Structure Changes Due to Service Deformation and Oscillations in Low Pressure Turbine Blades

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Abstract. Turbine blades are one of the most important machine parts in every power generator. Material for fabricating the turbine blades belongs to a group of chromium stainless steel (9-14% Cr), with medium content of carbon (less than 0,4%). A medium content of carbon is just needed for hardness/strength increasing of the blade body. The shape of a blade normally is complex, in a cross section it′s a deflected water-drop. As normal working conditions may be considered following parameters: 3000 rev./min, temperature inside the generator 80-120°C, and humidity over 80%. After 40 000 hours in service, those blades were brought to investigation, here will be reported the results of metallographic testing. The blades were normalizing annealed, and only thin sections at the top of the blade are quenched and tempered. After 40000 hours in service, the initial structure is changed. Some pores were metallographically detected and their aggregation combined with probable coagulation around non-metallic inclusions is observed. Those pores can lead to the crack formation. Aggregated pores are not at the same position with maxima oscillations or deformations in the working regime of such blades.

Introduction

Every turbine contains a great number of important machine parts but the blades [2,7], without any doubt, are one of the most important. Practically, there is no any part in power generator which posses such kinetic energy, wear of working surface, and in a normal regime works at 3000 rev/min, every day, every week, even a whole year, like a blade. Corrosion and/or erosion attack on blades are also available in moisture atmosphere [4,8], because the wet water vapor is an usual working media in low pressure turbine.

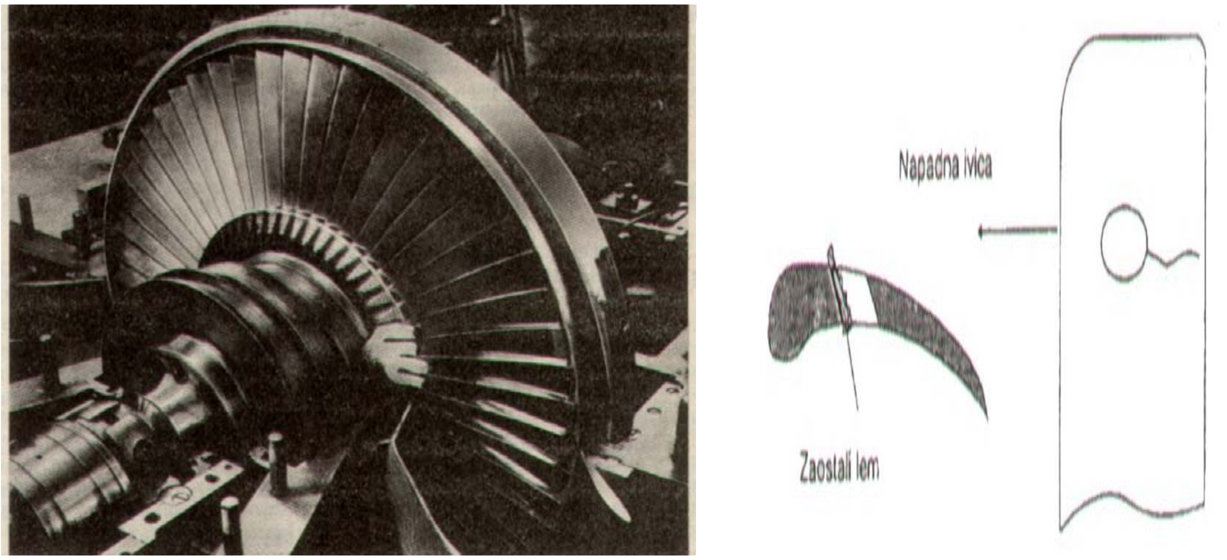
At the same time a blade, as a console type of machine elements, is subjected to (mostly harmonic) vibrations and oscillations. All of these stresses or influences, the chosen material (high chromium steel 12-14%Cr and ≈ 0,25%C) has to sustain. Deformations & oscillations in working regime of blades, now could be successfully monitored by using a laser technique [10].

It is shown in wider literature [2,5] that cracks in material of such turbine blades have appeared rather on the similar places, as like in or around the hole for bandage-wire, and also in places where vibrations reaching their highest value.

Many models were developed to estimate the crack growth rates [3,5], most of them are based on the characterization of fatigue cracks under known loading conditions (especially in laboratory experiments) using the stress intensity factor. In these investigations the promise is that the path of the crack is linear and that it′s plane of growth is normal to the loading axis. But, however, cracks seldom not propagate in a linear fashion [5,8], as it was stated here on a microscopic level. The changes in microstructure can occur due to factors as like: stress state, environment, load excursions, or local microstructural discontinuities.

Here are registered and presented a local variations in the microstructure and crack initiation which were find out in bulk material of low pressure turbine blades after 40 000 hours in service. But, when in the bulk material of the blade is undergoing to changes in microstructure, the formed pores and their coagulations could not be ignored for any further discussions of crack growth rate, and for prediction or estimation of rest working life, and so on.

Working conditions in low pressure turbine. Blades of different dimensions (lengths and mass) are arranged on turbine rotor in 38 rows, as it's shown in Fig. 1a). The working temperature inside the turbine is in the range of 100÷40°C: the highest incoming temperature does not overcome 100°C, while the outcoming temperature is at least 40°C.



a) b)

Fig. 1. View of turbine rotor with blades in maintenance repair a) and cross-section of a blade b)

Pressure inside the turbine is about 0,04 bar. The humidity of working atmosphere is high. The specific mass of wet vapor is much greater than in dry vapor. This fact implies on working conditions, i.e. it means that friction between wet vapor – blade surface will be smaller if dry vapor is used. In explained working conditions, environmentally-assisted corrosion, erosion or fracture became possible.

Experimental

Design of turbine blade, material and metallographic preparation. The turbine blades always have a specific design with the cross-section resembling a deflected water-drop, Fig. 1b). In some cases the hole is drilled in the blade for bandaging purposes, i.e. for decreasing the oscillations of the free end of the blade, Fig. 1b). Frequently, these holes are sources for crack initiations and their growth, so they may have begun the cause of the blade fracture, an accident extremely dangerous for the whole power plant [7-9]. Deformations along the one blade, at two values of harmonic oscillations are shown in Fig. 2.

The lines of vibrations are easily visible by using the method of holographic interferometry [10]. Greater oscillations and deformations of blade are positioned at lower frequency, see careful Fig. 2. It represents an acceptable explanation for the reason of crack appearing, see pos.1. in Fig. 2.

Low pressure blades are made of steel [7-12] similar to Č 4172 or according to DIN corresponds to X20Cr13. Namely, this steel belongs to a group of chromium stainless steels (9-14% Cr), with medium content of carbon (less than 0,4%). Such carbon content is needed not for corrosion resistance but rather for improving the strength properties of the blade body.

Metallographic investigations were performed using light microscope. The samples were prepared by using the standard technique of grinding and polishing, whereas Nital was used for etching. Microhardness of the polished surface of a sample was measured by a microhardness tester applying the load of 100 g.

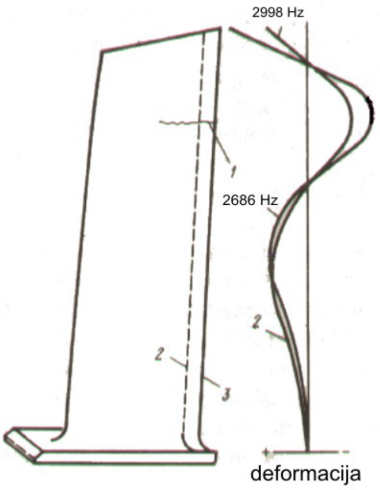
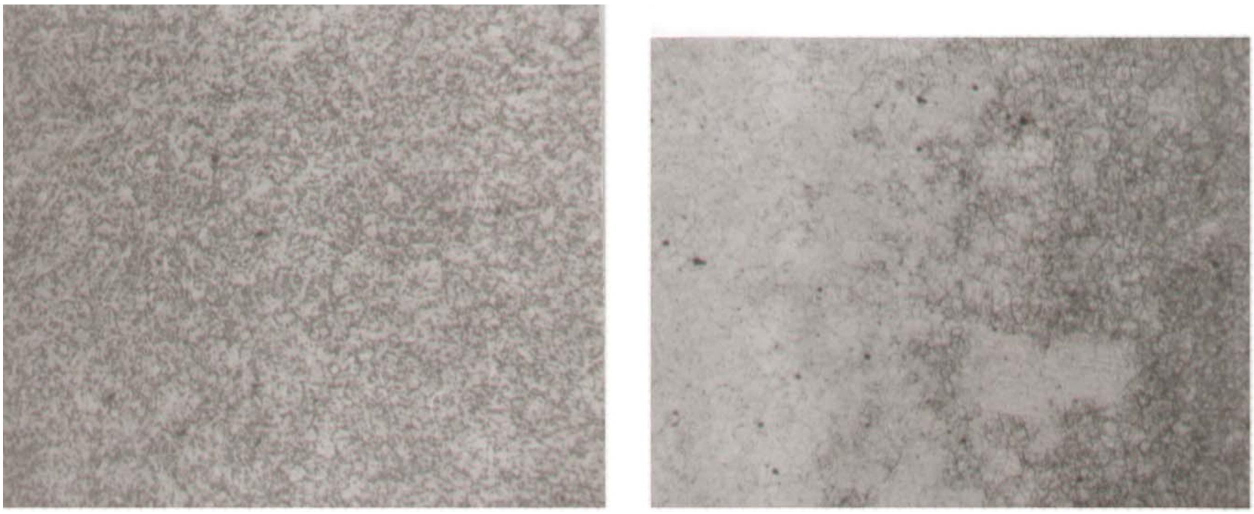


Fig. 2. Deformations along the blade for two values of oscillations
1-crack; 2-new edge of blade; 3- edge of blade

Results and discussion

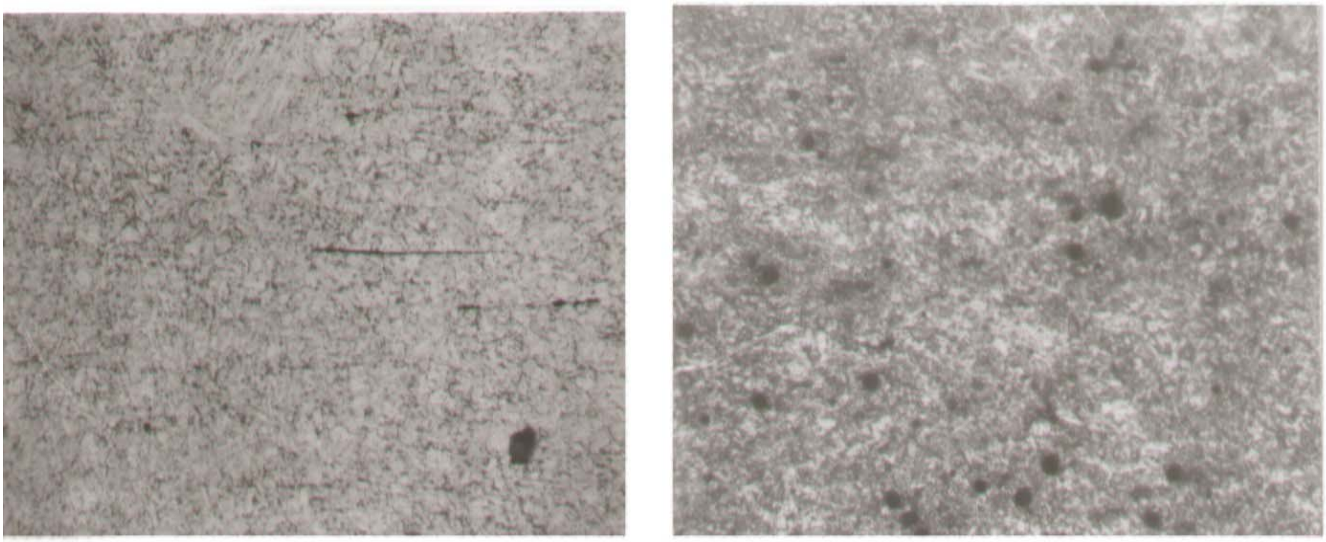
A mixture of ferrite and chromium carbides (Cr_7C_3 type) with retained austenite [1-6] is present in the microstructure of the blade after 40.000 hours in service. According to microhardness values (in the range of 240-27o $HV_{0,1}$) which are approximately the same along the cross section it is concluded that this structure is obtained by the normalizing annealing. This kind of structure is shown in Fig. 3a). However, the edge of the thinner part of blade is quenched and tempered with hardness ≈ 440 $\mu HV_{0,1}$, see Fig. 3b). Such a choice of heat treatment could be explained by the need for increasing strength and resistance to high level of vibrations on the blade edge.



a) b)

Fig. 3. Microstructure of turbine blade: a) fully homogenous structure and
b) quenched and tempered condition; x 185,

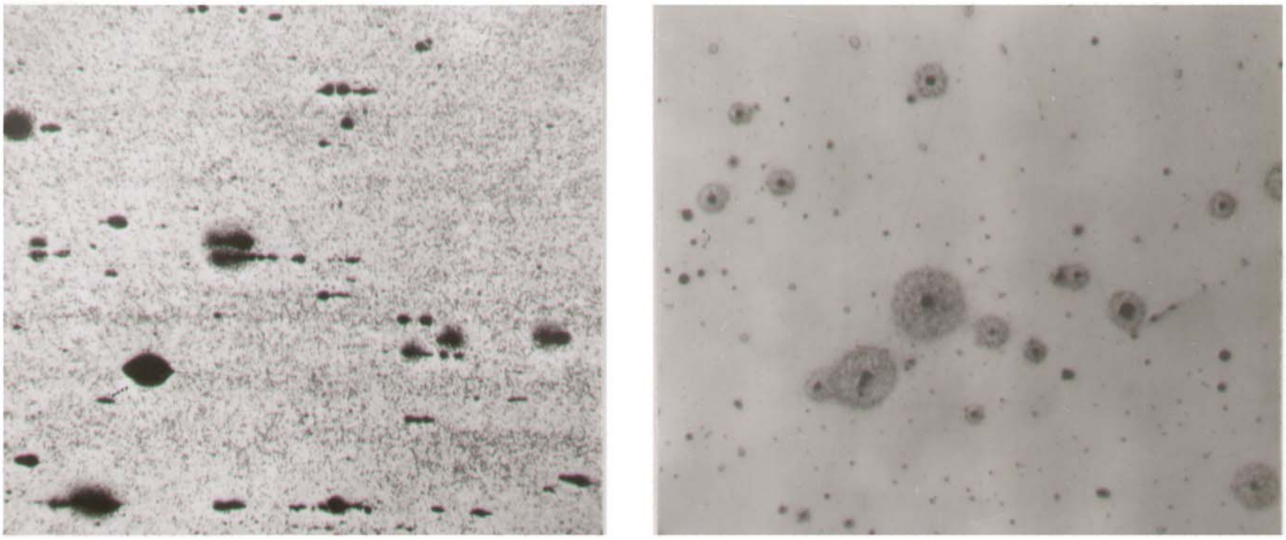
In addition, in the cross section of blade non-metallic inclusions are found, see Fig. 4a). These inclusions are visible both in longitudinal and cross-section of blade (Figs. 4a and b, respectively).



a) b)

Fig. 4. Non-metallic inclusions in a) longitudinal direction and b) cross section of blade, x 185

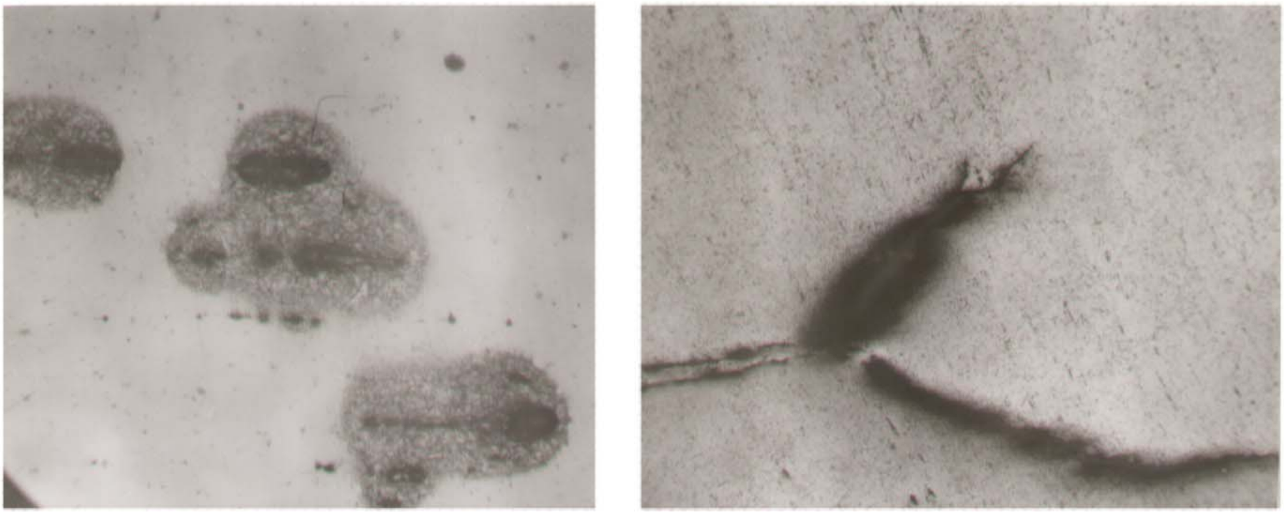
Serious problems may arise due to these non-metallic inclusions since they are surrounded by a number of individual pores (fig. 5a) or even characteristic “clouds” of pores are formed around inclusions (fig. 5b).



a) b)

Fig. 5. Non-metallic inclusions associated with pores in: a) longitudinal and b) cross sectional direction of the blade, x 185

The significant changes in the microstructure may arise when “clouds” are aggregated in clusters around non-metallic inclusions (Fig. 6a). As a consequence of such aggregation and probable coagulation of pores, the cracks will be easily formed, as it is shown in Fig. 6b).



a) b)

Fig. 6. Aggregated non-metallic inclusions a) and cracks in blade b) x 185

From the aspect of blade vibrations, the crack will be expected only at some positions, as it was illustrated in Fig. 2, This kind of crack usually is initiated at the blade surface. In another case, when an aggregation process of pores occurs, the coagulation and coarsening of pores may provoke the crack initiation not on the surface, but in the bulk of the blade material (Fig. 6b).

It should be mentioned that those coagulated pores could not be identified by using other testing techniques (ultrasound or similar) but only by using a metallographic analysis.

Contrary to previously reported results [7-9], some investigations [13-14] have shown that mechanical properties at the root of blade, in the case of low pressure turbine blade, obviously are not lesser than in other parts of low pressure turbine blade.

Conclusions

Results of metallographically investigated structure of turbine blades, after 40000 hours in service, can lead to the following conclusions:

- The initial microstructure (mixture of ferrite, carbides and retained austenite) corresponds to applied the normalizing annealing, except the thinner part of the blade which is quenched and tempered;
- Microhardness values corresponds to microstructural findings;
- Contrary to previous models predicting the crack initiation at the surface of the blade where deformations and vibrations reach the maximum values, the crack reported in this paper was detected in the bulk of material as a result of pores aggregations (or coagulations).

References

[1] Shrader, A. Rose, A.: De Ferri Metallographia, tom II, Russian translation, Moscow 1972, Metallurgia, pp. 26-46.

[2] Gidroerozija metallov, Moskva, 1976, Gosenergoizdat, pp. 86-97.

[3] Engel, L., Klingele, H.: An Atlas of Metal Damage, Wolfe Science Books 1981, pp. 62-72.

[4] Group of authors: The Appereance of Cracks and Fractures in Metallic Materials, Dusseldorf 1983, Stahleisen, pp. 10-31.

[5] Suresh, S.: Crack Deflection: Implications for the Growth of Long and Short Fatigue Cracks, Met. Trans., 14A/1983/pp. 2375-2385.

[6] Guljaev, A.P. Metallovedenie, Moscow 1986, Metallurgia, pp. 408-412.

[7] Tajra, S. Otani, R.: Teorija visokotemperaturnoj pročnosti materialov, Russian translation from Japanese, Moscow 1986, Metallurgia, pp. 130-153.

[8] Congleton, J., Wilks, T.P.: The influence of corrosion fatigue and air fatigue cracks in 13 %Cr turbine blade steel, Proceed. of Fifth International Conference – Mechanical Behavior of Materials, Beijing 1987, vol. 2, pp. 795-802.

[9] Nikitin, V.I.: Korrozija i zaščita lopatok gazovyh turbin, Leningrad 1987, Mačinostroenie, pp.78-103.

[10] Koebner, H.: Industrial Application of Lasers, Russian translation, Moskva 1988, Masinostroenie, pp. 76-93.

[11] Grigorjanc, A.G.: Osnovy lazernoj obrabotki materialov, Moscow 1989, Masinostroenie, pp. 47-80.

[12] Reports 2000-031; 2000-161 about low pressure turbine blade investigations from 37 and 38. row, From Institute for Testing of Materials, Belgrade 1993.

[13] Karastojković, Z., Momčilović, D.: Case Study – Cracks in Steam Turbine Low Pressure Blades, Materials for Advanced Power Engineering, Fifth conference, Liege – Belgium 1994.

[14] Karastojković, Z. Čubrilović, S.: Karakteristike magnetofluksnih i metalografskih ispitivanja lopatica turbine niskog pritiska, Seminar EPS-a, Beograd 1995, knjiga II, pp. 265-275.