Technological bases for increasing the durability of aviation parts by chemical heat treatment

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Abstract. The paper presents studies of the structure and properties of low-carbon alloy steels after carburizing. A comparison of four types of carburizing (batch carburization, conveyor carburization, fluidized bed carburization and ionic carburization) is made. The influence of technological modes of chemical-thermal treatment on the phase composition and amount of carbide phase in a carburized layer is considered. It is shown that the type of carburizing affects the operational properties of parts of aircraft mechanisms. The best results were shown by the details after ion vacuum carburizing. The increase in wear resistance and contact fatigue is associated with the formation of a high-quality surface layer having a higher hardness and a higher proportion of the carbide phase. Such properties cannot be obtained after conventional types of carburizing in a shaft or conveyor furnace. In this case, ionic carburizing and carburizing in a fluidized bed make it possible to halve the technological regime of carburizing in comparison with two other methods.

Introduction

For parts of aviation equipment operating under variable loads and intensive wear, chrome-nickel carburized steels of the C0.12CrNi3, C0.12Cr2Ni2WV, C0.2CrNi3, C0.2Cr2Ni4 and C0.2Cr3Ni2MoW types are used [1–3]. Despite the hardening processes used, the durability of these parts is insufficient. There are any methods of producing high-load parts, such as composite materials [4, 5] or ceramics [6]. Recently, methods of surface hardening by electro-mechanical processing [7–9] or plastic deformation [10] have been widely used.

The working surfaces of carburized teeth of high-loaded gears experience high contact stresses and sliding speeds. This is caused by a complex mechanism of high-speed wear. As a result, the matrix is first destroyed in the carburized layer, and then solid and brittle particles of carbides are chipped off.

To increase the resistance to contact destruction of gears, a strong surface layer is required, in which there is a developed carbide phase. The diffusion layer formed during gas carburization in the mine furnace does not provide such increased requirements. Higher layer properties can be obtained after carburization in a fluidized bed or by vacuum ion carburization. As is known, ion saturation processes provide the ability to control the phase and chemical composition of the layer. An additional important advantage is the reduction of the duration of chemical and heat treatment [11]. In [12, 13] it is shown that the equipment used for vacuum ion carburization allows you to quickly change the temperature of the process and its carburizing ability, and therefore adjust the effective thickness of the carburized layer.

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Therefore the authors work on optimizing the steel grade and their surface hardening modes to increase the durability of parts by increasing both contact fatigue strength and wear resistance.

**The purpose** of this work is to improve the technology of surface hardening of high-loaded gears made of high-nickel carburized steels.

**Materials and equipment of the experiment**

Authors are working to optimize the steel grade and its hardening modes to increase the durability of parts by increasing both contact fatigue strength and wear resistance. The study used [Table 1] steel C0.12CrNi3 (analogue in the USA — 3415 and Germany — 12NiCr) and C0.2CrNi2MoW (analogue in the USA — 4320 and Germany — 17CrNiMo).

| Content of elements, % | No | C    | Si  | Mn | Cr  | Ni  | W    | Mo | Cu |
|------------------------|----|------|-----|----|-----|-----|------|----|----|
| 1                      |    | 0.09–0.16 | 0.17–037 | 0.3–0,6 | 0.6–0.9 | 2.75–3.15 | –   | 0.4–0.6 | <0.3 |
| 2                      |    | 0.15–0.22 | 0.17–037 | 0.4–0.7 | 0.4–0.6 | 1.6–2.0 | 1.0–1.4 | 0.5–0.8 | <0.3 |

Two steels were subjected to carburization and subsequent heat treatment according to various technological modes. The quality of carburization is determined by the technological level of the process and the chemical composition of the steel. The chemical composition of steel for inherently coarse-grained steels, such as those of the studied, requires several high-temperature heats during the hardening process because the grain size in the steel affects not only the strength characteristics but also the technological properties of the steel. With the enlargement of the grain and an increase in different grain sizes, warping and the tendency to form cracks increases. Heterogeneous grain is accompanied by a decrease in impact strength after all types of heat treatment.

Therefore, to ensure the quality of parts, initial control of the structure of the steel coming for the production of parts is necessary. The microstructure of investigated steels is characterized by the presence of pronounced banding and non-metalllic (carbide) inclusions. To eliminate such a structure, pre-heat treatment is necessary, which can be used as diffusion annealing or normalization [14]. The use of diffusion annealing eliminates streakiness and heterogeneity, but leads to grain growth, which affects the properties after the final heat treatment, in addition, it is accompanied by obtaining a ferrite structure on the surface and, consequently, large allowances for machining, which is unacceptable for these steels. Therefore, for recrystallization it is better to use the normalization. After that the field of the size of the austenite grain is 10–12 points with an average conventional diameter of 9.9–4.9 μm. The final chemical heat treatment should ensure a rational carbon content in the surface layer and microhardness of the layer and of the core.

It should be borne in mind that the greater the difference in the carbon content of the surface and the core, the greater in the surface layer the compressive stresses, which inhibit the development of fatigue cracks. However, if the difference is too large, the stresses can be reduced due to the deformation of the core and this contributes to the appearance of cracks. Therefore it is necessary to observe the optimal amount of carbon in the surface layer. For steel C0.12CrNi3 carbon concentration should not exceed 0.75–0.80%, and for steel C0.2Cr3Ni2MoW — 0.90–1.0%. Both increasing and decreasing the concentration of carbon is reduced flexural strength, although the tensile strength and yield strength are growing.

The core strength of carburized parts must be within 1200–1500 MPa, while the bending strength is within 2100–2500 MPa. The core hardness of 34–42 HRC is considered acceptable. The core structure in parts that work for bending and torsion in the presence of shock loads should represent fine-needle martensite 2–3 points with the size of the largest length of the martensite needle 2–4 μm. The structure allows 10–15% excess ferrite, which slightly reduces the hardness of the core [15, 16].
Experimental results and discussion

Based on these considerations, authors analyzed the impact of various technological methods of carburization on the quality of carburized layers and the durability of parts. Carburization was carried out in four ways: 1) batch carburization (BC) in shaft mine furnace «MIMP-SSH-3»; 2) conveyor carburization (CC) in conveyor furnace «RG-805G» with a controlled supply of saturating gas; 3) fluidized bed carburization (FC) in chamber furnace «Holcroft»; 4) ionic carburization (IC) in «Seco Warwick» firms equipment.

Microstructure of carburized layer (Fig. 1), microhardness, depth of the carburized layer, hardness and core structure were studied. Carrying out the CC process of two steels eliminates the saturation of the surface with carbon, reduces the density of carbides, and increases the effective thickness of the layer (Fig. 1). Their distribution and diffusion redistribution of carbon increase the doping of the solid solution and the uniformity of the structure of the carbide zone: the difference in the size of the carbide particles decreases, and the density of their distribution is equalized.

As can be seen from the above data, after CC of steel C0.12CrNi3 at a depth of 0.2 mm, there is some decarburization of the surface with a decrease in its hardness \( H_{0.2} \) to 6000-6300 MPa, the carburization depth is 1.10–1.20 mm. The microstructure of the carburized layer is fine-needle martensite and 10-15% residual austenite in steel C0.12CrNi3 and 8-10% - in steel C0.2CrNi2MoW.

Along with this, a study of the hardness and wear resistance of parts was conducted (Fig. 2).

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The Fig. 2 shows the distribution of hardness after four ways carburization and heat treatment carried out after each method. As can be seen from the above data, the BC in shaft mine furnaces does not provide a satisfactory quality of the carburized layer. There is decarburization on the surface, in addition, when the depth of carburization is 1.8–2.0 mm, there is a broken carbide mesh in the surface layer. IC with followed heat treatment showed the best quality of the carburized layer (see Fig. 2). There is no decarburization on the surface, but the high hardness at a depth of up to 0.25 mm is due to the presence of scattered carbides in the surface layer. This hardness and structure is optimal for aviation equipment parts. Carburization CC and FC have satisfactory results. To reduce the time of carburization and increase the productivity of carburization equipment, we have studied carburization in the fluidized bed. When the part was carburized in a fluidized bed, a high hardness is obtained at a depth of 0.4 mm. The structure of the carburized layer has a layer with a carbide mesh. The structure of the core — large needle-like martensite.

Studies have shown that different carbon concentrations in the carburized layer of steel C0.2CrNi2MoW caused different effects on surface quality characteristics: surface hardness, wear resistance and contact fatigue strength (Tab. 2). The differences are due to the different proportion
of the formed carbide phase [17, 18]. The volume fraction of the latter affects the degree of localization of microplastic deformation and the level of development of local stress relaxation processes in the martensitic matrix [19]. It is determined that the IC method has higher indicators (see Tab. 2) [20].

![Image](image.jpg)

**Fig. 2.** Hardness $HRC$ (a) and wear rate $\nu_w$ (b) change over the thickness of the diffusion layer $l$ of steel C0.12CrNi3 after chemical heat treatment:
1 — BC, 2 — CC, 3 — FC or 4 — IC.

**Table 2.** The properties of steel C0.2CrNi2MoW after chemical heat treatment (BC, CC, FC or IC)

| No | Chemical heat treatment | Volumetric share carbides in the layer 0–20 $\mu m$, % | Surface hardness, $HRC$ | Wear rate $\nu_w$, $mm^3/min$ | Contact fatigue strength, $N_50\cdot10^6$ cycles |
|----|-------------------------|---------------------------------|------------------|------------------|---------------------------------|
| 1  | BC, $t=950^\circ C, \tau=5 h$ | 12                              | 59-61            | 25               | 4                               |
| 2  | CC, $t=950^\circ C, \tau=5 h$ | 15                              | 60-62            | 16               | 12                              |
| 3  | FC, $t=950^\circ C, \tau=2.5 h$ | 20                              | 62-63            | 18               | 24                              |
| 4  | IC, $t=950^\circ C, \tau=2.5 h$ | 25                              | 63-64            | 11               | 36                              |

**Conclusions**

Thus, the research shows that the optimal process for conducting chemical heat treatment is the process of ionic carburization treatment in chamber furnaces with a controlled carbon potential.

The carbon distribution should correspond to the values shown in Fig. 2 (curve 4) and the microstructure of the surface and core correspond to the structures: in the carburized layer fine-needle martensite 2–3 points, residual austenite 10–15%, volumetric share carbides in the layer 0–20 $\mu m$ in the amount of 20–25%.

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