Local ion nitriding process with hollow cathode effect computer modelling

K N Ramazanov, Yu G Khusainov, I V Zolotov

Department of Machine Building, Ufa State Aviation Technical University,
12 K.Marx Street, Ufa, Russian Federation

E-mail: ramazanovkn@gmail.com

Abstract. Modelling of glow discharge plasma with hollow cathode effect (HCE) was carried out. The computer model that allows predicting the temperature distribution during local ion nitriding with HCE and depth of the diffusion zone after the treatment was developed. The influence on the HCE on the temperature distribution for the gear was studied.

1. Introduction

It was proved in [1] that occurrence of HCE during ion nitriding raises the efficiency of the process (diffusion rate) and the ionization rate near the treated surface due to raising of generation of charged particles by oscillating electrons. The usage of a HCE is also a promising approach for local hardening treatment. It was experimentally proved [2] that HCE is created with special screens has following features: possibility of local surface treatment; high saturation speed; creation of diffusion layers with given phase composition and structure; high class of surface finish; possibility of ion nitriding and carbonitriding of surface-passivating materials without additional depassivating treatment; significant reduction of total process time since times of heating and charge cooling are reduced and intermediary technological operations for surface activation are removed; high cost effectiveness of the process since electric energy utilization ratio is increased and saturating gases consumption is reduced, which leads to an ecologically friendly process.

HCE has a complicated dependence on various energies, technological and geometrical parameters, thus systemic experimental diagnosis is difficult. The computer simulation hence becomes an important method to reveal the physics of treatment process.

Nitriding process with application of HCE becomes more complicated. In case of local ion nitriding with HCE the heating rate of the surface covered by technological mesh screen is greater than heating rate of remaining surface of the part. Therefore, there is irregularly temperature distribution during the nitriding process.

It is known that the temperature is the critical factor affecting the nitrogen diffusion into steel and diffusion zone formation of the nitrided case. Nowadays, modeling heating and diffusion processes during nitriding is an important task. Investigating and understanding processes occurring in the near-surface material of the part would give the possibility of using optimal process parameters and increasing nitriding efficiency.

In this paper we present our results of glow discharge plasma with HCE and thermal and diffusion processes during ion nitriding with HCE modelling.

2. Methods of study

Calculations were performed with a help of differential equations solver software. Theoretically model of ion nitriding process is based on heat equation and Fick's equation [7].

At the initial time the concentration of nitrogen in steel is equal to zero, the temperature is assumed to be 298 K:

$$c_0 = 0; T_0 = 293 K. \tag{1}$$

The third type boundary condition is used in the model of local ion nitriding process [8]:

$$(-D\nabla c)n = k_m(c_b - c), \tag{2}$$

where D is the diffusion coefficient, c is the concentration of nitrogen, n is boundary's normal vector, k_m is the mass transport coefficient, c_b is the bulk concentration of nitrogen.

$$n(-h\nabla T) = q_0, \tag{3}$$

where h is the heat transfer coefficient, T denotes to temperature, q_0 is the thermal flux through the boundary:

$$q_0 = j_i U, \tag{4}$$

where j_i is the ion current density, U – discharge voltage.

Thermal radiation to environment:

$$-n(-h\nabla T) = \varepsilon\sigma(T_{amb}^4 - T^4), \tag{5}$$

where T_{amb} is environment temperature, ε is emissivity coefficient, σ is the Stefan-Boltzmann's constant.

Current density during ion nitriding is about 1-3 mA/cm^2. HCE leads to increasing of current density up to 3 times comparing to conventional glow discharge and can reach 10 mA/cm^2 [5].

3. Results and discussing

HCE also affects ion concentration near cathode surface. We used results of plasma simulation to estimate this parameter. In Figure 1 showed calculated distribution of ion concentration in cathode 5 mm thickness cavity compared with experimental curve obtained by probe measurements.
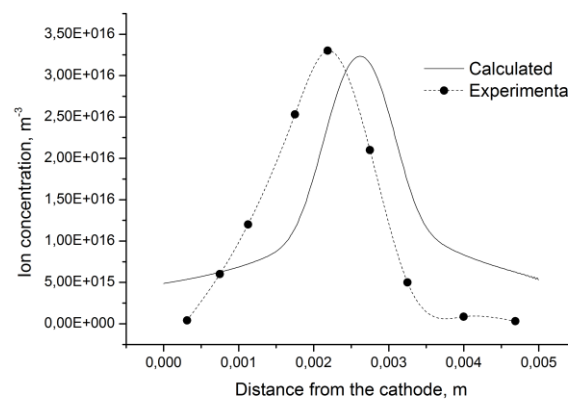

Figure 1. Ion distribution in cathode cavity.

Both curves have a similar shape and order, so obtained simulation data is in good agreement with experimental results. The distribution reaches maximum of about 3.5×10^{16} m^{-3}, which 1.5-2 times grater comparing with conventional glow discharge. It was proved that increasing of near concentration near treated surface leads to accelerating saturation process.

The temperature distribution was obtained as the result of model calculation. Temperature of the gear surface after 8 h of local ion nitriding with HCE is presented at Figure 2. Teethes temperature is about 550°C.
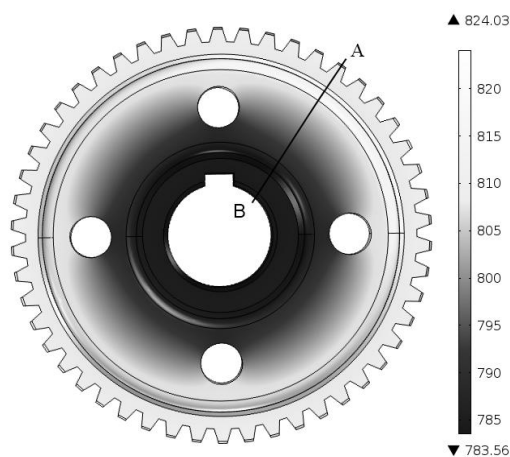

Figure 2. Calculated temperature distribution of the gear surface during nitriding process.

Calculations for gear with diameter of 200 mm show the maximum of temperature difference of 35° C (between area affected by HCE and uncovered area). Temperature distribution depends on size and shape of the part to be treated.
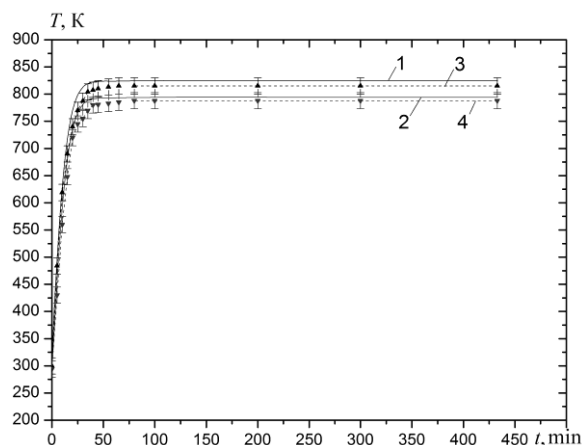

Figure 3. Temperature curves of A and B points of gear surface. 1 – calculated curve, point A, 2 – calculated curve, point B, 3 – experimental curve, point A, 4 – experimental curve, point B.

Figure 3 shows heating temperature curves of two points of part surface (A and B, figure 2), obtained by modelling and experimental measurements. Analysis of this curves shows that after reaching the maximum value of 550°C, temperature remains constant through all the process. It can be linked to a balance between incoming heat flux and thermal radiation. Time of reaching the process temperature is about 40 min (heating rate is 0.2°C per sec).

Calculated and experimental temperature curves (point A) of part cooling stage of the nitriding process are presented at figure 4.
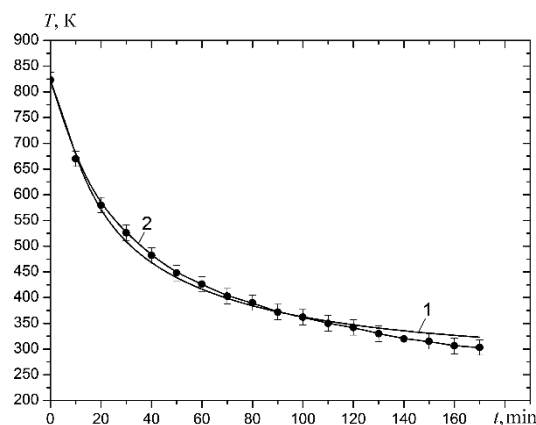

Figure 4. Temperature curves at cooling stage, point A. 1 – calculated curve, 2 – experimental curve.

Presented at Figure 4 curves has a practical application and allow to set the time of load cooling after nitriding with HCE of parts with different dimensions and shapes. As we can see, part cools to the temperature of 250°C (523 K) during about 30 min.

Distribution of nitrogen concentration in surface layer of material was obtained to estimate hardened case depth (figure 5). Modelling shows that nitriding with HCE during 8 hours leads to formation of 200 μm hardened diffusion layer.
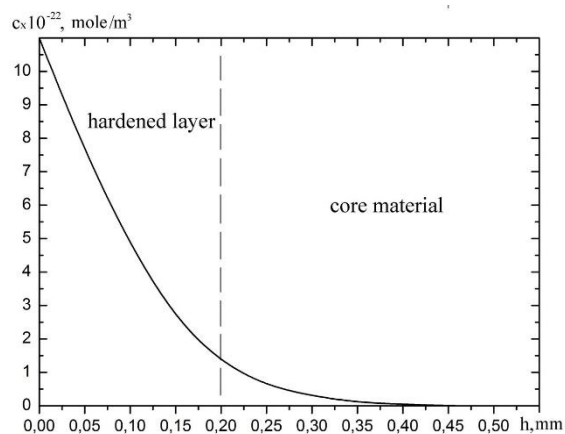

Figure 5. Calculated distribution of nitrogen concentration through the diffusion zone of nitrided case, T=550°C, t=8 h.

4. Conclusions

Increased ion concentration forms near treated surface in ion nitriding with HCE process. It leads to intensification of diffusion saturation process.

The computer model that allows predicting the temperature distribution in gear during local ion nitriding with hollow cathode effect (HCE) and depth of the diffusion zone after the treatment was developed.

The gear with diameter of 200 mm heats up to process temperature 550°C during about 40 min, after that the surface temperature remains constant to the end of the process. It is linked to reaching of balance between heat including and thermal radiation to environment. Maximum of temperature difference on gear surface is 35°C because of uneven heating rate of different surface areas. .

It is established that ion nitriding with HCE is an effective method of surface hardening of steels. Diffusion layer thickness of nitrided with HCE steels is about 0.2 mm.

References

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