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ENGINEERING SUPPORT OF THE QUALITY OF SURFACE LAYER OF TAB GROOVES IN THE DISCS MADE FROM HEAT-RESISTANT STEEL

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Abstract

The main idea of the work is to create scientifically grounded technological conditions for treatment of tab grooves in the discs from heat resisting steel, which stipulate formation of roughness of treated surfaces at the level of design requirements, useful compressive residual stresses and a defective surface layer, which increases reliability of operation of interlock in the absence of any defects on the working surfaces of tab grooves of various types, under conditions of maximizing efficiency of their treatment method. Dependences of roughness of the treated surface on the technological factors of the broaching process Ra = f (V, S, γ, HRC) have been proposed. As a result of experimental studies, the nature of distribution of residual stresses, depth and degree of strengthening of the surface layer, depending on the technological conditions of the tab grooves treatment, has been established. The article presents research of surface quality parameters; study all the selected parameters of the surface quality and surface layer and an algorithm to perform experimental work. The algorithm has been built on major principles of control and fixation methods, which stipulate use of non-destructive methods of control. Graphs of strengthening the surface layer of samples, depending on their processing modes and graphs of the distribution of residual stresses in the surface layer are also presented.

Keywords: *surface quality parameters, tab grooves and interlocks, heat-resistant steel*

1. Introduction

Continuous increase in the capacity of new gas turbine units, accompanied by an increase in operating temperatures, stresses, vibrations, etc., leads to a steady increase in requirements for materials used for their manufacture [2, 5]. New grades of het resistant materials need to be developed and introduced [6, 8]. The introduction of such materials is complicated by the lack of research in the field of their treatment by cutting method [7]. Dragging of tab grooves in the heat-resistant steel discs is a good example. During treatment by traditional technology, the quality of treated surfaces does not meet design requirements, many defects are formed in the form of burrs, ripples, rolling-and peening, etc., which is unacceptable in terms of complex intense operation conditions of the interlocks and may result in reduced reliability of the attachment, damage of the tail part of the blades, disk rim and engine as a whole (Fig. 1) [1, 10, 11].

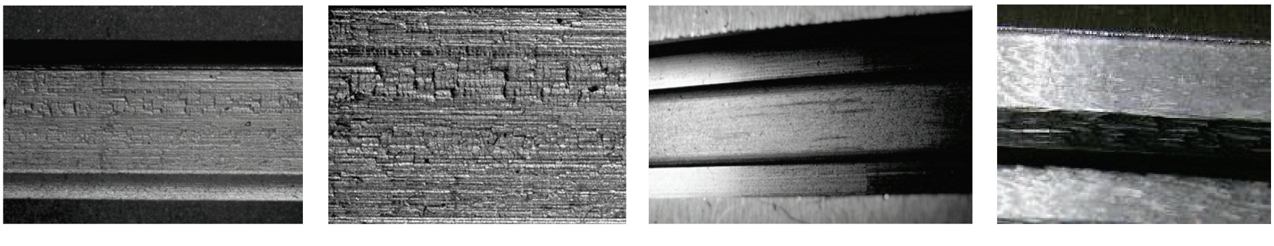

Fig. 1. Defects in the treated surface

Therefore, the study of the influence of geometric parameters of cutting tools, grades of its material, cutting conditions, type of lubricating and cooling fluids, specific features of the material being treated and cumulative effect of technological factors on formation of roughness of the treated surface, residual stress and strengthening of the surface layer in the process of dragging of the tag grooves of the turbine discs and compressors is a relevant scientific task that is of great practical importance for development of gas turbine building [3, 9, 10].

2. Research of surface quality parameters

An algorithm to perform experimental work has been developed to study the quality parameters. Having a limited number of samples, one should study all the selected parameters of the surface quality and surface layer. This algorithm has been built on major principles of control and fixation methods, which stipulate use of non-destructive methods of control, first of all, and then studies are performed with the use of destructive control methods. Therefore, at the beginning surface of all the samples has been studied visually and fixed, then its roughness was measured, then micro-hardness of surface was determined by pressing of diamond prism, residual voltage by layer-by-layer etching of the sample and micro-structure of method of bevelled sample were measured [4, 5].

The results of the study of surface roughness of tag groove elements treated at low cutting speeds show that discs hardness shall be ensured at the level of HRC 39...43 units by introducing additional heat treatment, what will reduce viscosity of the material and reduce sticking of chips on the front surface of the dragging tooth. In such conditions surfaces with roughness Ra = 0.64 μm are formed (Fig. 2a).

a) b) c) d)

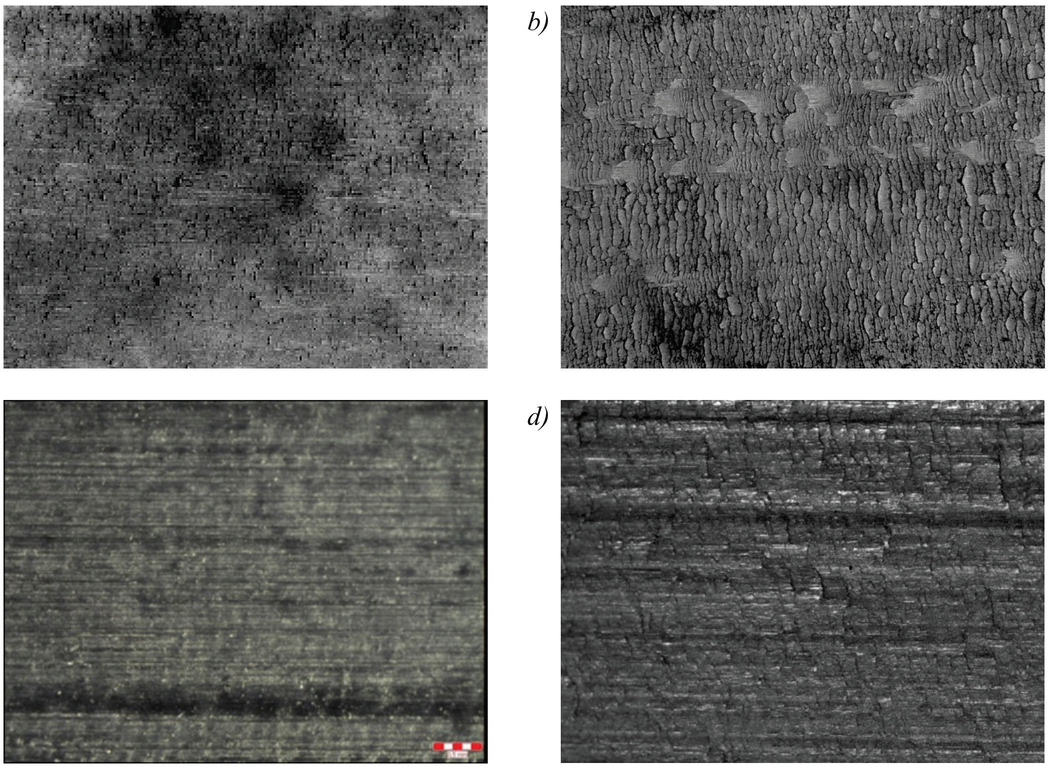

Fig. 2. Photo of the processed surface of the samples: a) Ra = 0.64 μm, V = 1 m/min, S = 0.03 mm; γ = 27º, HRC 39 b) Ra = 5.36 μm, V = 1 m/min, S = 0.07 mm, γ = 20º, HRC 32; c) Ra = 0.33 μm, V = 11.4 m/min, S = 0.1 mm γ = 20º, HRC 33; d) Ra = 4.84 μm, V = 8.7 m/min, S = 0.1 mm, γ = 27º, HRC 43

Increased feeding and reduced front angle are the most unfavourable conditions for formation of surface roughness in the drawing at low cutting speeds, while reducing hardness of the material up to 32 HRC (Fig. 2b).

In the case of treatment at increased cutting speeds, the inverse pattern is observed: samples with lower hardness have better roughness compared to the samples after heat treatment. An advantage in the range of cutting speeds of 11.4...18.1 m/min is especially noticeable. The smallest roughness of the surface of the samples with hardness HRC 33 is formed by using a tool with front angle γ = 20º. In the case of treatment of samples with hardness of HRC 43, the use of cutting speeds of 6.6...11.4 m/min should be avoided, and the use of cutting speeds of 4.5 m/min and 28.1 m/min is not desirable in case of treatment of "soft" samples. The lowest surface roughness was observed in a sample with hardness HRC 33 treated by a tool with front angle γ = 20º and feed S = 0.1 mm/tooth at cutting speed of 11.4 m/min (Fig. 2c). The worst surface roughness was observed on the sample with hardness HRC 43 treated at speed of 8.7 m/min with feed S = 0.1 mm/tooth and front angle γ = 27º (Fig. 2d).

Analysis of the study data of surface layer strengthening of tag groove elements during its cut shows that the smallest cold hardening of 3.08% is formed when the sample with hardness HRC 39 is treated at speed of 21.4 m/min, by a tool with front angle γ = 27º and feed S = 0.05 mm/tooth (Fig. 3a), and the largest one – 109.2% during treatment of the sample with hardness HRC 32 at speed of 6.6 m/min with front angle γ = 20º and feed S = 0.05 mm/tooth (Fig. 3b).

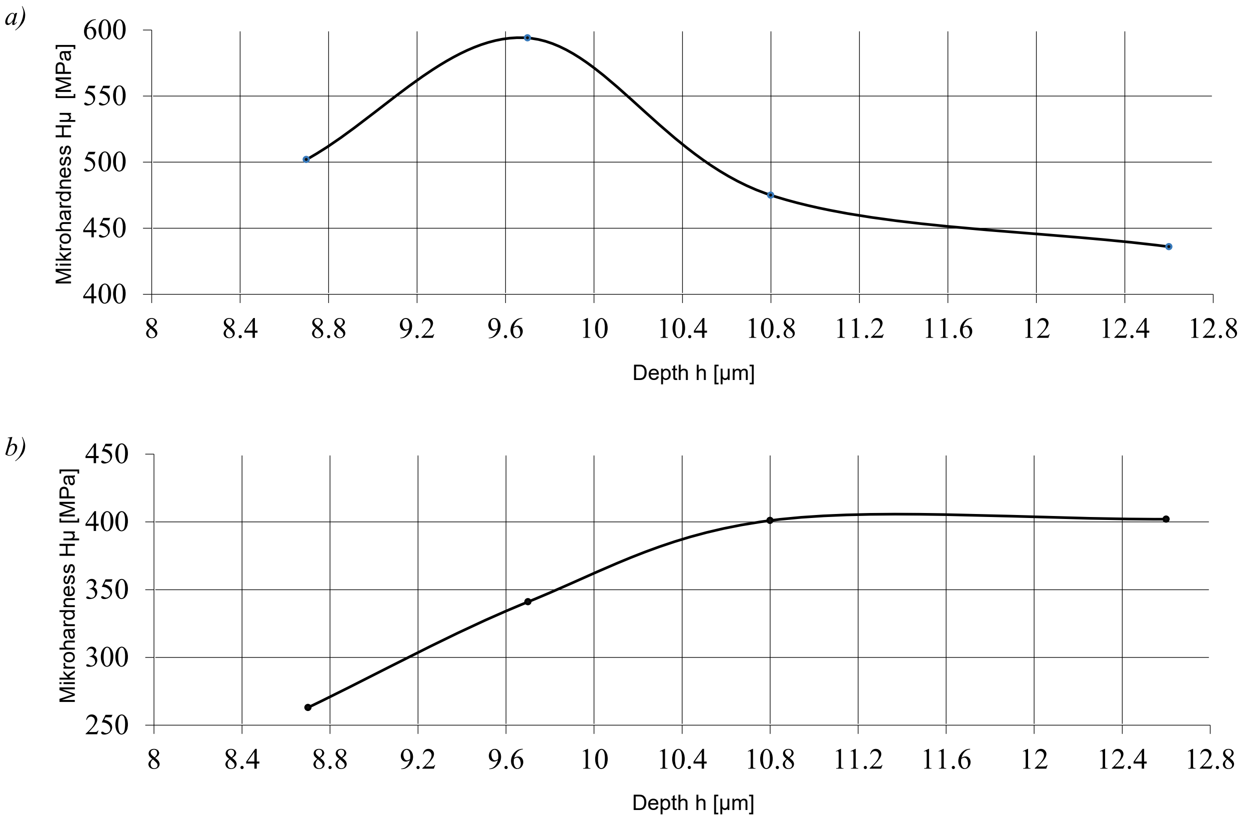

Fig. 3. Graphs of strengthening the surface layer of samples, depending on their processing modes: a) N = 3.08% b) N = 109.2%

The results of the study of residual stresses in the surface layer of samples treated at low cutting speeds showed that all residual samples produced compressive residual stresses on the surface. The minimum value is recorded at 33.19 MPa, the depth of the occurrence is 63 μm (Fig. 4a), maximum – 310.39 MPa at a depth of 77 μm (Fig. 4b).

From the analysis of the results of using increased cutting speeds, it is evident that undesired tensile stresses are formed on the treated surface. Only in one case, useful compressive residual stresses at cutting speed of 18.1 m/min are formed on the treated surface of the groove. (Fig. 5a). The maximum value of tensile stresses σ_0 max = 643 MPa. (Fig. 5b).

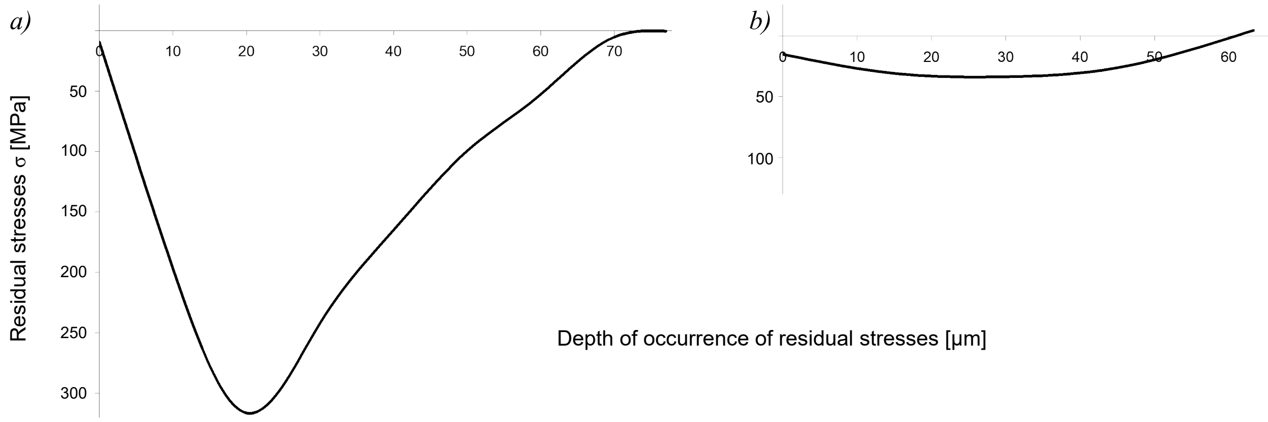

Fig. 4. Graphs of the distribution of residual stresses in the surface layer: a) σ_0 = -310.39 MPa, V = 1 m / min, S = 0.03 mm, γ = 27º, HRC 39; b) σ_0 = -33.19 MPa, V = 1.5 m/min, S = 0.03 mm, γ = 27º, HRC 32

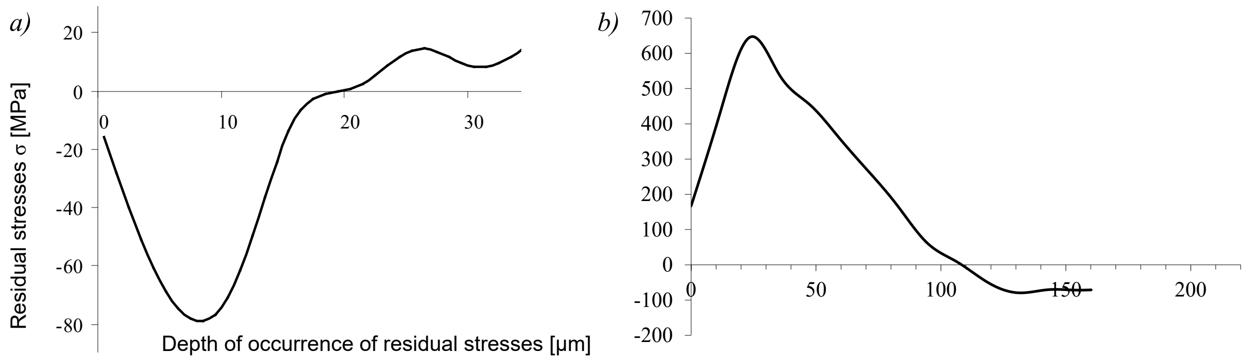

Fig. 5. Graphs of the distribution of residual stresses in the surface layer: a) σ_0 = -79 MPa, V = 18.1 m/min S = 0.05 mm, γ = 20º, HRC 32; b) σ_0 = 643 MPa, V = 4.5 m/min, S = 0.05 mm, γ = 27º, HRC 39

3. Structure and analysis of dependence Ra = f (V, S, γ, HRC)

The study of roughness of the surface treated at cutting speed of 1...1.5 m/min showed that partial dependencies are not proportional; therefore, dependence (1) with a sufficient degree of accuracy was approximated by the equation of regression of the power form:

$$\mathrm{Ra} = C \cdot V^{a_1} \cdot S^{a_2} \cdot \gamma^{a_3} \cdot \mathrm{HRC}^{a_4}, \qquad (1)$$

where:
C – calculated auxiliary factor,
Ra – response function,
V – speed of broaching,
S – feed,
γ – front angle,
HRC – hardness of the treated material,
a_1, a_2, a_3, a_4 – degrees of power.

At all stages of mathematical planning, the statistical verification of the reproducibility of the experiments, significance of the coefficients of the model and its adequacy was ensured. Dependence (2) in the natural space looks as follows:

$$\mathrm{Ra} = \frac{3 \cdot 10^{11} \cdot V^{0.6386} \cdot S^{0.822}}{\gamma^{0.5143} \cdot \mathrm{HRC}^{6.0778}}, \qquad (2)$$

provided:

$$\gamma^{0.5143} \cdot \mathrm{HRC}^{6.0778} \neq 0.$$

According to this model hardness of the treated material, feed and cutting speed have the greatest influence on the roughness of the surface, whereas front angle – the smallest. Considering that it is expedient to reduce the amount of lifting on the tooth (feed) in the course of dragging only to the level of the radius of sharpening of the cutting edge (ρ), whereas surface roughness may be reduced adjusting the ratio of cutting speed and hardness of the treated material. This dependence enables predicting the level of surface roughness as per the specified given parameters of basic technological factors, or at given roughness, to determine what values should be taken by basic technological factors in the process of treatment. The difference between calculated and measured values does not exceed 23%, which indicates the high accuracy of the obtained dependence.

In order to build a model in extended range of cutting speeds of 1...28.1 m/min, one of the algorithms of the group method of data handling (GMDH) has been selected. The task of building a model was to determine the function (3):

$$M\left\langle \ln y \middle| \vec{x}, 1/\vec{x}, \sqrt{\vec{x}}, 1/\sqrt{\vec{x}}, \ln\vec{x}, 1/\ln\vec{x} \right\rangle = F\left(\vec{x}, 1/\vec{x}, \sqrt{\vec{x}}, 1/\sqrt{\vec{x}}, \ln\vec{x}, 1/\ln\vec{x}, \vec{\upsilon}\right), \quad (3)$$

where:

$M\left\langle \ln y \middle| \vec{x}, 1/\vec{x}, \sqrt{\vec{x}}, 1/\sqrt{\vec{x}}, \ln\vec{x}, 1/\ln\vec{x} \right\rangle$ – is mathematic expectation of values ln y,

$F\left(\vec{x}, 1/\vec{x}, \sqrt{\vec{x}}, 1/\sqrt{\vec{x}}, \ln\vec{x}, 1/\ln\vec{x}\right)$ – operator unknown in terms of appearance and structure (functional relation),

$\vec{\upsilon} = \left\| \upsilon_0, \upsilon_1, ..., \upsilon_m \right\|$ – unknown vector of the parameters being estimated.

The search for a model type was performed in the class of power polynomials. As a result of data processing on PC, the obtained model (4) looks as follows:

$$Ra = 6.3 - \frac{\sqrt{V}}{HRC^2} \cdot \left(68.2 \cdot HRC - 40.9 \cdot V\right) + HRC^2 \cdot \left(\frac{0.0001}{\sqrt{S}} - \frac{0.003}{\sqrt{V}}\right) + 15.6 \cdot \frac{S}{\sqrt{\gamma}}, \quad (4)$$

The analysis of the dependence structure shows hardness of the treated material, cutting speed and feed have the greatest influence on the roughness of the treated surface Ra. The verification of the adequacy of the model enabled using it in studies of the influence of V, S, γ, HRC on the formation of roughness of the treated surface of the steel samples.

4. Conclusions

1. Dependence of the roughness of the treated surface on technological parameters of drawing the heat-resistant materials of the martensitic class with the increased viscosity in the range of cutting speeds of 1...28 m/min has been established, while implementing the algorithm of the method of group consideration of an argument to find a mathematical model in the class of power polynomials.
2. It has been experimentally proved that the surface roughness of the tag grooves of the turbine and compressor discs of high and low pressure at the level of design requirements in the absence of undesired traces of treatment and any defects is achieved by introducing additional thermal operation into the technological process to ensure disc hardness HRC 40...43, and by drawing grooves at a speed of 1 m/min, or increasing the speed of drawing to 14.5...18.1 m/min due to the use of high-speed drawing equipment.
3. It has been established that surface layer is strengthened, while drawing steel ЕП517-Ш at speeds V = 1...1.5 m/min and V = 4.5...11.4 m/min for the discs with hardness HRC 32 at feed rate to the tooth of S = 0.05 mm/tooth and front angle of drawing γ = 20º and at speed V = 21.4...28.1 m/min, at S = 0.1 mm/tooth, as well as the drawing of samples with hardness

HRC 39 at speed V = 1...1.5 m/min, what is useful for tag grooves of discs operating at relatively low operating temperatures, at the same time, the surface of tag grooves of turbine discs, operating at temperatures of 750...1530°K, should not be strengthened, as strengthening reduces the limit of durability and longevity the stronger, the higher the working temperature, therefore, on the groove surface, it is recommended to form a small defective layer by drawing discs with hardness HRC 32 at speed V = 8.7...28.1 m/min at feed rate to the tooth of S = 0.05...0.1 mm/tooth and front angle of the drawing $\gamma = 20^o$, or by drawing discs with hardness HRC 39 at speed V = 14.5...28.1 m/min at feed rate to the tooth S = 0.05...0.1 mm/tooth and front corner of drawing $\gamma = 27^o$.

4. It has been established that the desired compressive residual stresses in the surface layer of the tag grooves of the compressor discs are ensured by drawing discs of different hardness at cutting speeds V = 1...1.5 m/min by a tool at S = 0.05...0.1 mm/tooth and front angle of drawing $\gamma = 20...27^o$, or drawing discs with hardness of HRC 32 at speed V of 18.1 m/min at feed rate to the tooth of S = 0.05 mm/tooth and front angle of drawing of $\gamma = 20^o$, and for turbine discs any residual stresses available are not significant, since residual stresses relax at high temperatures and with long service life. Formation of stretching residual stresses on the surface of tag blades of the discs is not allowed.

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