Increase of operational properties of tools and machine parts nitriding the powder mixture

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Abstract: The effect of diffusion layers and alloying elements on surface hardness, micro-coarseness, and wear resistance of hardened tool steels in a nitrogen-containing medium is Studied. The experiments showed that nitriding in the powder mixture strengthens the surface layers in 2–3.5 times without reducing the volume strength of the material in question, which contributes to the preservation of high structural strength of tools and machine parts. It was found that nitriding in the dispersed powder mixture provides increased wear resistance of 1.3–2.5 times of steel, which can significantly improve the reliability and durability of products. Mathematical models of wear resistance of the investigated steels after the proposed hardening technology of nitriding are obtained.

1. Introduction

The creation of high-quality products with high structural strength with economical use of materials contributes to the reliability and durability of products, which is an urgent task in engineering today.

Structural strength depends on the design features of the part (shape and size); mechanisms of various types of destruction of the part; the state of the material in the surface layer of the part; processes occurring in the surface layer of the part, which leads to failures when working [1].

The hardening of the surface layers provides long-term and reliable operation of the material in the operating conditions of the products, which is associated with a complex of strength properties that are in the greatest correlation with the service properties of this product [2-5]. Reliability and durability of tools and machine parts are determined by the structural strength of the materials from which they are made. The performance of many products-wear resistance, corrosion resistance and others – are determined by the properties of the surface. To obtain high structural strength characteristics of the surface layers, various methods of surface hardening are often used, which allow to increase the service life and reduce the cost of repair of worn products [6]. Given the need to improve the performance of tools and machine parts, is an important task of research aimed at further improvement and development of surface hardening technology products. This suggests that the subject of research on the directional regulation of the processes of phase and structure formation of hardened layers on steel products through the use of effective methods of impact on the surface layers is relevant.

The Strengthening of the surface layers on the principle of interaction with the surface is carried out by changing the chemical composition of the surface (chemical and thermal treatment), applying a new material to the surface (spraying, deposition, surfacing, application of enamels and paints), etc. [7]. Types and methods of coating of metals are diverse and are classified as diffusion [8], thermomechanical [9], chemical[10] , vacuum plasma [11], etc. The choice of a method of saturation is carried out in accordance with the type of production, the required thickness of the surface layers, the necessary performance properties of the product. At present, there is a wide variety of processes of chemical and thermal treatment associated with the saturation of the surface of metals with various elements [12-19]. Of all the chemical-thermal hardening processes, nitriding is the most versatile and suitable for tool steels. However, the existing methods of nitriding (gas, liquid, ion-plasma, etc.) are a fairly long process (up to 50-100 hours) or require expensive equipment [17]. In this regard, the development of new nitriding technologies that provide accelerated saturation of the metal surface with nitrogen while maintaining the strength of the base material is of great practical importance. At the same time, it is advisable to use new developments of chemical and thermal hardening without additional costs for expensive equipment. Therefore, there is reason to believe that the issue of using a new technology of nitriding in the powder mixture to speed up the process of saturation of the surface layers of steel, increasing the performance properties of tools and machine parts, necessitates research in this direction. The conducted research was aimed at obtaining high performance properties of tools and machine parts by nitriding in a powder mixture.

To achieve this goal, you need to solve the following tasks:

- to determine the impact of the developed nitriding technology on the degree of hardening of the surface layers and the volume strength of tools and machine parts;
- to study the effect of chemical-thermal hardening in a nitrogen-containing medium on the wear resistance of steels;
- to obtain mathematical models of wear resistance of steels after the proposed hardening nitriding technology.

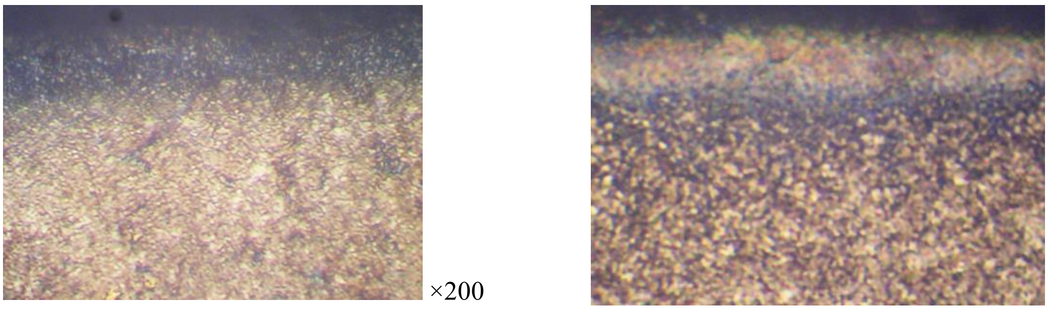
2. Materials and Methods

Materials for the study selected tool steels for different purposes, such as 3Cr3Mo3V, 5CrNiMo, 9CrSi and W6Mo5Cr4V2, this allowed to study in detail the structure of diffusion layers and the effect of alloying elements on wear resistance of hardened alloys during nitriding in the powder mixture.

The sample container was placed in a thermal furnace. The content of atomic nitrogen in the powder mixture, namely melamine (66.67 %) is 1.7 times higher than ammonia (up to 40 %), which allowed to speed up the process of saturation of the metal surface compared to traditional gas nitriding. Nitriding of steels was carried out at a temperature of 550 °C for 5 hours.

3. Results of research of operational properties of steel by nitriding in powder mixture

The microstructures of the diffusion layers of tool steels obtained after hardening in a nitrogen-containing medium are shown in Figure 1 and Figure 2.

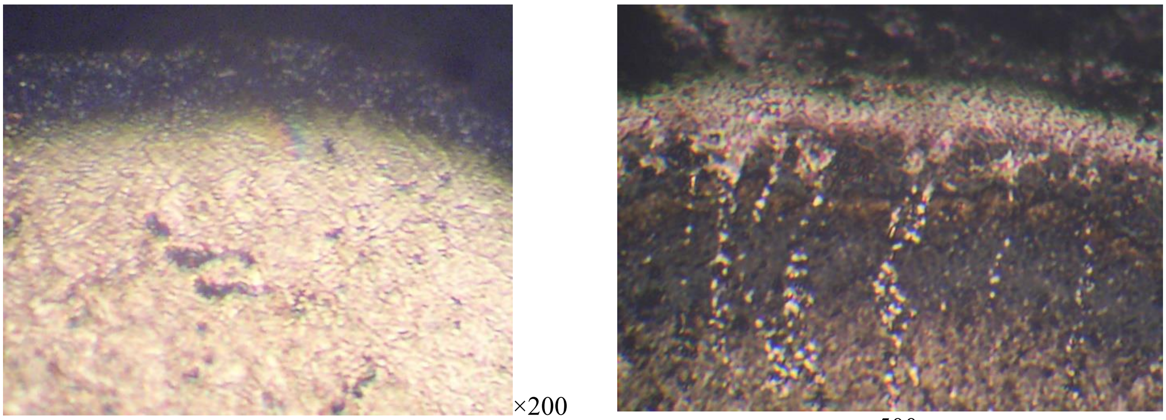


×200 ×450

(a) **(b)**

Figure 1. Microstructures of diffusion layers of tool die steels 5CrNiMo **(a)** and 3Cr3Mo3V **(b)** after nitriding

The investigated steels were subjected to qualitative phase analysis after nitriding, which revealed, as expected, the presence of nitrides, carbides and carbonitrides of iron and alloying elements in the investigated steels.



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(a) **(b)**

Figure 2. Microstructures of diffusion layers of tool steels 9CrSi **(a)** and W6Mo5Cr4V2 **(b)** after nitriding of drills

It should be especially noted that the analysis of the obtained diffractograms showed the formation of nitride phases of different stoichiometric composition in the surface layer (Fe_2N, Fe_4N). Thus, in high-speed steel after nitriding according to the proposed technology, iron nitrides were detected ε-Fe_2N, γ'-Fe_4N, nitrides of alloying elements Cr_2N, W_2N, Mo_2N, VN, carbides Fe_3C, WC, W_2C, MoC, Mo_2C, VC, V_2C, Cr_3C_2, Cr_7C_3, $Cr_{23}C_6$, oxides FeO, Fe_2O_3, Fe_3O_4, WO_3, WO_2, MoO_2, MoO_3, Mo_2O_3, CrO_3, Cr_2O_3, V_2O_3, V_2O_5 and a solid solution of nitrogen in α-iron.

For testing, smooth (surface roughness $R_a \leq 1{,}25$ µm) cylindrical specimens without corrosion and scale were used. Before the test, the samples were subjected to burnishing to achieve a complete fit of the samples to the skin under conditions identical to the test conditions. Wear of the tested samples was obtained under the same conditions, i.e. the samples passed the same friction path within the entire test series.

The essence of abrasive wear is the destruction of the metal with hard abrasive grains during plastic deformation and micro-cutting of rubbing surfaces. For tools and machine parts, abrasive wear is most often prevalent compared to other types of wear. Therefore, the work carried out tests on samples of this type of wear to assess and predict the resistance to abrasive wear of finished products.

Studies to determine the degree of resistance to abrasive wear were carried out on the machine for abrasion testing AP 40.613.20 R 43/82 (Germany). The degree of wear was studied by controlling the weight loss of the tested samples. with the set pressing force was carried out on the abrasive material at a constant speed and along a certain path.

It has been shown that the hardness of the surface layers after nitriding increased by 2–3,5 times depending on the steel grade. Thus, the surface hardness of tool steel 9CrSi increased in 2,5 times (up to 10.1 GPa), high speed steel – 2 times (12.5 GPa) and die steels 3Cr3Mo3V and 5CrNiMo – 2.5–3.5-fold (from 11.2 to 11.7 GPa) respectively. This is due to the influence of nitrides, carbides and carbonitrides of iron and alloying elements of the investigated steels formed in the surface layers.

Nitrided surface with high hardness, high wear resistance. Its greatest values are the continuous layers of ε-phase ($Fe_{2\text{-}3}N$) with a minimum nitrogen content and carbonitride phase type $Fe_{2\text{-}3}(N,C)$, characterized by high hardness and plasticity. Almost the same wear resistance is characterized by (ε+γ′)-phase and γ′-phase.

After nitriding, the wear resistance of high–speed steel W6Mo5Cr4V2 and die steel 3Cr3Mo3V in the first test cycle increases by 2.0-2.5 times, and then with the continuation of wear tests at 2–5 cycles, the wear resistance is slightly reduced and remains at a high level. Thus, the zone of internal nitriding in steels increases wear resistance by 1.7–2.0 times.

In steels 5CrNiMo and 9CrSi after chemical and thermal treatment wear resistance in the nitride zone increases by 1.5–1.7 times on the friction path of 40 m (the first cycle), and in the internal nitriding zone the increase in wear resistance occurs in 1.3–1.5 times on the friction path of 80–200 m (2–5 cycles), which is provided by a nitrided solid solution with dispersed Fe_4N nitrides (γ'-phase).

On the basis of the obtained equations, graphs of the dependence of wear resistance before and after nitriding are constructed (Figure 3).

The graphs show that after nitriding, the wear resistance of steels increases during the first cycle (40 m) of tests, and then remains almost at the same high level regardless of further cycles (2–5) of tests, i.e. does not depend on the friction path (from 80 to 200 m). This is due to the presence of nitrides and carbonitrides of iron and alloying elements in the surface diffusion layers of tool steels, which is confirmed by x-ray phase analysis.

4. Discussion of the research results

The obtained results of the study of phase and structure formation, micro-coarseness, surface hardness, wear resistance of the hardened layers, thickness of diffusion layers on tool steels 3Cr3Mo3V, 5CrNiMo, 9CrSi and W6Mo5Cr4V2after nitriding in the powder mixture indicate that the proposed method of surface hardening of alloy steels can significantly increase the hardness of the surface layers and in turn contributes to a significant increase in the service life of tools and machine parts.

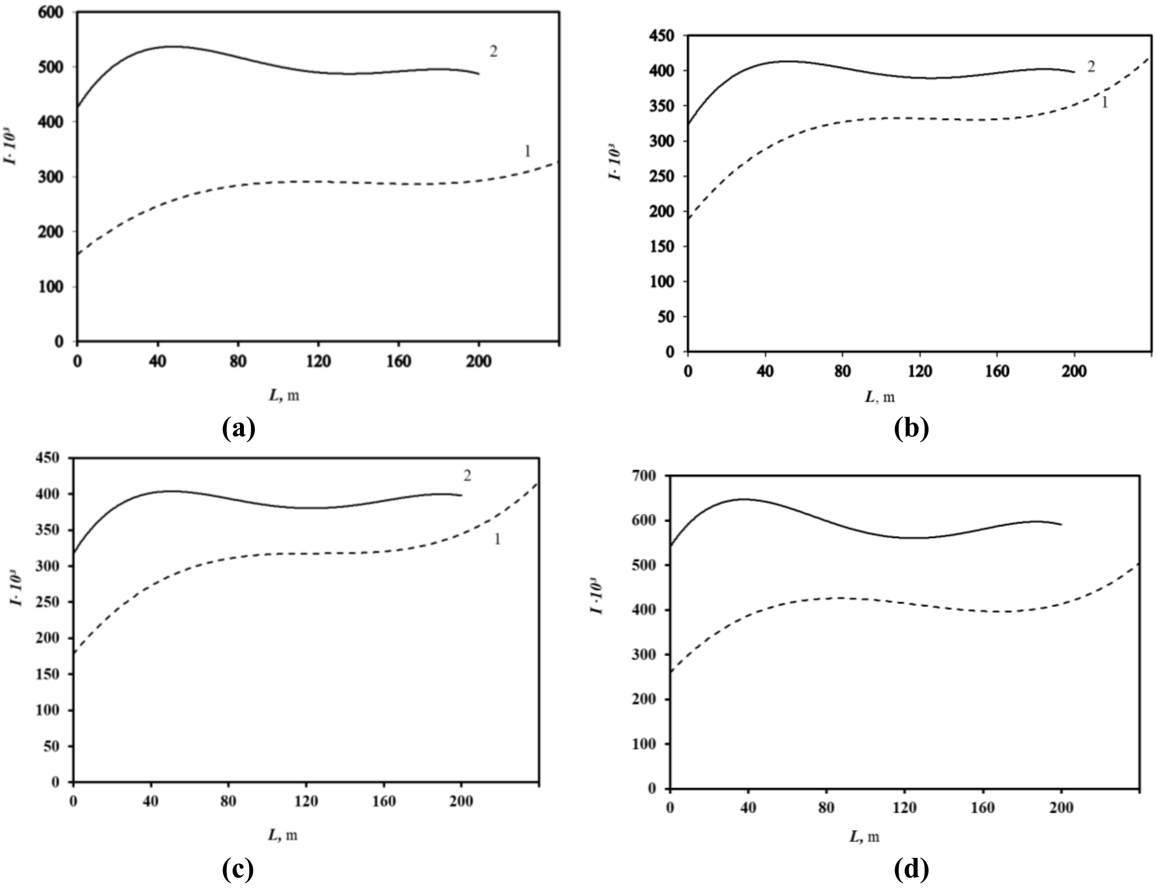
Indeed, after saturation with nitrogen at a temperature of 550 °C for 5 hours on the surface of alloyed tool steels formed a diffusion layer consisting of a nitride zone and a sublayer of α-solid solution. This, in particular, can be seen in Figure 1 and Figure 2 – microstructures of the strengthened layers confirm the presence of classical diffusion layers with clearly expressed nitride and transition zones. Such a change in microstructures leads to a change in the properties of steels, namely, the hardness of the surface layers after nitriding increased by 2–3.5 times (up to 10.1–12.5 GPA), and the depth of the hardened layer was 0.18–0.32 mm depending on the steel grade.

In this sense, of particular interest is the interpretation of the results of qualitative phase analysis after nitriding in the powder mixture which confirms the establishment of the presence of nitrides, carbides and carbonitrides of iron and alloying elements in the studied steels.

It should be especially noted that in contrast to traditional nitriding methods, the proposed method of diffusion saturation of the surface of steels using a nitrogen-containing powder mixture is favorably different and allows us to assert the following:

- processing speed compared to conventional nitriding increases 5–10 times due to the acceleration of diffusion processes and reduce the number of preparatory operations,
- the possibility of combining technological operations (leave with nitriding),
- no warping of tools and machine parts due to low nitriding temperatures (550 °C),
- reduction of materials and energy costs,
- the processes are non-toxic and environmentally friendly.

That is why the proposed method of improving the performance of tools and machine parts should be recognized as promising and possible for use in enterprises and in the laboratory.



1-after preliminary heat treatment, **2** - after nitriding

Figure 3. Graphs of wear resistance before and after nitriding of tool alloy steels 3Cr3Mo3V **(a)**, 5CrNiMo **(b)**, 9CrSi **(c)** and W6Mo5Cr4V2 **(d)**

5. Conclusions

Studies have shown that the developed technology of nitriding of tool steels allows to strengthen the surface layers in 2–3.5 times without reducing the volume strength of the material in question, which contributes to the preservation of high structural strength of tools and machine parts.

It is experimentally proved that the chemical-thermal hardening in a nitrogen-containing medium allows to increase the wear resistance of steels by 1.3–2.5 times, which in turn contributes to a significant increase in the durability of products.

Mathematical models of wear resistance of the investigated steels after the proposed hardening technology of nitriding are obtained.

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