

Stability of the Process of Restoring Parts and Improving the Quality of Processing

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Abstract: The analysis of ways to increase the durability of worn parts after restoration by surfacing methods is carried out. The technology of gas-baric nitriding of such parts in containers is proposed, which provides compressive residual stresses on the surface and increases hardness. The technology is recommended for small and medium-sized businesses. The simulation of the processing allows not only to obtain preliminary results, but also to control the processing itself by including technological parameters in the calculation. The application of the similarity principle creates conditions for using the results of work for other nitriding processes.

INTRODUCTION


An urgent problem at present is the issue of sustainable development of the technology of restoring machine parts by various methods, as well as the issue of the quality of restored equipment. One of the directions of restoration is the use of welding technologies (surfacing, hard facing), which allow you to restore the dimensions of worn surfaces and give the necessary properties to the built-up layers.


At the same time, these processes are high-temperature, which leads to deterioration of the properties of the base layers located under the built-up metal. In addition, the built-up layers contain gas and slag inclusions, which are stress concentrators, and in some cases hot and cold cracks. These factors are compounded by the presence of tensile residual stresses in the built-up metal. This condition of the restored parts leads to their reduced durability during operation by 40-50% compared to newly manufactured parts. Thus, in many cases, repair costs by restoring parts with welding technologies are not very effective.


Increasing the performance characteristics of such parts is achieved by methods that provide compressive residual stresses and higher mechanical characteristics on the restored surface of the parts. Such methods include:


- quenching and tempering, which also partially align the chemical composition of the built-up layer and the substrate, but are an additional high-temperature treatment and require appropriate equipment and additional financial and time costs;
- surface plastic deformation (cold work);
- thermochemical treatment (processes of nitro cementation, cementation, nitriding, etc.).

In our opinion, gas nitriding is the most acceptable way to harden the parts recovered by surfacing. This process does not cause noticeable deformations and warping of the machined parts, does not require subsequent heat treatment to form the final properties, ensures the removal of welding residual stresses in the entire part, ensures the formation of compressive stresses on the treated surface (up to 600 MPa) and increases hardness and wear resistance regardless of the chemical composition of the built-up layer. Moreover, obtaining a nitrided layer on the entire

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surface of the part only enhances the effect of the restoration and hardening process.

It should be noted that repair production usually refers to small-scale and single. Therefore, it is necessary to develop acceptable technologies that are easy to implement, do not involve the use of complex specialized equipment that meet the requirements of energy conservation and ecology.

Currently existing nitriding technologies are more focused on large-scale and serial production. They are well-developed, highly efficient equipment has been created and reliable control systems exist. However, even at large enterprises that are not equipped with nitriding equipment, there is often a need to harden single or small series of parts and tools. In small and medium-sized enterprises, such a need always exists. That is, for the needs of small-scale and single production of repair enterprises, small and medium-sized businesses, there are no relatively simple hardening technologies and equipment for their implementation.

2 DEVELOPMENT OF THE TECHNOLOGICAL PROCESS OF GAS-BARIC NITRIDING

In our opinion, the processes carried out in closed containers are the most acceptable for small-scale and single production. Such processes are carried out without the use of ammonia either in powdered solid media or in the gas atmosphere of the container when the entire volume is divided into a gas preparation and saturating space. They are referred to as gas-baric nitriding, in which the saturating medium is spontaneously formed as a result of the interaction of components located inside a closed container or retort. During the processing, a minimum exchange with the environment and a minimum output of harmful gases is ensured. At the end of the processing, all harmful components pass into neutral forms when the container or retort is cooled. The heating of containers with parts is carried out in any chamber, shaft gas or electric furnaces, or in contact heating or frequency heating units.

To carry out the process of gas nitriding in closed containers, we have developed a technology in which a gas saturating medium is formed at saturation temperature due to dissociation of the salt component inside the container. To prevent the escape of the gas medium from the container and provide it with the necessary saturating capacity, a fusible shutter is

used. The basis of the fusible gate is quartz sand (SiO_2) and boric anhydride (B_2O_3).

Samples of 40X (GOST 2590-88) or 5140 AISI steel were subjected to nitriding, quenched from a temperature of 840 °C and high tempering. The thickness of the layer was determined by the distribution of hardness, which gradually decreased as it moved away from the surface into the depth of the part. The total thickness of the layer was taken as the distance from the surface to the place of alignment of the hardness of the layer and the hardness of the core of the samples. After saturation with nitrogen at 510 °C for 2 hours, a layer of α – solid solution, 0.35 mm thick, was obtained on this steel. At the same time, the nitride layer was practically absent. The level of residual compressive stresses was 600 MPa.

A comparison of the growth rate of the diffusion part of the nitrated layer in a standard gas process using ammonia showed that a layer equal to 0.3-0.35 mm is formed on medium-carbon alloy steel at 510 °C for 15 hours (Lahtin, Arzamasov, 1985).

The maximum hardness on the surface is provided when the nitriding temperature decreases. In particular, at a temperature of 510 °C, it was 770 kgf/mm², and at 570 °C – 575 kgf/mm². This result is completely consistent with the results of many studies on the nitriding process.

The increase in hardness on the surface is most affected by the amount of the salt component and the temperature of the pre-tempering. In the first case, due to an increase in the nitrogen potential of the gas medium, in the second – due to a greater tendency of the layer to form dispersed inclusions of nitrides with their coherent bond with a solid solution.

Thus, the developed gas-baric nitriding technology ensures the production of high-quality nitrated layers at a rate exceeding the growth rate of layers during gas nitriding in an ammonia medium. Its main advantage is the short processing time to obtain technologically acceptable nitrated layers based on α – solid solution. The technology has high environmental safety and is recommended for use in the processing of restored and new parts and tools of single and small-scale production of small and medium-sized businesses. At the same time, the durability of the restored and nitrated parts approaches the durability of the newly manufactured parts. In general, this technology ensures the stability and efficiency of repair production.

3 MODELING OF THE PROCESSING

Modeling of the gas-baric nitriding process allows you to study the process more deeply and obtain predictive processing results, which make it possible to calculate the service life of restored and nitrided parts.

Analytical methods of modeling diffusion processes in nitriding based on atomic (microscopic) and thermodynamic (phenomenological) diffusion theories are most often used (Lahtin, = Arzamasov, = 1985; Lahtin, Kogan, SHpis, Bremer, 1991; Mittemeijer, Somers, 1997; Popov, 1962; Lifang, Mufu, 1990; Lifang, Mufu, 1989; Michel, Gantois, 1993; Ratajski, 2003). The purpose of these methods is to derive differential equations for solving Fick's equations describing diffusion phenomena, determining nitrogen diffusion coefficients, establishing patterns of formation of phase composition, etc. At the same time, when switching to predictive calculations for controlling technological processes of nitriding, nitriding of alloy steels and the formation of properties, certain difficulties arise associated with the use of complex mathematical calculations and with a large calculation error.

3.1 Application of The Similarity Principle to Nitriding Processes

The theory of similarity in the modeling of technological processes allows, after the correct formulation of the problem and the compilation of a system of equations based on physical phenomena, to formulate the conditions for the uniqueness of the solution.

Mathematical and physico-chemical analysis of the processes occurring in the saturating space, on the treated surface and in the treated material during nitriding made it possible to choose the kinetic coefficient (D , in a number of works it is called the effective diffusion coefficient) as a dimensionless complex characteristic in the formula of the parabolic regularity of the growth of the phases of the layer:

$$y = D\sqrt{\tau}, \quad (1)$$

where y is the thickness of the layer, τ is the duration of the process, D is the kinetic coefficient.

The kinetic coefficient, in our opinion, is an integral complex characteristic reflecting the influence of the totality of individual factors during

nitriding and combining the stages of processes in the saturating medium, on the treated surface and the formation of phases of the nitrided layer in a solid. The kinetic coefficient integrally and spontaneously takes into account the following characteristics (Krukovich, Fedotova, 2019):

- diffusion coefficient and properties of interacting elements (atomic radii, crystal lattices, type of interaction, etc.);

- the state of the base metal and its phase composition at the processing temperature;

- phenomena occurring on the metal surface in the saturating medium under consideration and the degree of their stability under the conditions of the process;

- changes in the reactivity of the treated surface during saturation.

The kinetic coefficients of phase growth on technical iron and low-carbon steels for the gas-baric process during processing for 2 hours were $D_{\alpha}^{500} = 285$; $D_{\varepsilon+\gamma'}^{500} = 3,0$. These values are called the **reduced kinetic coefficients**.

The temperature and time dependence of these coefficients was determined, which makes it possible to include these patterns in the process model. In accordance with the similarity principle, an "internal" scale is selected, at which the numerical value of the coefficient is expressed as a percentage relative to its initial reduced value. That is, the graphs are plotted in the coordinates of the influence factor – kinetic coefficient (in %). The time dependence is described by the equation:

$$D_{\alpha}^{\tau} = -4,8188\tau + 102,75; \quad R^2 = 0,9898 \quad (2)$$

and the temperature dependence is determined by formulas:

$$D_{\alpha}^T = K_{\alpha} \cdot D_{\alpha}^{500};$$

$$K_{\alpha} = 0,2281e^{0,0029 \cdot t} \quad (3)$$

$$D_{\varepsilon+\gamma'}^T = K_{\varepsilon+\gamma'} \cdot D_{\varepsilon+\gamma'}^{500};$$

$$K_{\varepsilon+\gamma'} = 0,0059e^{0,0102 \cdot t} \quad (4)$$

where τ is the duration of the process, h;

t is the temperature of the process, °C.

The influence of alloying elements in steels on the thickness and hardness of the nitrided layers is carried out in accordance with the calculation programs (Fedotova, Krukovich, 2021; Fedotova, Krukovich, Lebedev, 2022).

To calculate the thickness of the α -layer, a regression equation was obtained that relates the main technological factors of variation:

$$y=0.565+0.15X_1+0.9X_2-1.05X_3-0.1X_4, \quad (5)$$

where x_1 is the processing time, h (interval 2 – 6 h);

x_2 – processing temperature, °C (interval 510 – 570 °C);

x_3 – the amount of salt component, g (12 – 60 g);

x_4 – pre-tempering temperature, °C (interval 530 - 590 °C).

To determine the specific thickness of the nitrided layer under the specified experimental conditions, the values of the factors in this equation should be substituted on a coded scale, which are calculated from the corresponding values on a natural scale for any experimental conditions according to the formula:

$$x_i = \frac{X_i - X_{i0}}{\Delta X_i}, \quad (6)$$

where X_{i0} is the natural value of the factor at the main level;

ΔX_i is the natural value of the variation step;

X_i is the natural set value of the variation factor;

x_i is the code value of the variation factor.

The regression equation (5) is obtained as a result of statistical processing of the results during mathematical planning of experiments using fractional and full factor experiments. All the coefficients of the equation turned out to be statistically significant.

The linear regression equation for calculating hardness at a distance of 25 microns from the surface (at the beginning of the α – solid solution zone), depending on the variation factors, in the case under consideration, has the following form

$$HV = 654.25 + 3.5x_1 - 52.75x_2 + 41.75x_3 + 30x_4 \quad (7)$$

The hardness value at a distance from the surface (l mm) for the considered process conditions can be calculated by the formula:

$$HV = -4385.1 \cdot l^3 + 6461.5 \cdot l^2 - 2974.8 \cdot l + 766.23 \quad (8)$$

4 CONCLUSION

The presented work shows the wide possibilities of increasing the stability of the repair production process when restoring parts with welding technologies. For these purposes, it is proposed to use gas-baric nitriding technology, which has high energy saving and environmental friendliness. The parts recovered by surfacing after nitriding have a service life approaching the durability of newly manufactured parts.

The given data on the modeling of nitriding technological processes make it possible to create a general model and effectively manage the processing technology itself and its results. The application of the similarity principle creates conditions for using the results of work for other nitriding processes. The error of the calculated values does not exceed 10% compared to experimental data.

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