel after the activation by Pb powder

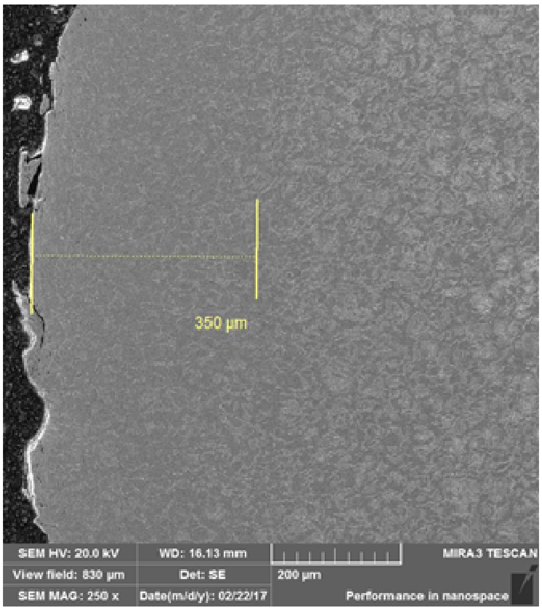
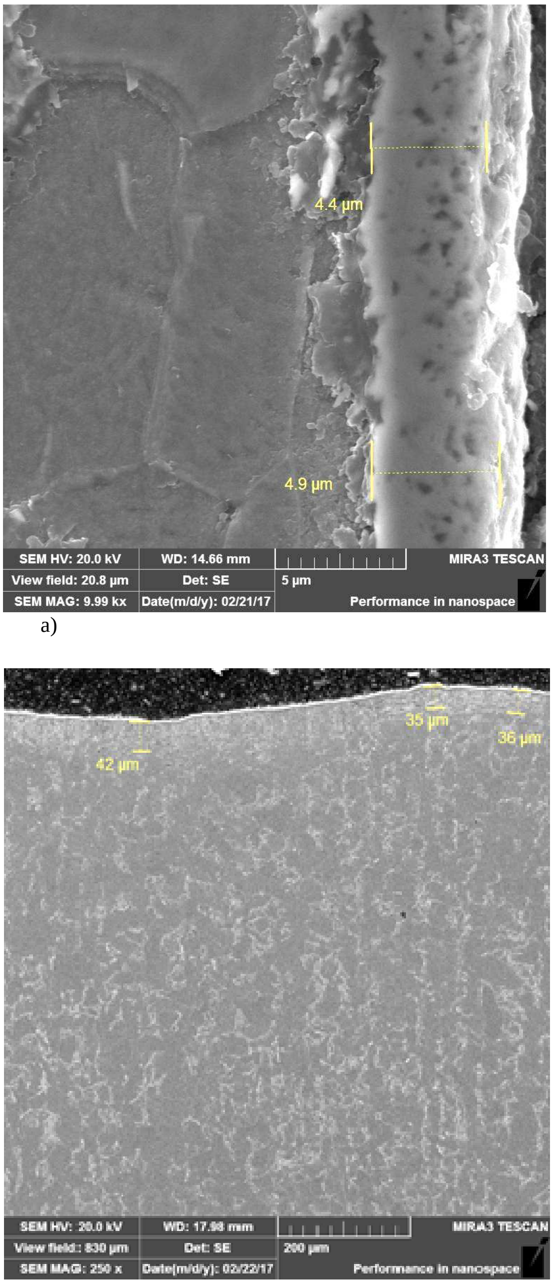


Fig. 4. Structure of a sample activated by Pb after nitriding

Apparently, Pb leads to a decrease in the diffusion activity during subsequent nitriding. In addition, a thin nitride layer mainly of the ε-phase ($Fe_{2-3}N$) is formed. This layer can be actively cleaved during following sample preparation. Activation of low-carbon steel by NaF powder in SDP mode causes activation of the subsequent nitrogen diffusion process (Fig. 5).



a)

b)

Fig. 5. Structure of steel activated by NaF powder after nitriding: (a) nitride layer, (b) transition layer

Thus, the average thickness of the nitride layer and the transition zone in the initial sample was 2.5 μm and 350 μm, in activated by NaF - 4.6 μm and 40 μm, in the Pb-inhibited sample, the transition zone was 350 μm, the nitride layer was not detected. The transition zone after nitriding of the initial steel (Fig. 3) is much thicker (8.7 times) than the similar zone obtained after nitriding of the NaF-activated steel of the same composition (Fig. 5), while on Pb-activated steel the thickness of the transition zone is equal to the thickness on the initial sample (Fig. 4).

The microhardness of Pb-activated steel at a depth of up to 0.1 mm is 1.4 times lower than that of the initial sample. The microhardness of NaF-activated steel at a depth of up to 0.1 mm is 1.2 times higher than that of the initial sample (Fig. 6).

The decrease in the thickness of the transition zone at NaF-activated steel is explained by the use of a too coarse powder fraction (> 250 μm). This reduced the density of the penetrating flow and caused the sticking of large particles to the surface of the processing sample, which complicated the diffusion of nitrogen during subsequent nitriding. It is confirmed by the fact that in the structure of NaF-activated steel there are practically no channel elements.

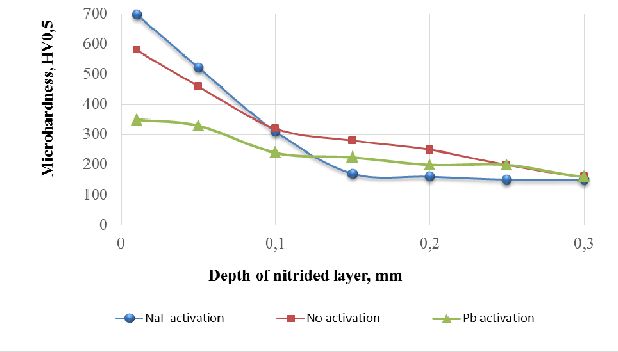


Fig. 6. Microhardness of nitrided samples

IV. CONCLUSION

Based on estimates of changes in the size of nitride layers and transition zones formed on low-carbon steel (0.2%wt. C) without activation, with the activation by NaF powder and by Pb powder, the following conclusions can be drawn:

The use of Pb powder to pre-activation of the steel leads to inhibition of the diffusion activity and to a decrease in the hardness of the layer in 1.4 times.

The use of NaF powder to pre-activation of the steel activates the nitriding process and increases the hardness of the layer 1.2 times

Initial steel and Pb-activated steel after nitriding allow to get the thickness of the transition zone of 350 microns, while at the same time, at NaF-activated steel, the thickness of the transition zone decreases by 8.7 times. It is necessary to use a finer fraction of NaF to activate the samples to a greater depth.

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