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The field of rational application of the methods of hardening treatment

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Abstract. The paper presents data on the research of influence of various methods of hardening on physico- mechanical characteristics of surface layer and performance indicators of details from heatproof, difficult-to-cut steels and titanium alloys working in extreme conditions.

One of the main problems of modern engineering is the lack of durability of parts, especially working under alternating loads [1, 2, 3]. Therefore, an additional technological impact is required, which will increase their operational performance.
Various methods of hardening treatment have been developed, including surface plastic deformation [4, 5] (ball rolling, ultrasonic hardening (UH) [6], diamond burnishing, vibration rolling, shot blasting, etc.). and thermoplastic hardening (TH) [7, 8].

However, the scope of the various methods has not been definitively determined. Obviously, in each case, for a particular part, you need to choose a specific method of hardening technology. For example, the use of ultrasonic vibrations for hardening treatment is an effective way to improve the performance of machine parts. When ultrasonic vibrations are introduced into the processing zone, the resistance of plastic deformation and the friction force on the contact surfaces are reduced, which significantly reduces the static deformation forces.

Thermoplastic hardening (TPH) is used in the manufacture of critical parts operating at elevated temperatures and alternating loads, such as blades and disks of gas turbine engines (GTE). Due to the formation of favorable compressive residual stresses in the surface layer with a large depth of their occurrence with minimal plastic deformation increases the reliability and durability of hardened parts. Detailed process of TPH is described in [7]. Schematically TPH technology is presented in Fig. 1.

To implement the TPH technology, installations and methods of hardening have been developed, which are protected by patents [8-13]. Various aspects of TPH technology are described in [14-17].

The calculation method for determining residual stresses is described in detail in [18]. It is based on the technological parameters of the TPH process: heating temperature, holding time at this temperature and coolant pressure.

The essence of the TPH method is to heat the parts to a temperature below the beginning of structural-phase transformations and powerful spray cooling with water at a pressure of 10-20 atm. This pressure is necessary to ensure that the steam layer formed on the heating surface of the hardened part does not interfere with the heat transfer from the

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hardened layer. At the same time, useful compressive residual stresses are formed in the surface layer with a minimum of deformations and a absence of deformation hardening. In this case, the TPU process does not affect the roughness of the treated surface of the hardened part.

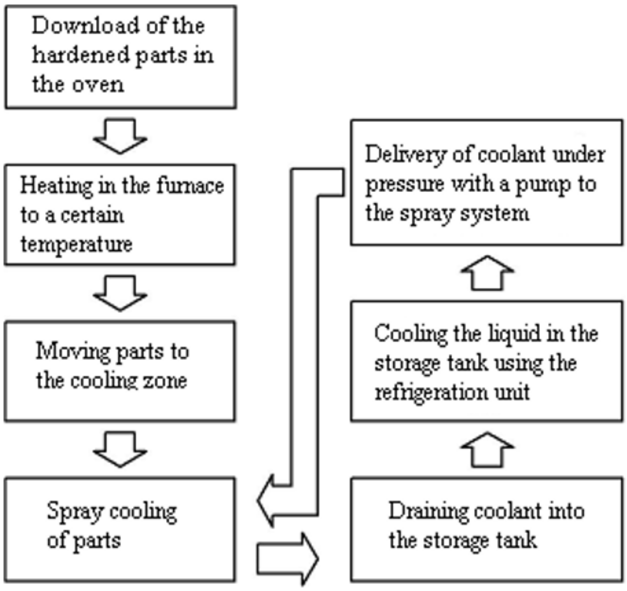


Fig. 1. The block diagram of technological process of TPH

Variants of the TPH method and the specific constructions of the units for implementing the method of hardening depend on the design, material and operating conditions of the hardened part [8-13, 19].

The TPU method is effective for a limited class of materials. This is primarily the nickel-based alloys used for critical parts working at elevated temperatures and alternating loads. In particular, these are turbine blades of gas turbine engines (GTE).

A smaller effect is achieved on titanium and structural alloys from which discs of turbines, blades and discs of GTE compressors are made.

It is very effective to use TPH for gas turbine blades with heat-shielding coatings operating under extreme conditions. In this case, the TPH process is used twice - before and after applying the heat-shielding coating. Before coating in the surface layer of the hardened part, a powerful epure of the compressive residual stresses is formed. During the deposition of heat-shielding coatings in the surface layer of the hardened part, relaxation and redistribution of residual stresses in the newly formed surface layer occurs. As a rule, heat-shielding coatings are very fragile. Therefore, the generated compressive residual stresses for brittle coatings are very useful.

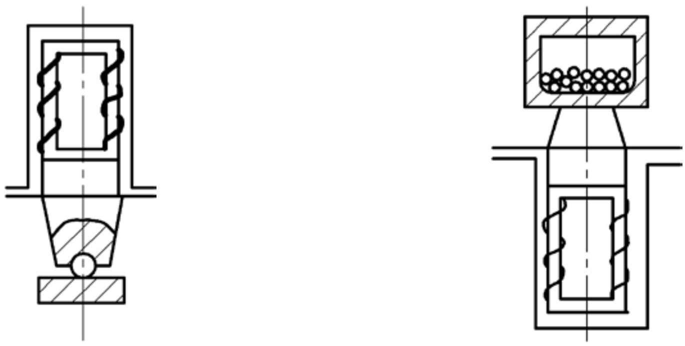
Repeated TPH after application of coatings enhances the positive effect of the formation of compressive residual stresses in the surface layer.

The peculiarity of the TPH method is that the shape and dimensions of the hardened part, including the very complicated part, is practically irrelevant.

Another important factor is that the TPU method can strengthen the internal surfaces of parts. For example, cooling blades with heat-shielding coatings operating at temperatures of about 10 000°C and maximum alternating loads, the first signs of the appearance of microcracks are detected in the holes at the boundaries of the base material and coating. The TPH method makes it possible at the same time to strengthen both the inner and outer coated surfaces of the blade as well as the transition zones.

As is known, the performance characteristics of the parts are determined by the physico-mechanical parameters of the surface layer [6, 20]. Therefore, it seems expedient to determine them for heatproof and titanium alloys after ultrasonic and thermoplastic hardening.

There are various ways of transferring ultrasonic vibrations to the treatment zone. So in Fig. 2a is a diagram of the UH. The deforming element (ball) is located freely in the face cavity of the trafo of the oscillating system, which is pressed against the workpiece with a certain static force. Since there is no rigid kinematic connection between the tool and the workpiece, the productivity of the process is increased [21]. Figure 2b shows a scheme for hardening details of a complex shape with free balls in the container, which is part of the ultrasonic oscillatory system.



a b

Fig. 2. Technological schemes of ultrasonic hardening: a- ultrasonic hardening by a ball, b- ultrasonic hardening by free balls

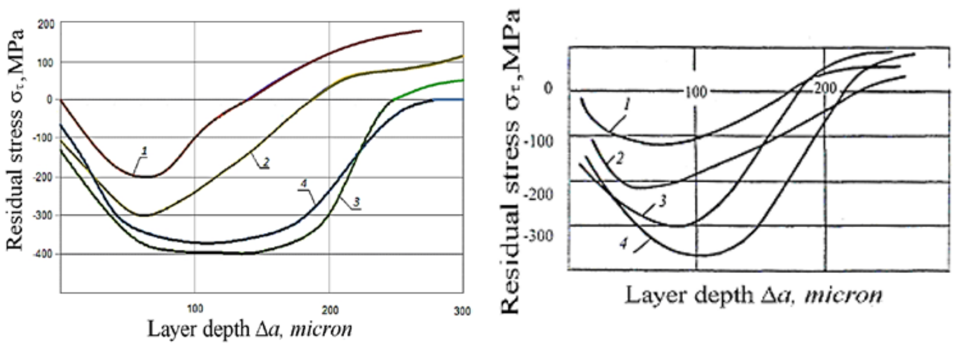
The main parameters of ultrasonic hardening are static force, the speed of rotation of the part, advance, amplitude and frequency of oscillations, the diameter of the ball. Heatproof, difficult-to-cut steels and titanium alloys characterized by high specific strength and heat resistance at high temperatures (up to 700° C), corrosion resistance, low thermal conductivity, etc., were hardened. The studies were carried out on the materials of EI 893, EI 437B, VT 9, VT 22, etc.

An increase in the surface hardness by 10-15% was found with the static force increasing to Ps = 150-200 N, similar results are observed with an increase in the rotation speed of the component V. As the amplitude of the oscillations increases from 5 to 15 μm, the hardness is maximized. The value of the advance determines the rate of application of the deforming force at each point of the machined surface. The highest values of hardness take place at feedings of S=0.07-0.09 mm /rev. At S> 0.01 mm /rev the hardness decreases, which is associated with a decrease in the rate of the application of the load. The dependence of microhardness on Ps is similar to the change in surface hardness. Thus, the maximum values of strain hardening of titanium alloys are observed at Ps = 150-200 N and V=30m/ min, and the depth of its propagation, depending on the material, is 0.25-0.4 mm with the highest degree of hardening 18 - 20%. The maximum is at a distance of 0.1-0.15 mm from the surface. At the same time, the strain rate ε_i increases to 0.12. This is due to the high rate of deformation in UH.

Studies have shown that the static force Ps influences the roughness most of all with ultrasonic hardening, with increasing the contact area of the tool with the workpiece surface and the depth of penetration. The maximum decrease in the height of the microroughness occurs at Ps = 150-200 N, further increase in the force leads to a partial destruction of the surface layer and an increase in the microroughness.

With ultrasonic hardening of the titanium alloy VT9 with a change in the static force Ps from 50H to 250N, the residual stress values increase from 200 MPa to 400 MPa (Fig. 3a). The UH free balls generates in the surface layer samples from the EI 437B alloy compressing residual stresses σ_τ. As can be seen in Fig. 3b, the magnitude of the residual stresses is influenced by various factors. As the amplitude of the oscillations increases from 5 to 25 μm, σ_τ increases from 110 to 360 MPa with a deposition depth of up to 230 μm.

Increase the treatment time by free balls up to 150s also leads to an increase in σ_τ. Moreover, the largest values of residual stresses are at some distance from the surface, which correlates with the results of the investigation of strain hardening.



a b

Fig. 3. Residual stresses after UH

a- material VT 9
Hardening Modes: f=20 kHz, V=30 m/min, ξ=15 μm, S=0,1 mm /rev
1.P_s =50N, 2. P_s =100N, 3. P_s =200N, 4. P_s =250N

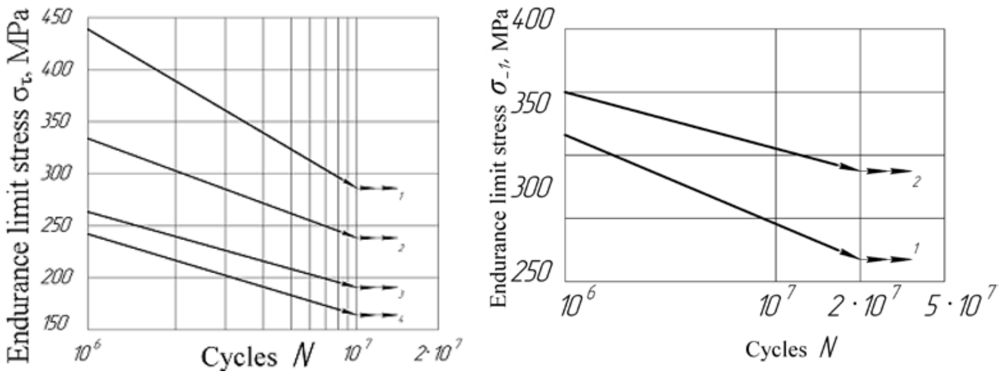
b- material EI 437B
Hardening Modes: f=20 kHz, d=5mm
1.ξ=5 μm, 2. ξ=10 μm, 3. ξ=15 μm, 4. ξ=25 μm

The performance characteristics of machine parts, including heatproof and titanium alloys, are greatly influenced by such physico- mechanical parameters as residual stresses, surface roughness and strain hardening. The results of determining the endurance limit after grinding and ultrasonic hardening by free balls showed that the relatively low values of the endurance limit after grinding can be explained by the presence of tensile residual stresses in the surface layer. With UH, residual compressive stresses up to 400 MPa are formed in the surface layer, while the degree of strain hardening reaches 18-20%. Depending on the modes of ultrasonic hardening, the fatigue strength of heatproof and titanium alloys increases to 450 MPa. At the same time, the endurance limit increases to 48%.

Fig. 4 presents the results of the influence of various methods of final processing of the turbine blades from the EI 893 (Fig. 4a) and EI 437B(Fig. 4b) alloys on the endurance limit.

The TPH technology allows:

• Increase the endurance of the blades in comparison with the traditional hardening methods by 30 ... 40%;
• Increase the life of the GTE by 30 ... 40%;
• Increase the overhaul cycle of GTE in 1.5 ... 2 times;
• To form a favorable stress state with the magnitude of the compressive residual stresses at a surface of 500 ... 600 MPa with strain hardening of 5 ... 8%.
• Strengthen the details of complex shapes, including internal surfaces.



a b

Fig. 4. Limits of endurance of new turbine blades
1. TPH, 2.UH, 3. without hardening with stabilizing tempering, 4. without hardening and stabilizing tempering
1. without TPH, 2. TPH

Analysis of the results of the study made it possible to establish that the TPH is characterized by higher residual stresses σ_τ, although the strain rate ε_i is much lower than for ultrasonic hardening. Therefore, the scope of application of TPH: details of complex shape including internal surfaces of parts of gas turbine engines operating at temperatures above 500-6000° C. In operating conditions at lower temperatures, it is advisable to use ultrasonic hardening.

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