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Fractographic Study of Fatigue Failure of a High-Pressure Turbine Rotor Blade

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Abstract. The paper presents the results of a factual study of the fracture surface of a high-pressure turbine rotor blade with a fatigue crack. The study of the fracture relief showed that on the fracture surface of the blade near the trailing edge there is a zone of brittle transcrystalline and intergranular fracture, surrounded by an intragranular fracture with a developed microrelief. Further crack growth in the direction of the leading edge was carried out by a fatigue mechanism. As a result, it was found that the main cause of blade failure is the formation and development of a fatigue crack in the direction from the trailing edge of the airfoil to the leading edge.

INTRODUCTION

The object of the study was a high-pressure turbine blade with operational failure in the form of a crack in the blade.

The purpose of this work is to study, using fractographic methods, the nature of blade fractures in the destruction zone.

In the course of the work, the identification of the blade and the assessment of its external state were carried out, the relief of operational fractures was investigated. The study was carried out using methods, optical microscopy and scanning electron microscopy.

An external examination of the blade airfoil surface revealed that during operation the blade was subjected to repair operations (mechanical cleaning, welding-surfacing restoration of the blade edges).

As a result of fractographic studies, it was found that the cause of blade destruction is the formation and development of a fatigue crack in the direction from the trailing edge of the airfoil to the leading edge. The initiation of cracks (formation of a focus) occurred in the near-surface layer of the metal of the trailing edge by the type of volumetric cracking from the action of high loads corresponding to the ultimate strength of the material. The exposure to high loads was short-lived. Further development of cracks occurred under the action of a vibration load. The form of the focus by the type of volumetric cracking suggests that the cause of its formation is a complex stress state in the shoulder blade, which has arisen as a result of a short-term overload, possibly of thermal origin.

On the basis of the obtained research results, it was concluded that the probable cause of the formation of brittle cracks in the near-surface layer of the trailing edges was the thermal (welding-surfacing) repair work on the blade.

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RESEARCH TECHNIQUE

Research was carried out on the working blade of the high-pressure turbine of the GTK-10-4 unit, which has a crack in the feather, which has arisen during operation “Fig.1”. The Customer did not provide information about the material, manufacturer, operating history and repair work for the blades transferred for research.

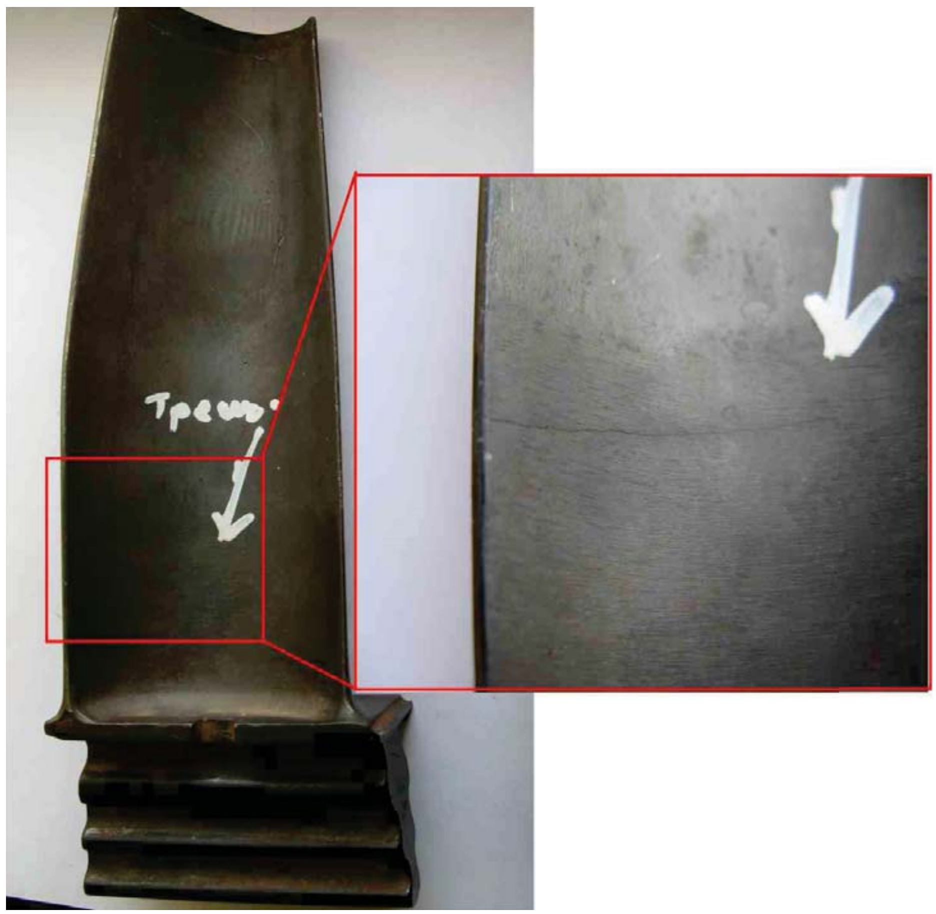

FIGURE 1. General view of a cracked working blade

SAMPLE PREPARATION

For research, the surface of the blade was subjected to a general visual inspection in order to assess the state of the surface, as well as to determine the locations of sampling. For research, samples were prepared for carrying out a fractographic study of the fracture surface. The fracture opening was made due to their abrasive cutting along two parallel sections located at a distance of about 10 mm on both sides of the path of the cracks and one longitudinal section passing through their end points.

RESEARCH METHODS

Assessment of the condition of the surface of the scapula was carried out using a stereoscopic microscope "Citoval" with a magnification of up to 100 times.

To assess the nature of the destruction of the blade, the surface of the opened fracture was examined using a "Citoval" stereoscopic microscope and a "Jeol JSM-6390" scanning electron microscope “Fig.2”.

(a)

(b)

FIGURE 2. Research microscopes
a, – stereoscopic microscope "Citoval"; b - scanning electron microscope "Jeol JSM-6390"

RESEARCH RESULTS

Assessment of the condition of the surface of the blades

The surface of the feather of the damaged scapula was examined visually and with the help of a "Citoval " stereomicroscope. On the surface of the feather from the side of the trailing edge, cracks were found, with a length of 32 mm along the trough, located at a height of 26 mm from the lock shelf, and developing towards the leading edge “Fig.1”.

The surface of the blade from the side of the trough is rather uniform, covered with a predominantly dark brown oxide film. On the surface of the back, the color is heterogeneous - from light brownish in the lower part of the feather, above, almost to the end, the color is black with mottling. On the surface of the blade airfoil “Fig.2”, rather rough multidirectional risks (traces from the applied mechanical cleaning) are revealed. At the leading and trailing edges along their entire length, there are multiple local stress concentrators in the form of short transverse scratches from the stripping performed and small craters with particles embedded in them. Apparently, these are traces of erosional wear of the surface from previous exploitation. In addition, “cuts” are observed in some areas of the edges, distorting their original rounding radius. The root surface of the backrest has a transverse stripping to a height of 30 mm from the shelf, above 30 mm, the surface along both edges is stripped from the side of the backrest and trough. The presented signs of mechanical action on the blade airfoil indicate that the blade has already been repaired and, accordingly, the blade is reused. On the back of the blades, there are small craters up to 0.5 mm in size with small particles embedded in the surface and dark soot spots, indicating a high level of contamination of the gas flow entering during the last operation[1].

The end surface of the blade on the back side and along the leading edges has a dark brown color and an increased roughness in comparison with the rest of the surface, which indicates the effect of higher temperatures on these areas. The upper edge of the thinning has wear with burrs along the end, both towards the trough and the back, in addition, metal cuts are observed in the corner zones at the trailing edges.

Assessment of the condition of the locking parts revealed clear traces of fretting“Fig.3”, indicating a change in the amplitude of their swing, and, consequently, the likelihood of resonant oscillations.

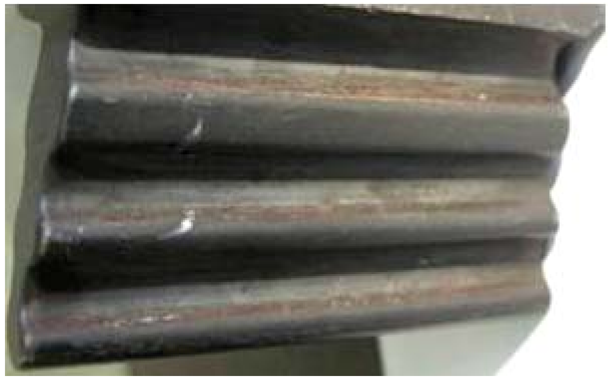

FIGURE 3. Fretting wear on the blade lock.

In general, the conducted studies of the state of the surface of the damaged blade revealed a general "picture" of unfavorable factors of repair and operational nature:

- the presence on the edges of multiple surface stress concentrators of mechanical origin (multidirectional scratches of cleaning, traces of erosive wear and small dents preserved from the previous period of operation), as well as traces of poorly performed reconditioning surfacing repair (inhomogeneous spots of deposited metal, frozen metal droplets);
- a non-uniform oxidation state and roughness of the surface of the feather parts of a blade indicate a local high-temperature effect (overheating)[2] that took place during operation;
- the presence of carbon deposits due to contamination of the affected gas stream;
- changes during the repair of the rounding radii of individual sections of the edges as a result of the repair;
- uneven wear of the thinning, as well as fretting on the flanges of the blade lock part, gives reason to believe that the emergency blades experienced high vibration loads[3].

From the set of unfavorable factors identified above, the most probable cause that led to the destruction of the blades under study, one can single out the unevenness of the high-temperature impact (both operational and repair). This, in turn, allows us to assume that the cause of the failure of the blades could be high thermal stresses at the border of the feather zones with the greatest temperature difference (high temperature gradient).

Assessment of the nature of destruction of blades

The investigated blade had damage in the form of a crack located in the trailing edge of the feather in planes parallel to the lock flange. To study the fracture surface of the blades, samples were preliminarily cut out of the feather, including the fracture zones. A general view of the fracture surface of a damaged rotor blade, obtained after mechanical crack opening, is shown in “Fig.4”. The fracture surface is oriented normal to the feather axis, located on the side of the trailing edge of the blade, smooth, covered with a dark oxide film, and semi-concentric lines are visible on the surface, that is contains signs of fatigue growth. The characteristic growth semi-concentric fatigue lines developing from the trailing edge towards the input edge allow one to indicate the location of the beginning of the crack propagation from the trailing edge.

The study of the fracture relief using an optical and scanning electron microscope showed that on the fracture surface of the blade near the trailing edge there is a zone of brittle transcrystalline and intergranular fracture[4], surrounded by an intragranular fracture with a developed microrelief “Fig.4”.

In the blade shoulder, the brittle fracture zone partially extends to the side surface of the airfoil from the side of the trough and has the shape of an irregular ellipse with dimensions of 550x300 μm, elongated from the central section of the fracture surface located near the end of the trailing edge to the side surface of the blade from the side of the trough. The intragranular fracture surrounding the brittle fracture zone has signs of fatigue cracking in the form of viscous facets with grooves and fan-shaped scars, diverging from the brittle fracture zone to the outer surface of the blade from the trailing edge and towards the leading edge. This nature of the fracture makes it possible to determine the seat of destruction of the blade airfoil as a zone of brittle fracture near the end of the trailing edge. The brittle fracture zone is predominantly intragranular facets, misoriented relative to each other so that the fracture surface of this section does not lie in the plane of fatigue growth of the main crack , that is, the formation of a focus is not associated with the stress state pattern from the action of working loads. The shape of the brittle fracture area (focus) in the form of a conditional ellipse with the ratio of length over the blade surface to depth as 1 to 2 shows that the formation of the center was, apparently, subsurface with an exit to the outer surface from the side of the trough. After that, the destruction developed by the growth of cracks by the fatigue mechanism.

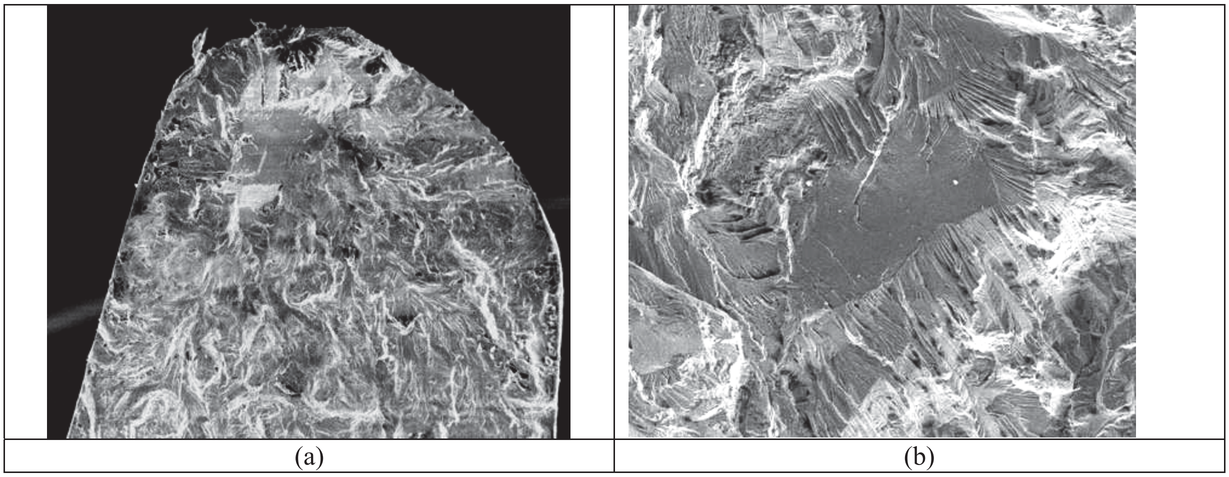

FIGURE 4. View of the fracture surface of the blade airfoil from the side of the trailing edge.
a, – crack growth topography, brittle intergranular fracture;
b - topography of the fracture of the blade airfoil at the stage of fatigue crack growth.

CONCLUSIONS

A fractographic study of the high-pressure turbine rotor blade, which collapsed during the operation of the GTK-10-4 unit, was carried out.

The following is installed:

1. The main reason for the destruction of a blade is the formation and development of a fatigue crack in the direction from the trailing edge of the airfoil to the leading edge.

2. The formation of a focus of destruction occurred in the near-surface layer of metal of the trailing edge of the blades by the type of cracking from the action of high loads corresponding to the ultimate strength of the material. The impact of high loads was short-term, so that after the formation of defects, their development took place under the action of a vibration load. The shape of the focus in the form of a zone of volumetric cracking suggests that the cause of its formation is a complex stress state in the blade bridge, which has arisen as a result of a short-term overload, possibly of thermal origin.

3. The probable reason for the formation of a brittle crack in the end face of the trailing edge can be considered the fact that thermal repairs were carried out on the blade airfoil. A characteristic indicator of thermal repair work is the presence of solidified melt drops on the fracture surface in the brittle fracture zone at the trailing edge of the

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