

THERMAL STRESSES IN THE BLADES WITH AND WITHOUT TBC BASED ON THE TEMPERATURE DISTRIBUTIONS MEASURED USING THERMAL IMAGING CAMERA

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Abstract. Turbine blades used in the jet engines are subjected to frequent and rapid temperature changes. As a result of the hot gases influence the temperatures excess 1000°C. Certain conditions for the blades generate local thermal stresses. In this paper the thermal stresses are calculated on base on experimental measurements of the temperature distributions using the high resolution thermal imaging camera FLIR SC7000 registered the distribution of temperature field for the blades with TBC and without TBC. The distribution of stresses in the blades based on the collected measurement data has been calculated. The calculations were made using FEM method implemented in COMSOL.

Keywords: THERMOGRAPHIC MEASUREMENT, THERMAL STRESSES, FINITE ELEMENT METHOD, MECHANICAL STRESSES, BLADE MATERIALS, DESIDN.

1. Introduction

The conditions within gas turbines are extreme: the pressure can be as high as 40 bar, the temperature more than 1000 K. Any component must therefore be carefully designed to be able to withstand thermal stresses, vibrations and loads asserted by the fluid rushing through the turbine. Therefore, it is very important to recognize the thermostresses arisen in blades due to the temperature gradients. Particularly, the distribution of real temperatures in-situ at work of engine is crucial. Usually, calculation of "internal stresses" or thermostresses in the turbine blades is based on modeling of the temperature distribution [1,2]. There are many works (see, for example, Refs. 3-10) where an analyses of thermostresses in the turbine blades was performed using the finite element method (FEM) assuming some theoretical distribution of temperature. From other hand, real distribution of temperature are playing an crucial role for estimation of the real thermostresses distribution in situ at work of engine.

In this paper is proposed the method of the real temperature distribution measurements. The measurements for the turbine blades with and without thermal barrier coatings (TBC) have been performed. Simultaneously, the calculations of the thermostresses distribution are provided for these blades using the COMSOL computer Program. The significant differences in this distribution for blades with and without TBC are demonstrated.

2. Description of the measurement method

2.1. Object of research. The blades were made from the JETHETE M-152 high strength stainless steel which is a 12 % Cr, about 3 % Nickel, molibden, mangan, Silicon, carbon.



Fig. 1 The turbine blades: left – without TBC, right – with TBC.

The TBC were performed from ceramic material consisted ZrO_2 (zirconium oxide) mostly. The fig.1 show the blade without TBC on left and the blade with TBC on the right site.

2.2. The temperature distribution measurements. Measurement of the temperature distribution was made using the high resolution thermal imaging camera FLIR C7000. Temperature range of camera was set from 200°C to 1500°C. The frequency of measurement was 25Hz. In order to perform correct measurements of the temperature distribution on the surface researched there was

made series settings to verify several parameters of the camera: emissivity of the object, apparent temperature– this parameters is important, when the measuring element is characterized by low emissivity; atmosphere permeability, distance between the objective of camera and the sample researched – this parameter is important because big part of radiation of the object is absorb in the air so the optimal distance was 1,35m.

The thermographic measurements were made for the blades heated in the chamber imitated the combustion chamber of the jet engine. In the chamber (dimensions: 240mm x 300mm x 140mm) were installed 2 gas burners powered by propane butane gas. This installation allows to record thermal excitation of blades as well as to observe differences in the cooling of the blades with TBC coating and without one. In order to provide the cooling conditions closer to real engine the air-flow with velocity of 20 m/s has been used for cooling of the blades. Controllable table (fig.1) with a rotor mechanism enable us to observe all surfaces of researched elements in reality time: the angle of rotation is changed from 0 ° to 360 °.

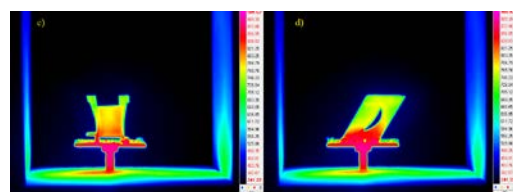
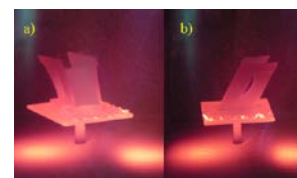


Fig. 2 The Blades measured located in a specially designed heating position in the combustion chamber: a) and b) images was carry out in visible light, c) and d) in IR region using the thermography camera.

In fig. 2 are shown the pictures of the blade located on rotating table. The pictures in fig. 2a and fig. 2b were obtained in visible light, whereas the pictures 2c and 2d – in the IR region using the FLIR SC7000 camera.

3. Experimental Results

The results of thermographic measurements for two types of blades (with TBC and without TBC) are presented in figs. 3-6 as actual temperature distribution on their surface. In fig.3 is shown the actual temperature distribution on the blade surface for the case with maximal heating. This time point is chosed as initial: $t=0$.

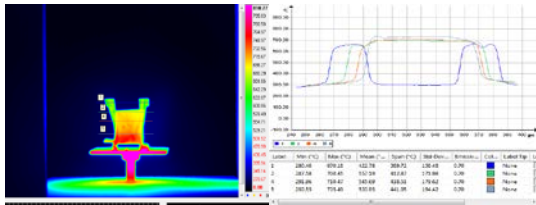


Fig.3 The temperature distribution for blade without TBC obtained by thermographic measurements at maximal heating: initial point of time, $t=0s$.

In next fig.4 is shown the temperature distribution on the same blade surface (shown in fig.3) after the 60 second cooling.

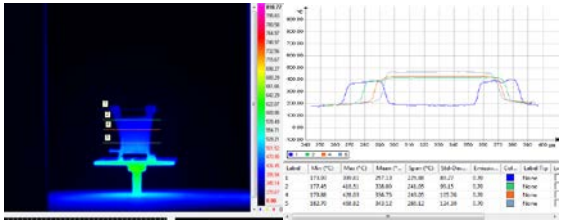


Fig.4 The temperature distribution for blade without TBC obtained by thermographic measurements after the 60s time cooling: time point is $t=60s$.

Such measurements of the surface temperature distribution were performed for each second during the 180 s time cooling of blade. Analogical measurements were carried out for the blade with TBC barrier. The results are presented in fig. 5 and fig. 6.

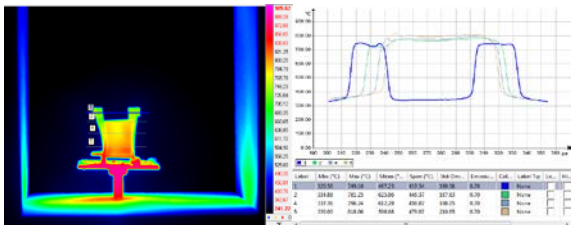


Fig.5 The temperature distribution for blade with TBC obtained by thermographic measurements at maximal heating, initial time point, $t=0 s$.

It is possible to notice that for last case of blade the maximal temperature $T_{max} = 818^{\circ}C$, at $t=0$ was achieved whereas at the same process of heating only $T_{max} = 735^{\circ}C$, at $t=0$ takes place for the case of blade without TBC

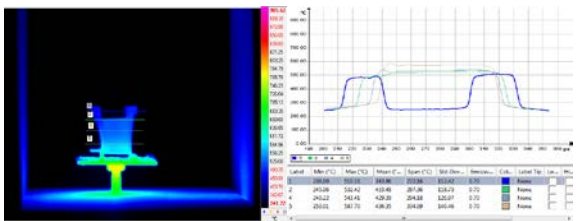


Fig.6 The temperature distribution for blade with TBC obtained by thermographic measurements after the 60s time cooling: time point is $t=60s$.

Despite of the same parameters and the same time of thermal excitation the temperature distribution for both case of blades is different: more high temperatures were achieved and process of cooling is more slow for the vane with the TBC coating.

4. Calculations

The thermal stresses in the blades researched are calculated on base on experimental measurements of the temperature distributions presented above. COMSOL is a Computer Program Environment available for the thermostresses calculations [11]. For this aim were used two main library of COMSOL: the Structural Mechanics Module dedicated to the analyses in the 2D or 3D coordinate system and the Heat Transfer Module to investigate the effect of heating or cooling in the devices, components, or processes. That is module to study the mechanisms of the heat transfer – conduction, convection, and radiation – often in collaboration with other

physics, such as structural mechanics. Program dispose of the Material Library with data for 2500 solid materials, such as Young's Modulus or heat and electrical conductivity, the temperature dependences of these parameters take place also. The M-152 alloy is available in the COMSOL Material Library. Among the data covered by the Material Library, there are the linear elastic model (requires a reference temperature that is set to 300 K) and the Poisson's Ratio that is set to 0.33, a number comparable to that for other stainless steels. The coating has been taken into account.

The calculations of thermostresses are based on the motion equation as well as on the heat transfer equation using the FEM method [12]. The first step of the thermostresses calculations was obtaining the voluminal temperature distribution on base of the experimentally measured surface temperature distributions. The example of such results is presented in fig. 7 where the inner temperature distributions are presented according three planes for the blade without TBC.

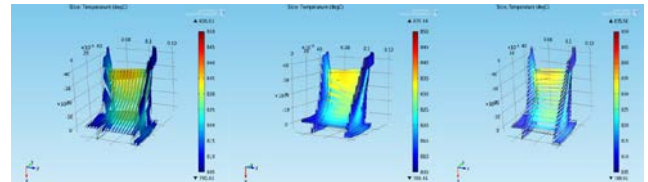


Fig. 7 The inner temperature distributions obtained according three planes XY, YZ and XZ for blade without TBC.

The temperature gradient distributions for blades researched is next step of calculations. In fig. 8a,b are presented such as distributions in the form of arrows the lengths of which is proportional to values of gradients. In fig. 8 are shown the points of maximal gradients which have achieved the values of above than 38000 K/m.

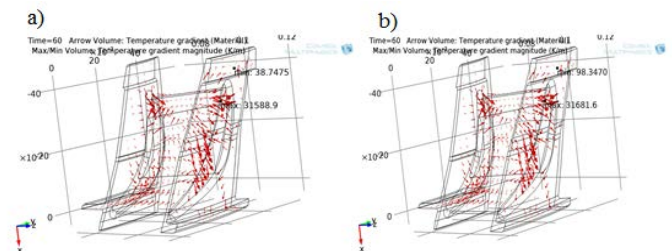


Fig. 8 The temperature gradient distributions obtained for blades: a) without TBC; b) with TBC

Third step is calculation of thermostresses and the results of these calculations are presented in Fig. 9a,b.

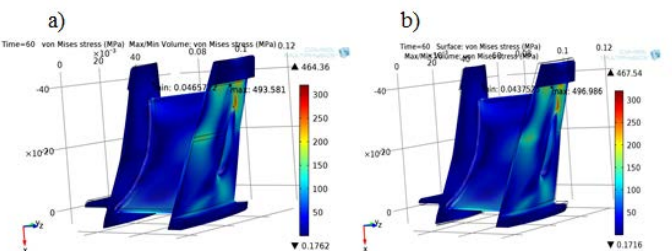


Fig. 9 The thermostresses distributions obtained for blades: a) without TBC; b) with TBC

In the fig. 9a as well as 9b are shown points with maximal value of stress. These values are 493.6 MPa for blade without TBC and 496.9 MPa for blade with TBC and these values are regarding to points where the maximal temperature gradients takes place. Whereas, the most volume of both blades is sized by low level of thermostresses, namely: below 100 MPa. At the same time this level is lower for blade with TBC.

5. Discussion and Conclusions

It is interesting to consider the temperature dependences of the thermostresses $\sigma_T(T)$ in different points of the blades. The curves of the $\sigma_T(T,x,y,z)$ are presented in fig.10 a, b. In inset of fig.10 are shown points on blade for which the $\sigma_T(T,x,y,z)$ curves were calculated.

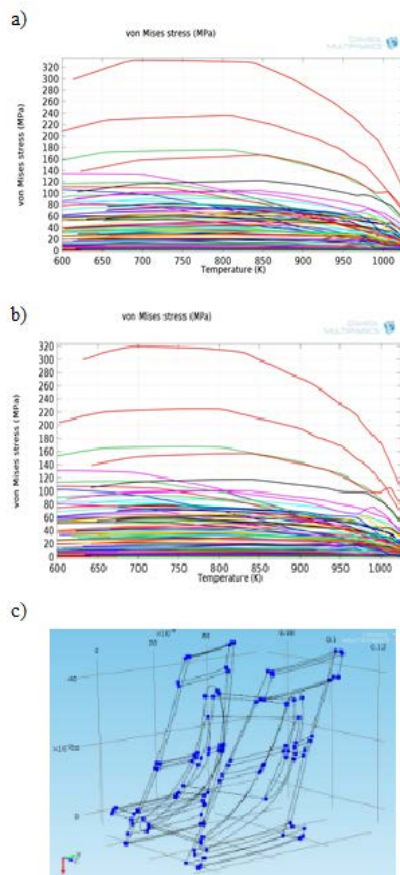


Fig.10 The curves of thermostresses $\sigma_T(T,x,y,z)$ for different points of the blades: a) blade without TBC; b) blade with TBC; c) are shown the points for which are calculated the $\sigma_T(T,x,y,z)$ curves.

The $\sigma_T(T,x,y,z)$ – curves are calculated for case of cooling of blades from temperature of maximal heating: to $T_{max} = 818^\circ\text{C}$ or 1091K. It is possible to see that maximal values of stresses are achieved at temperatures between 700K and 800 K. The $\sigma_T(T,x,y,z)$ – curves for blade with and without TBC covering are similar, particularly, in case of points with maximal stresses. Some differences take place for points where thermostresses are lower: the character of dependences is similar but level of stresses is lower for blade with TBC covering. The largest differences take place for the curves of total displacements.

The curves of displacements $\delta l(T,x,y,z)$ for different points on the vane surface are of great interest because that are values of real deformations in blades while the total displacement don't means the linear extension (thermal dilatation) but length of trace for individual points at deformation. In fig.11 are presented the $\delta l(T,x,y,z)$ - curves for blade with and without TBC-covering. The total displacements for the blades with and without TBC are different: in the case of blade with TBC the total displacements are smaller. The character of the $\delta l(T,x,y,z)$ dependences it seems to be similar but really in case of the blade without TBC-covering the region where the displacements are changing is twice as big what show a non-homogeneous tendency for displacements of significantly more large values for different points.

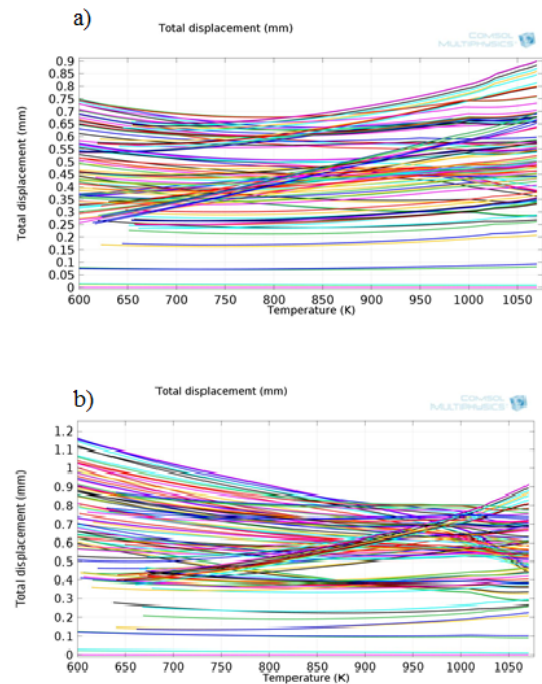


Fig.11 Total displacements of chosen points in blades after cooling during 60s: a) for blade without TBC; b) for blade with TBC

Therefore, the thermal stresses aroused in the turbine blades are calculated on base on experimental measurements of the temperature distributions using the thermographic high resolution camera FLIR SC7000. The measurements were performed at heating of the blade in special chamber imitated the combustion chamber of the jet engine. That one and careful calibration of thermographic camera enable us to obtain the real distribution of temperature for different surfaces of blades. The measurements were performed for blade with thermal barriers coatings (TBC) and for blade without TBC. Numerical calculations were carried out on the base on these experimental data using Program COMSOL what enable us to state differences in the deformations in the blade with TBC in comparison with the blade without TBC. Whereas, the blade without TBC show a non-homogeneous tendency for displacements of significantly more large values for different points of the blade, on the other hand, the absolute values of thermostresses are similar.

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