Application of the complex parameter of strength and ductility to assess the state of the blades' material at different periods of operation

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Abstract. The paper is devoted to the study of the material's condition of guide blades made of heat-resistant nickel alloy with different operating time. It is established that the structure of the blade material and their mechanical properties are not satisfactory for further operation. To recovery the performance properties and structure of the blade material, several types of heat treatment were tested and the optimal one was chosen. The complex parameter of strength and plasticity is calculated and on its basis the estimation of degree of recovery of blade' material after heat treatment is carried out.

1 Introduction

The guide blades are operated under the conditions of elevated temperatures (up to 800° C), the erosive effects of air flow, vibration and cyclic loads. Spikes in the blade material' temperature in the process start-ups, shutdowns, and at variable turbine conditions result in high temperature stresses. Another common type of damage to the blade material are corrosion pit that form on the trailing edge. Given the deterioration of the plastic properties of the material and changing the structure which occur during the operation of the blades [1,2], these factors can lead to the nucleation and propagation of cracks and brittle fracture of the material [3].

The aim of the study is to assess the changes occurring in the blade's material made of nickel heat-resistant alloy after prolonged operation and after recovery heat treatment using experimental and theoretical approaches.

2 Research objects and results

The objects of study were guide vanes of the 3rd stage, which were operated 25773 and 28070 hours, respectively.

The microstructure (after25773 hour) of the material trailing edge contains an invalid local allocations of needle carbides (needle length up to 35 microns). Small segregations of carbides $Me_{23}C_6$ are located at the grain boundaries of carbide MeC. The size of the

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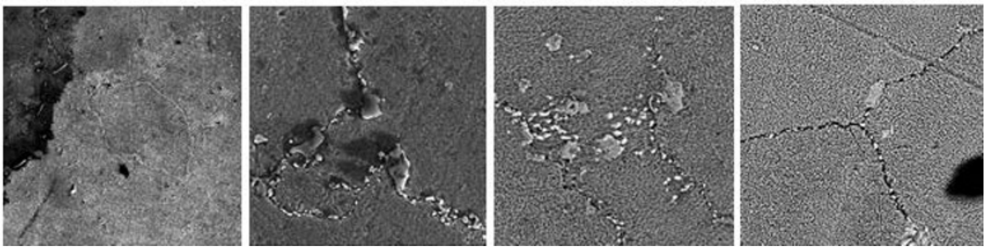
carbide phase at the grain boundaries varies from 0.5 to 8 microns. Large irregular carbide particles are contained both in the body of the grains of the nickel matrix and along their boundaries (fig. 1 a,b). It is known that the local formation of a large number of carbide particles causes depletion of close zones with carbon and refractory elements. Small particles of the γ’-intermetallic phase (~0,01 - 0,05 microns) have a spherical shape and are evenly distributed over the body of the grains. Partial dissolution and a change in the shape of the particles of γ’-phase are observed, which indicates a decrease in coherence between this phase and the base metal. The described changes occurring with the hardening phase can lead to a decrease in the mechanical properties of the alloy.

The analysis of the microstructure showed that the blade (after 28070 hour) material contains a large number of areas with accumulation of large carbides having a size of 10 to 15 microns. These areas are located mainly at the grain boundaries. The γ’- phase has an irregular “butterfly” shape, and its size is from 0.2 to 0.8 microns. Changes in the structure of the material occurred in all parts of the blade (feather and blade root) (fig. 1 d,c). The microhardness of the material after operation varies over the body of the blade and ranges from 3.7 to 5.7 GPa. Table 1 shows the mechanical properties of the material of the blades.



a, x500 b,x500 c, x2000 d,x2000

Fig. 1. Microstructure of the alloy of the guide blade after operation for 25773 hours (a, b) and 28070 hours (c - trailing edge; d - blade root).

Table 1. Mechanical properties of the blade material in the initial state and after operation.

Material condition	**σ_B, MPa**	**$\sigma_{0,2}$ MPa**	**δ,%**	**ψ,%**
literary source[1,2,3]	≥900	≥800	2,5	3
after operating time 25773 h.	740	350	1,5	3
after operating time 28070 h.				
feather center	910	570	5	7
trailing edge	960	545	4	4

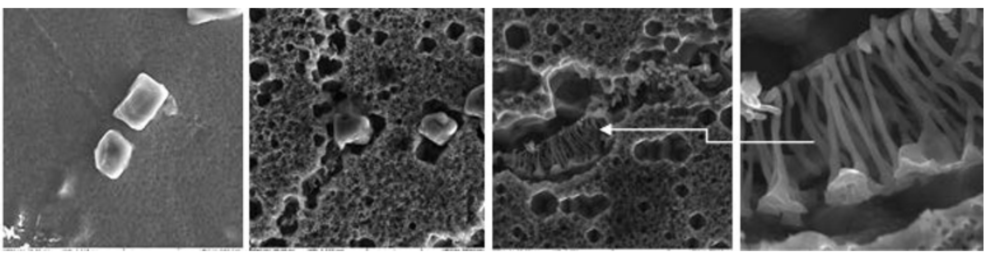
Critical changes in the microstructure, a decrease in the mechanical properties of the blade’s material, as well as a large operating time (according to the operating instructions, the maximum operating time is 25000 hours) indicate the need for the use of recovery heat treatment.

Heat treatment was carried out to restore the structure. For machine parts made of nickel alloys, homogenization is used, during which the structure is stabilized and the degree of segregation is reduced, thus increasing the volume content of γ’-phase particles. During high-temperature aging, large γ'-phase particles dissolve. It should be noted that the choice of recovery heat treatment modes to achieve the optimal shape, size and distribution of particles of the hardening phase does not always lead to an improvement in mechanical properties. The formation of Me_6C carbide particles of an unfavorable lamellar form during homogenization at a temperature of 1210°C and further cooling practically eliminates the improvement of properties by controlling the structure of the γ'-phase [4,5,6].

Two modes of heat treatment were tested on the specimens, adjusted for the condition of the blade material after operation: №1: heating to 1200°C, 3 hours, air cooling; № 2: heating to 1200°C, 3 hours, cooling in the furnace.

The use of mode №1 for the blade material (after 25773 hours of operation) led to a partial restoration of the microstructure: there was a size reduction of γ'–phase particles, dissolution of small carbides $Me_{23}C_6$, large carbides have a size of ~ 5 microns, which is permissible, but undesirable, since it can lead to embrittlement of the material (fig. 2). The microhardness of the material was - 4.70 GPa. With regards to the mechanical properties of the samples, the use of mode №1 led to their partial recovery, mode № 2 was ineffective.

The application of heat treatment according to the mode №1 for the blade after 28 070 hours of operation also led to a positive change in microstructure, namely: the globular carbide phase precipitate (average size 0.5 to 2 microns). The intermetallic phase has an almost regular cubic shape with a particle size of ~ 0.5 microns, however, in the material of the trailing edge, the intermetallic particles remained in the form of a “butterfly”. The microhardness of the material was 3.10 GPa.



a, x10 000 b,x10 000 c, x10 000 d,x40 000

Fig. 2. Microstructure of the blade material after heat treatment: a - mode №1; b - mode №2; c, d – filamentous carbides at the grain boundary.

Table 2. Mechanical properties of the blade material after various modes of heat treatment.

Type of heat treatment	**σ_B, MPa**	**$\sigma_{0,2}$ MPa**	**δ,%**	**ψ,%**
after operating time 25773 h. + mode № 1	930	540	7	9
after operating time 25773 h. + mode № 2	820	530	3	11
after operating time 28070 h. + mode № 1	900	630	9	9

Evaluation of the performance characteristics of the blade material using a comprehensive index of strength and ductility. It is known that the plastic properties of a material (ψ, δ) are often interrelated with its strength properties ($\sigma_{0,2}$, σ_B), where σ_B – tensile strength, $\sigma_{0,2}$ – offset yield strenght, δ – elongation on failure, ψ – contraction of area at fracture. With increasing values of the strength characteristics of the material, the indicators of plastic properties usually decrease. Also, the elongation value affects the interval between the yield strength and tensile strength. As a rule, the smaller $\sigma_{0,2}/\sigma_B$ the greater δ.

To assess the performance characteristics of the blade material after operation and thermal treatments, we use an approach based on the calculation of a complex parameter of strength and ductility [7]

$$C = \frac{\sigma 0{,}2}{\sigma B} + \frac{\delta}{\psi} \tag{1}$$

Calculations showed that the value of the complex parameter of strength and ductility C decreases significantly: after 25773 hours 1.8 times, after 28070 hours 1.3 times. The application of heat treatment according to mode №1 for an alloy with a lesser operating time did not give a complete recovery of mechanical properties which was confirmed by the values of index C, it makes up only 79% of the strength and plastic characteristics of the new material. The degradation of the blade material with an operating time of 28,070 hours was less, as evidenced by the high value of ***C***, therefore, heat treatment led to ~ 98 % level of normalized properties of the material.

Table 3. Results of calculation of complex criteria.

Type of heat treatment	***C***
literary source [1,2,3]	1,7222
after operating time 25773 h.	0,9730
after operating time 28070 h. feather center trailing edge	1,3407 1,5677
after operating time 25773 h. + mode № 1	1,3584
after operating time 25773 h. + mode № 2	0,9191
after operating time 28070 h. + mode № 1	1,7000

3 Conclusions

The experimental and theoretical analysis of the condition of the blade material gives a complete picture of their degradation and the possibility of their recovery.

As the studies showed, in the blade material after long-term operation (> 25 000 hours), irreversible changes in the microstructure occur, which cannot be completely eliminated by heat treatment.

To extend the operation of the blades, it is necessary to observe the temperature regimes, the regulations of inspections, as well as to carry out timely repair of the blades.

The use of a complex parameter of strength and ductility C allows to assess the degradation of the operational properties of the blade material in a simple practical way.

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References

1. A. S. Zubchenko, M. M. Koloskov, Yu. V. Kashirskiy *Directory of steels and alloys*. (2nd edition, EXT. and Rev. - Moscow: Mashinostroenie,(2000) (in Russian)

2. *Instructions for extending the service life of the material of the main elements of turbines and compressors of power gas turbine plants* CO 153-34.17.448-2003. (in Russian)

3. *Heat-resistant steels and alloys*. Reference book. S. B. Maslenkov. M.:Metallurgy (1983)

4. S.V. Kirikov., V.N. Perevezentsev Yu.P. Tarasenko *Analysis of morphological characteristics of intermetallic phase in heat-resistant Nickel alloys*. VESTNIK of Samara University. Aerospace and Mechanical Engineering. **Vol. 15, No. 4. P. 216-223**. (20165. Yu.P. Tarasenko., I.N. Tsareva, O.B. Berdnik, M.K. Chegurov *The causes of cracks in the feather of turbine blades during operation.* Internet joutnal "the Bulletin of scientific-technical development", **№12(52), Pp. 30-38.2**. (2011) (in Russian)

6. Yu.P. Tarasenko, O.B.Berdnik *Optimization of the heat treatment mode to extend the life of the blades of high pressure turbines*. Materials Science, **No. 5, P.24-29** (2012)

7. Yu.I. Gustov, D.Yu. Gustov, I.V. Voronina *Derived criteria of ductility and strength of metallic materials.*Vestnik MGSU. **No. 9. P. 39—47.** (2014) (in Russian)