A NON-DESTRUCTIVE METHOD TO ASSESS A DEGREE OF OVERHEATING OF GAS TURBINE BLADES

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Abstract

The paper has been intended to propose an objective, non-destructive method to assess a degree of overheating of gas turbine blades material. The method has been based on the opto-electronic recognition of images of blade surface layers to extract characteristics thereof for both overheated and serviceable blades. Any image of a blade surface layer is analysed within the Fourier plane by means of a computer-generated version of a matrix of ring-wedge detectors. A ring-wedge detector enables good effects when used to assess health/maintenance status of gas turbine blades. Results of examining microstructures of both overheated and serviceable blades are the confirmation. Findings can give grounds for a method of diagnosing to what degree blades in operation suffer overheating.

Key words*: turbine blade, diagnosing, visual method, microstructure*

1. Introduction

The diagnostic examination is usually aimed at determining health/maintenance status of an engineering object. In the case of complex structures, the diagnostics plays an important part in the assessment of real time of failure-free operation. Extremely varying operating conditions of particular components and sub-assemblies of engineering objects are factors of great importance that affect operating conditions. While operating a turbine engine, no matter whether an aircraft, a marine or a traction one, various failures to engine assemblies occur. The most common ones are the blade's material overheating and thermal fatigue. Elimination of this kind of failures is always carried out as a major engine repair, which results in tremendous cost [1, 5].

A decision on whether the repair is necessary is taken by a diagnostician who can diagnose condition of individual components with a visual method, using e.g. a videoscope (Fig. 1). The recorded image of the surface layer of a component under examination gives grounds for the assessment of the component's condition. It is compared to standard images of similar components, both fit and unfit for use, e.g. turbine blades.

This kind of condition assessment proves very subjective, since it depends on the diagnostician's knowledge and vision. Light that falls on the surface is reflected and, therefore, objects can be observed. Shapes and colours of surfaces of metal objects become distinguishable. Although a skilled and efficient diagnostician can distinguish over a wide range of colours (ones within the scope of 400 through 700 nanometers, starting with violet to dark red), any mistake due to his subjective assessment can result in acknowledging an unserviceable (overheated) blade for a fit-for-use one, and vice versa. In the first case, an engine failure may happen in a short time, in the second one – an expensive major repair of the engine may be effected. Therefore, the diagnostician's decision is verified with a destructive method. The component under examination is subjected to analysis of microstructure of the microsection [5, 7].

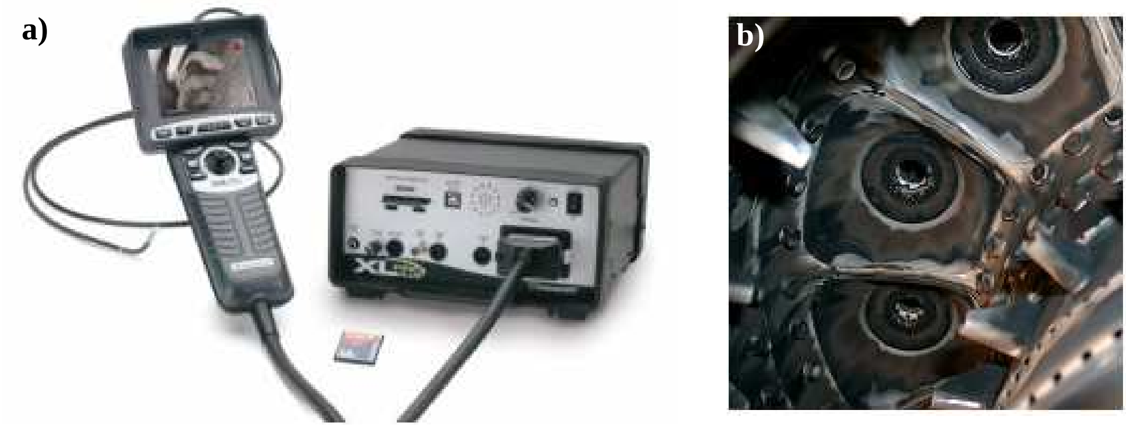


Fig. 1. A commercial videoscope (a), and a jet engine combustor on the videoscope screen (b)

In the case illustrated with Fig. 2, one cannot explicitly determine whether the surface of at least one of the presented blades indicates the material overheating. Furthermore, according to criteria in force until now, nothing can be said about the degree of overheating. No objective criteria have been determined to explicitly and in a non-destructive way assess the degree of the blade's material overheating [3, 4].

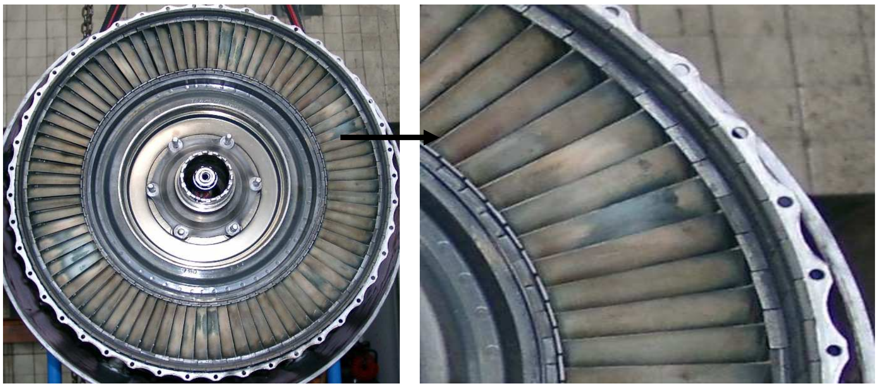


Fig. 2. A gas turbine with visible changes of colours on blades surfaces [4]

2. Methods of analysis of light signals reflected from a metallic object's surface

Dynamic development of technique of acquiring images, both monochromatic and colour ones, facilitates extensive and easier use of information included in recorded images to satisfy needs of the diagnostics. From the diagnostician's point of view, the correct colour assessment proves of great significance in many cases [4, 6]. It is often used in numerous diagnostic procedures in areas such as cartography, chemical industry, aviation. A decision is made by comparing a standard colour with that/those of recorded images. In [12], an advisory system has been suggested to assist objective colour assessment as a method to determine petroleum products that affect corrosion of metals. In the postulated system, methods of fuzzy logic are used to assess and classify colours. Authors of [10 - 12] present also methods of calculating a membership function of the analysed point of a colour image to determine colour (area) according to the classification of colours based on the CIE chromaticity diagram, the so-called colour triangle.

In the present-day diagnostics, integrated image analysers (image matrices) are more and more common. They are used in various image recording/analysing techniques aimed at acquisition of the quantitative and qualitative information on investigated states and phenomena represented by means of images [10]. Among various assisting methods, morphological methods of image conversion are of particular interest. They are among the most significant methods in the computer-image analysis, since they are a preliminary step to create more complex operations connected with analysing shapes of objects and their positioning to each other.

Images of uniform structures, commonly called ‘textures’, build up a characteristic group. They are of great importance in many areas of science and technology, e.g. metallography, crystallography, tribology, etc. Extraction of their characteristics (e.g. statistical parameters, Haralick’s parameters) would enable to classify them and then to infer on characteristics of materials, objects, and processes represented with texture images [9].

A method that makes use of laser technology [2] is an interesting non-destructive solution to assess (diagnose) condition of rotor blades that do not rotate. Properties of laser radiation are used in the course of investigation. Examined are differences between the incident and reflected radiations. The diagnostic testing work with dynamic excitation engaged provides interferograms that determine forms of blade vibration at different resonance frequencies. This is a source of information on the blade’s dynamics, and hence, on mechanical properties, design condition, etc. of this blade.

Sarnecki J. [8] applied a ring-wedge detector to recognise images of tribological-wear-effected products to diagnose types of wear of bearing systems.

3. Methodology of image acquisition – of luminance (brightness) and chrominance (colour) of surface layers of gas-turbine blades

The jet’s gas-turbine rotor blades made of the ŻS6 alloy (Fig. 3) are subject to tests. The blades have been covered with alitised layers (consisting of aluminium and other elements) for protection against high-temperature gas affecting them.

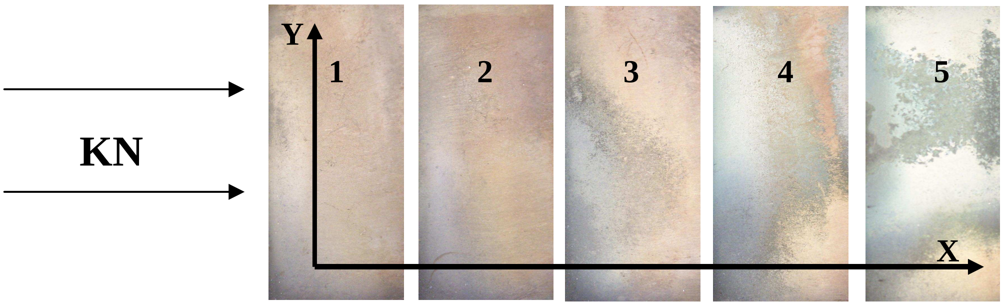
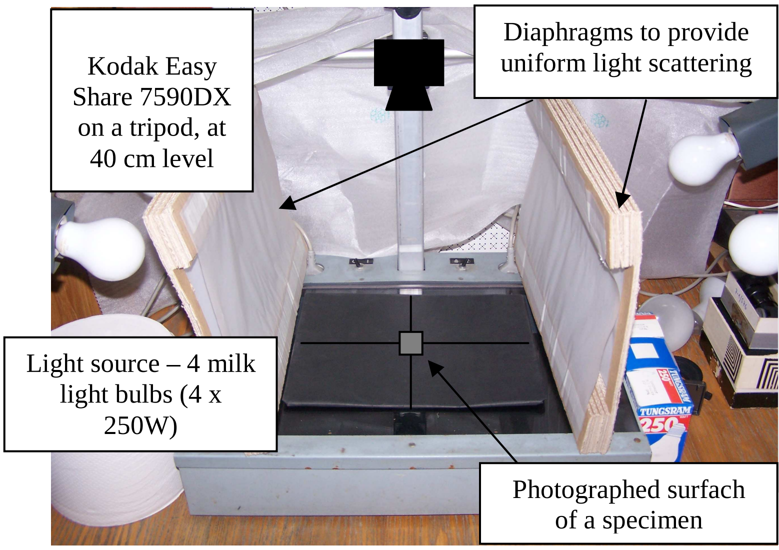


Fig. 3. Surface layers of gas-turbine blades in service (KN – edge of attack)

Colour and intensity feature light – the visible radiation (a part of the electromagnetic spectrum), which are recorded with human organ of sight. In case of a digital camera it is the built-in optics that focuses light rays and plays a part of the ‘organ of sight’, and the electronics, i.e. a light-sensitive sensor. An image in front of the camera lens is mapped against surface of matrix provided with detectors furnished with tri-colour RGB filters (RGB – three primary colour constituents, i.e. red - R, green - G, blue - B) which enable detection of particular colours.

To simplify, the acquired information on the intensity of colour distribution in case of colour images, and of shades of grey (grey scale) in case of monochromatic images is recorded on a memory card in the form of points called pixels, which form an image [9].

Modern methods of image analysis have found applications in broadly understood technical diagnostics. As a primary advantage of this type of diagnosing one should mention the non-destructive nature of the method to acquire information on health/maintenance status of a given object. The described non-destructive method enables determination of the condition of a given surface, i.e. of a surface layer discerned as luminance (brightness) and chrominance (colour) that reach a recording device, i.e. a camera. The photographing and the recording of images were both carried out on a test stand (Fig. 4).



Conditions of image acquisition:
- light source – light in the visible spectrum;
- angle of incidence of light rays - 45º;
- angle of image detection - 90º;
- acquistion of images in the same resolution and zoom;
- sensor: matrix 5.360 MPx (effective pixels 4.977 MPx), size CCD 1/2.5’’, mask R G B

Fig. 4. Test stand to acquire images of surface layers of turbine blades

Repeatability of results was proved by photographing blades under the same conditions, with suitably matched parameters of the digital camera. Application of diaphragms ensured uniform reflection of light from the metal surface to provide uniform light scattering. The diaphragms eliminated light reflections that cause over-exposure of obtained images. Identical photographing conditions enabled comparisons of changes in colours of surface layers of blades showing different health levels. The image recording format was adjusted to satisfy needs of image compression according to Exif 2.2 standards. In order to maintain as much information about the recorded image as possible, compression was set to the lowest level acceptable.

4. Analysis of images of turbine blade surfaces

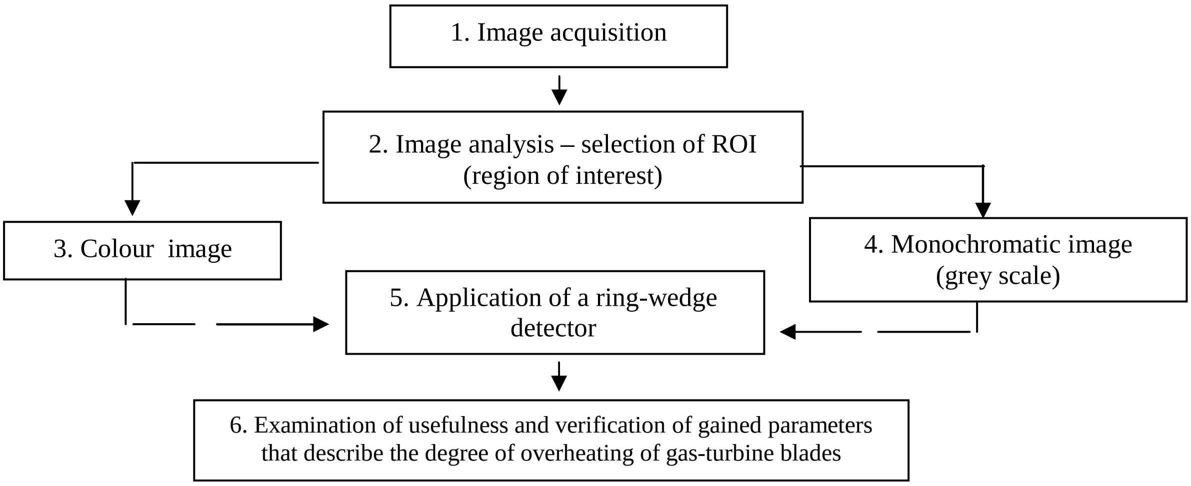


Fig. 5. Acquisition, and computer colorimetric and spectral analyses of signals from blade surfaces – a diagnostic model

Some representative regions of blade surfaces (averaged ROI – regions of interest) were chosen to explicitly describe the blades. The RGB colour image is a model that results from receptive properties of the human eye and is based on the fact that the sensation of almost all colours by the eye can be effected by mixing - in some pre-set proportions – only three selected light beams of some suitably matched spectral bandwidths. In the RGB model of colour identification there are only three constituents: R - red, G - green, and B - blue. Therefore, it is an additive model, where each colour is obtained by means of combining three primary colours. Hence, each channel is analysed separately. Colour images were analysed using the Matlab software (Image Processing Toolbox).

A colour image was converted into a monochromatic one, i.e. one, for which information on colour distribution is negligible. Using the Matlab software (Image Processing Toolbox), a colour image was converted into one representing the grey scale (256 grey levels). It was investigated whether the ‘black-and-white’ information is sufficient to describe changes in colours due to high temperature affecting the blades.

A ring-wedge detector was used to analyse images. It is a circle-shaped instrument, which comprises two parts: the first one includes concentric-located rings, whereas the second one is formed with wedges that join in a common vertex in the middle of the detector. Each of the regions is a surface photodetector that transforms intensity of the incident light into a signal proportional to intensity of this light. A computer-generated hologram (CGH) shows shape identical to that of the ring-wedge detector, and is also composed of areas of rings and wedges. Therefore, the CGH acts as an extractor of features (characteristics) from images in the domain of frequency. Results of analyses of colour images of turbine blades, and those within the grey scale are presented in Fig. 6. Values of rings and wedges for blades no. 4 and 5 evidently stray from those for the remaining blades.

5. Microstructure of turbine blades

Mechanical and technological properties of any alloy are closely related to its microstructure, which in turn strongly depends on the sort of heat treatment applied. Affected with multiple temperature fluctuations, the alloy is subject to thermal fatigue. High temperature affects also the surface layer. The turbine blades are made of high-temperature nickel-base alloy ŻS6. They are covered with alitised layers to increase their high-temperature creep resistance.

Metallographic microsections of blade specimens were prepared with standard methods to be then etched with a reagent of the following chemical composition: 30 g $FeCl_2$ + 1 g $CuCl_2$ + 0.5 g $SnCl_2$ + 100 ml HCl + 500 ml H_2O. The microstructure was observed by means of a light microscopy, and SEM - the scanning electron microscopy.

Examination of microstructures of the alitised layer and the ŻS6 alloy shows that the effect of exhaust gas of high temperature on turbine blades under examination resulted in decohesion of the alitised layer and modification of the strengthening phase $\gamma^{‘}$ (Figs 7 and 8). Fig. 7 shows regular (correct) structures of the alitised layer and the ŻS6 alloy of turbine blade no. 1 (see Fig. 6), where as Fig. 8 shows overheated microstructures of the alitised layer and the ŻS6 alloy of turbine blade no. 5 (see Fig. 6). The alitised layer suffered swelling, pop-offs also occurred, and even worse, cracks were initiated due to thermal fatigue (Fig. 8a). The image of microstructure of the ŻS6 alloy shows secondary precipitates of fine-dispersion phase $\gamma^{‘}$(Fig. 8b), effected with exhaust gas of high temperature. The phase $\gamma^{‘}$morphology proves that after having exceeded critical temperature, the alloy suffers overheating and any turbine blade cannot be considered serviceable (fit for use) any more.

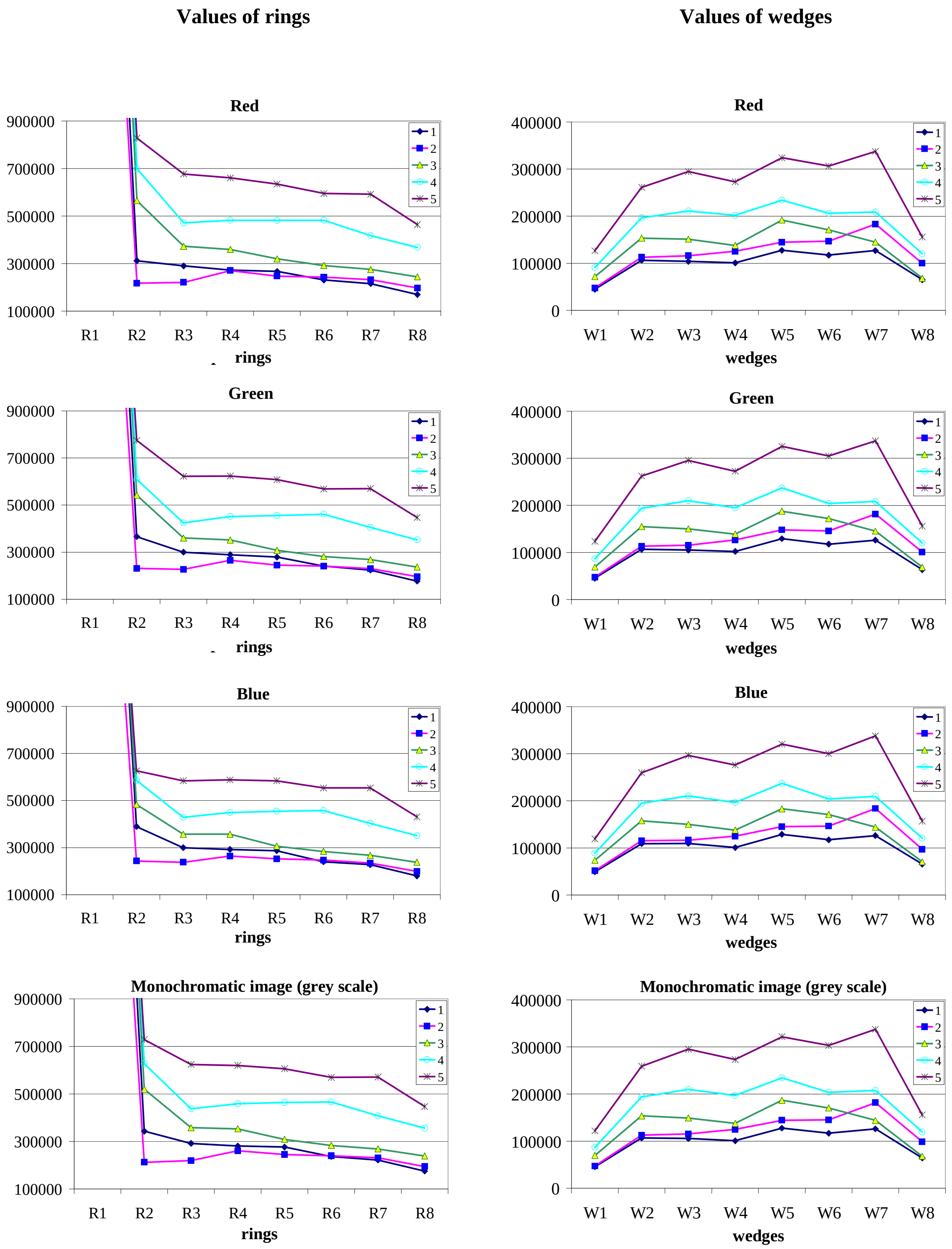


Fig. 6. Values of rings and wedges for particular turbine blades

According to A. Dudziński [5] and A. Poznańska [7], any modification of this kind of the strengthening phase γ' proves susceptibility to brittle cracking. Furthermore, A. Dudziński states in [5] that any blade made of a very similar alloy EJ-929, subjected to a creeping test should be recognised overheated after exceeding temperature 1188 K. The acquired images of microstructure of blade no. 5 can give good grounds to assess a degree of overheating of gas-turbine blades made of the ŻS6 alloy.

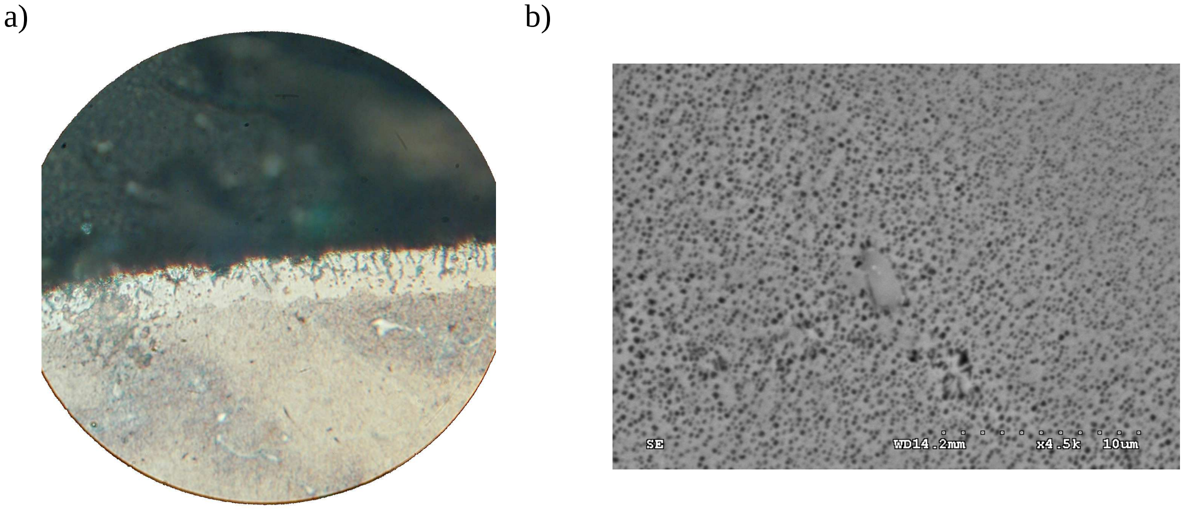


Fig. 7. Regular (correct) microstructure of a turbine blade: a) of the alitised layer, x 450, and b) the ŻS6 alloy, x 4500

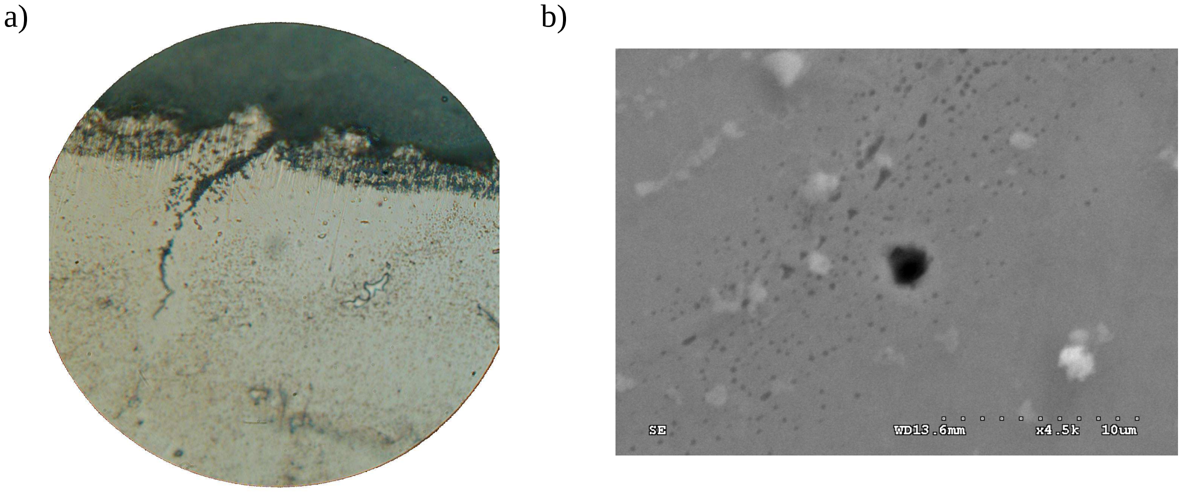


Fig. 8. Overheated microstructure of a turbine blade: a) of the alitised layer, x 450, and b) the ŻS6 alloy, x 4500

6. Summary

Findings of experimental work on high temperature affecting gas-turbine blades made of the ŻS6 alloy have been presented in the paper. The operated blades of aircraft jet engine were subject to examination. A ring-wedge detector was used to analyse images of surfaces of blades showing different health levels. Results of blade-microstructure examination have entitled a statement that blade no. 1 shows regular (correct) structure, whereas blade no. 5 – the overheated one. Comparing these results to those of analysing images of blade surfaces, the following can be stated: blades no. 1 to 3 show correct condition, since values of rings and wedges remain comparable. On the other hand, blades no. 4 and 5 are overheated, because values of rings and wedges differ considerably from those for blades mentioned above. Therefore, correlation has been shown between the blade-surface image and condition of microstructure of turbine blades made of the ŻS6 alloy and covered with the alitised layers.

The intended aim of applying both a visual non-destructive method used in the diagnostics of engineering objects and the methodology of analysing blade-surface images acquired in visible light spectrum was to gain some cognitive information of great importance. In practice, this information could be used to assess changes in the microstructure, i.e. the overheating and thermal fatigue of components and sub-assemblies of engineering objects affected with variable high-temperature heat loads.

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