Characterization of flawing on feather surface of low pressure compressor blades from VT-3 titanium alloy

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Abstract. The article provides the results of the study of flawing on feather surface of low pressure compressor blades. These defects were identified during flaw-detective etching treatment, and were intentionally, with the help of mechanical and electrical influences. During the study, comparison of the microstructure of the feather surface of blades in the area of identified and specially caused defects was made in order to determine their nature and the cause of their formation.

1. Theoretical part of the study

Now titanium alloys are one of the most widespread engineering materials for production of blades of gas-turbine engines (GTEs). There are many types of titanium alloys such as VT3-1, VT5-1, VT8, VT9, OT4-1, etc. Their properties as high strength, corrosion resistance, heat resistance and others cause the choice of titanium alloys as structural material. However, titanium alloys have also a number of shortcomings, for example, low conductivity and high physical and chemical activity to oxidizing processes at high temperatures. It should be considered during the production process of parts and products from titanium alloys as the listed shortcomings can lead to emergence of defect at manufacturing and production stages.

In view of this, a crucial task in the production process of GTE compressors blades from titanium alloys is early recognition and identification of the defects including which are not breaking a metal denseness as well as the subsequent elimination of those defects.

GTE compressors blades manufacturing is involved the following operations: die forging, grinding, polishing, brightening, etc. During passing of all these stages, the feather surface of blades contacts with stamping, heading and processing tools. If the stamping or machining mode is not selected correctly, or it fails to meet the requirements of technology to cool the heading tools than on the blades surface there are specific spots in the form of burns.

A burn is a defect representing local change of structure and phase of an alloy composition as a result of local surface overheating of a semi-finished or end product.
Burns are followed not only local phase and structural changes of blades surface material. Beyond that, there are changes of stress-strain behavior of a machined surface in a burn spot. A gas pickup increases and an alpha case can be formed as a result. In this case, surface retained tensile stresses occur, which can lead to flawing and destruction of GTE blades.

The burns, which have arisen at rather low-heating temperature, are hard if not impossible to find with the naked eye. According to the technology applied now burns on blades from titanium alloys are disclosed by the method of control chemical etching in aqueous solutions of mix of nitric and fluoric acids. In the process of control etching burns are revealed as white spots with a characteristic light dull halo. It occurs at the expense of various speeds of etching in a burn point in comparison with the intact surface of a blade.

Aside from the etching, there is an additional method of confirmation of burn existence. The last is based on the determination of microhardness in a place with the enhanced etchability. The matter is that in the course of a local warming up and due to the high chemical activity the titan begins to absorb intensively the gases which are contained in air. At the expense of what there is an increase in microhardness of the warmed surfaced point in comparison with the main material of a part or product. Thus, the measurement of microhardness additionally allows to confirm an existence of a local surface space with the changed structure.

There is another problem in the identification of burns. It is important to distinguish them from the other defects having similar appearance and similar structural changes. Examples of such defects are nonmetallic inclusions considerably enriched with oxygen and nitrogen and places on the blade surface with an abnormal etchability, which differ in chemistry from base metal.

2. Experimental part of the study
For the purpose of this paper, the characterization of flawing in places with the enhanced etchability on feather surface of low pressure compressor blades from VT3-1 titanium alloy will be described. Confirmation of the nature of the detected defects will be carried out by comparing the structural changes in the areas detected during control etching, and in areas with artificially induced cauterezation.

The blades have been made from the original blank by electroforging, at the end of which they were taken out from a stamp of isothermal installation by cold pincers for a feather. Then operations of machining, polishing, brightening and etching for flaw inspection have followed.

During etching on a surface of a feather of both blades near an output edge over the shroud platform the spots of a lighter (shiny) hue than other dull gray surface of the blades have been found on both sides. Also for the purpose of comparison of a microstructure, burns have been artificially induced at the surfaces of the feather of both blades under the shroud platform. Those burns were made during machining and as electric burns.

After flaw detection etching the burns, which are artificially induced during machining, have an appearance of white spots on a dull grey background of the main blade material. The electric burns have an appearance of round shape light shiny spots with a dull light-grey halo around them against the background of a dull grey color of the main blade material. The electric burns carry both drop-through and part-through character. The appearance of the studied blades with identified and artificial induced burns is shown in Figure 1.

Then the research of the surface of the blades under an electronic microscope has been conducted. The following observations were made:
- In the place of the spots found on the output edge of both blades after flaw detection etching there are structural changes consisting in the overquenching of beta-titanium alloy (Figure 2 (a)) in comparison with an initial state of the main blades material (Figure 2 (d));
- In the place of the burns, which are artificially induced during machining, similar structural changes are observed, with the only difference that the overquenching of beta-titanium alloy is more significant (Figure 2 (b));
Figure 1. The appearance of the studied blades: (a) the blade with artificially induced burns during machining; (b) the blade with artificially induced electric burns

Figure 2. The fine structure of the blades material in the studied places: (a) in the place of the spots found after flaw detection etching, (b) the machining burn, (c) the electric burn, (d) the main material, x5000
- The structure consisting of large-sized polyhedral beta-grains is observed in the place of electric burns (Figure 2 (c)).

Cross microsections through the places with burns have been made with a research objective of possible structure changes on section. The analysis of polished microsections has allowed to establish the following:

- The macrostructure of the main material of both blades is identical. It corresponds to 1 or 2 point of 10 scoring scales of macrostructure for titanium alloys. The background is dull.
- The microstructure of the main material of both blades has 2 or 3 type of the alpha-beta titanium alloy scale (Figure 3).
- Any structural changes on the section of both blades in the places with the spots on the output edge are not revealed after flaw detection etching;
- In the material macrostructure in the places with the burns, which are artificially induced during machining, the structural changes connected with a material overquenching in the form of white speck up to 0.53 mm in depth (Figure 4 (a)). At the same time there is a shiny background of material in the places with the spots;
- The microstructure corresponds to the same 2 or 3 type of the alpha-beta titanium alloy scale as the main blade material. Herewith there are changes of fine structure in the form of a beta-titanium alloy overquenching. That is typical for heating to temperatures of 800÷850°C, i.e. below temperature of polymorphic transformation (Figure 4 (b)).
- In the material macrostructure grain enlargement detected in the places with the electric burns. That grain enlargement is up to 5÷6 points of 10 scoring scales of titanium alloy macrostructures. The background is shiny. There are zones of thermal influence (ZTI) around the burns (Figure 5 (a)).
- In the places of the electric burns the microstructure with large-size polyhedral beta-grains is observed (Figure 5 (b)), which is typical for heating above the polymorphic transformation temperature.

Figure 3. Typical microstructure of the main blade material, x5000.
According to requirements of the engineering specification for the blades of a rotor macrograin size is allowed up to the 3rd point, background and microstructure are not specified, and burns are not allowed. The microstructure should correspond from 1 to 5 types from No.2 scale of the industry-specific standard and burns are not allowed.

Structural changes, which are typical for the burns, manifest themselves in the form an existence of the beta-titanium alloy overquenching, macrograin enlargement, a shiny background and alpha constituent disappearance.

Also measurements of microhardness in the places with the burns and in the main material were carried out. Results of the measurements of microhardness and a relative difference between microhardness in the places with burns and in the main material are given in table 1.

Spectrographic analysis revealed that the material grade of both blades is a VT3-1 titanium alloy, which conforms fully to the process requirements according to the drawing of the part.
Table 1. Results of the measurements of microhardness and a relative difference between microhardness in the places with burns and in the main material

| A reference number of the part | A relative difference between microhardness in the place with a spot or a burn and the main material, % |
|-------------------------------|--------------------------------------------------------------------------------------------------|
|                               | In the place with the spots revealed at flaw detection etching | In the place with the burns, which are artificially induced during machining | In the place with the artificially induced electric burns | Main material |
|                               | Microhardness, Vickers number, kgs/mm² | 100 | 100 | 100 |
| In the place with the spots revealed at flaw detection etching | 501 | 519 | 27/30 | |
| In the place with the burns, which are artificially induced during machining | 527 | - | 27* | |
| In the place with the artificially induced electric burns | - | 743 | 77* | - |

* The microhardness difference on the blades should not exceed 20% according to requirements of the engineering specification.

3. Conclusions
The conducted research has allowed to draw the following conclusions:

The material grade of both blades corresponds to the VT3-1 titanium alloy provided by the process requirements according to the drawing of the part.

Three types of defects were found on the blades of interest. Those are the burns revealed at flaw detection etching, the ones artificially induced during machining, and the electric burns.

The structure changes caused by the burns found after flaw detection etching are surface alterations. They consist in the beta-titanium alloy overquenching, as well as increasing the microhardness of the material. Such type of burns can be corrected by carrying out the stabilizing annealing.

The beta-titanium alloy overquenching and the increase in microhardness are found in a blade material microstructure with the place of the burns, which are artificially induced during machining, and those are typical for heating up to the temperatures in the range of 800÷850°C.

In the places with electric burns the study revealed an existence of large-size polyhedral beta-grains and a significant increase in microhardness. Those are typical for heating above the polymorphic transformation temperature. Such defects are nonremovable.

References
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