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# Microstructural Behaviour of Protective AlSi Coatings under Thermal Load

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**Abstract:**

*Aircraft engine turbine blades are exposed to high temperatures, high static, variable stresses and strong cyclic thermal loads during their operation. The investigated blades originate from the engine DV2 which is appointed for light training combat aeroplane, where sudden changes of engine transition state are in progress mostly during flight manoeuvring. Under these conditions the engine is liable to suffer from unstable running as surging or failure of the fuel system for a several seconds. These undesirable features of engine cause that the critical value of the output gas temperature* $T_{4C}$ *is exceeded and damage of the turbine blades is extensive owing to degradation or total loss of protective coating. A short-time (5 to 20 s) exceeding of the operating temperature* $T_{4C}$ *by up to several tens of degrees degrades the surface layers of the blades and reduces their service life compared to the planned service life of 1500 flight hours. This work deals with degradation of protective coating on rotor blade of the high pressure turbine (HPT) under condition that the temperature of blades would reach the temperature of outgoing gases. The blades were heated in the laboratory and the temperature of blades was admeasured by platinum-rhodium thermocouple. Degradation of coating was analysed by scanning electron microscope. The aim of the work was to get new attainments of AlSi coating behaviour at high temperatures without corroding medium*

**Keywords:**

*Aircraft engine, protective coating, degradation, superalloys, rotor blades*

## 1. Introduction

In future years, gas turbine engines will have the potential to reach new heights of efficiency and service life and engineers will have to design new types of protective coatings. The intended coating and substrate form a continuum.

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Two basic criteria have to be kept in mind: the ability of the coating to protect the component from degradation and the ability of the coating to retain, over the long term, its protective properties in the aggressive environment [1, 2]. Efficiency in the gas turbines is primarily given by increasing the gas temperature incoming to the engine turbine [1, 3]. Beside the high temperatures and their changes resulting in the increase in temperature gradient, the engine operates under high pressure, huge stresses and in the presence of corrosive and oxidation atmosphere. During the operation, materials of engine components undergo degradation. Environmentally induced high-temperature failure modes are:

- High-temperature oxidation;
- Hot corrosion;
- Spallation;
- Mechanical distress;
- Solid-state diffusion;
- Thermomechanical fatigue cracking.

The process of burning is performed in a combustor chamber at the temperature of 2273 to 2473 K and the temperature of the outgoing gases can reach up to 1800 K [4]. Sudden transition regimes of the combat aircraft during running result in irregularity of the temperature field and the stress loading of the stator and rotor blades is significant. In addition, unstable running, such as a surging or a failure of the fuel system, the damage of the blades can be much more expressive.

Rotor blades analysed in this work are from a DV2 engine. The DV2 aircraft engine is a by-pass turbo jet, double-rotor, double-shaft engine of a modular design (11 modules). It is primarily designed for light training fighter airplanes, but apart from that also for small transport planes. It has found its applications in airplanes L 59 (in Slovak, Czech, Egyptian and Tunisian armies), JAK 130 and L 15 (China).

One of the factors influencing the reduction of service life of the gas turbine rotor blades is a short-time excess of the operating temperature $T_{4C}$, which is 705 ºC at starting the DV2 engine and 760 ºC in operating modes. The critical temperature of outgoing gases is admeasured behind the engine turbine.

The aim of this work was to find out the influence of the high temperature gases on the change of coating microstructure under condition when the increased temperature of gases reached the value indicated in the engine DV2. It is well-known that the properties of coatings depend on their chemical and phase composition, as well as on their thickness. Aluminide coating with addition of silicon protects the blades against hot-corrosion [5]. For these reasons were analysed both average thickness of coatings after exploitation and aluminium and silicon changes in contents. These analyses should reveal the temperature fraction of degradation and without mechanical loading.

## 2. Microstructural Analysis of Rotor Blades of Engine 91016

The HPT rotor blades (Fig. 1) are made by precision casting of the JS6K nickel superalloy; its chemical composition is given in Table 1. The engine 91016 had 25 hours and 18 minutes of flight operation. Overheating occurred at the Egyptian operator’s due to surging, during which the overheating period was 7 seconds. Another 27 seconds of overheating was due to a control fault, with the instability caused by surging becoming gradually decayed. The temperature peaks in the graph reached 1094 ºC (Fig. 2).

*Tab. 1 Chemical composition of JS6K superalloy*

| Chem. element | Ni | C | Co | Cr | W | Mo | Ti | Al | Nb | Fe | B | Ce |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| wt. % | base | 0.12<br>0.20 | 4.0<br>5.0 | 9.5<br>12.5 | 4.5<br>5.5 | 3.5<br>4.8 | 2.5<br>3.2 | 5.0<br>6.0 | 5.5 | 2.0 | 0.02 | 0.015 |

*Fig. 1 Blade of high pressure rotor turbine*

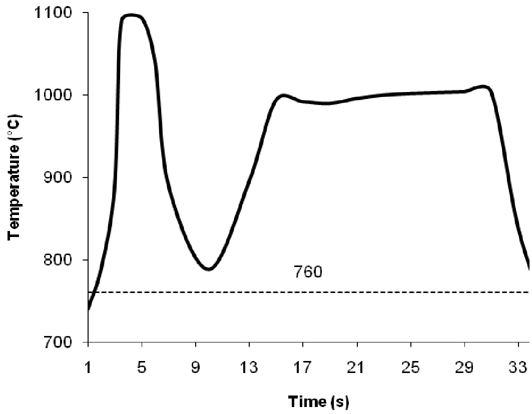



*Fig. 2 Waveform of critical temperature excess of engine 91016*

The AlSi coating of the undamaged blade is formed by an outer Al-sublayer and a diffusion Si-sublayer. The average thickness value of the layers was in the range of 20-40 µm. The microstructural analysis of AlSi coating of the investigated blade was compared with blade without operation. From the compared microphotographs it is obvious that the protective AlSi coating of the 91016 engine is totally destroyed (Fig. 3 and Fig. 4).

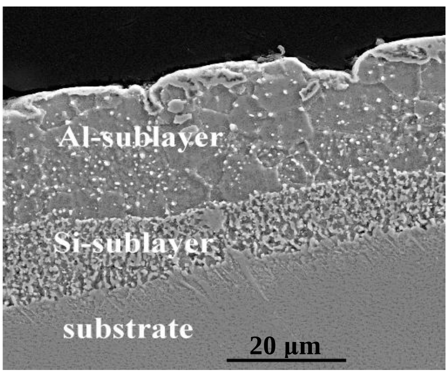



*Fig. 3 AlSi coating on blade without operation*

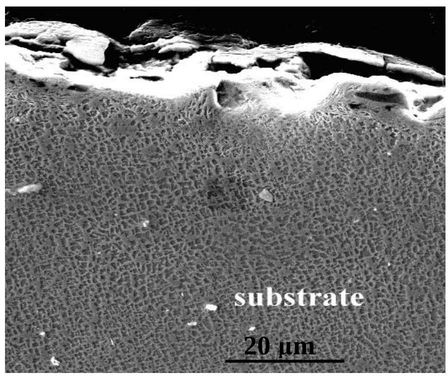



*Fig. 4 Damage of 91016 blade*

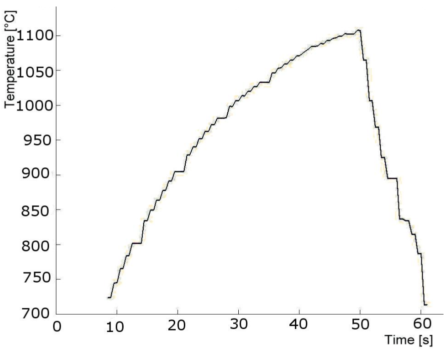
## 3. Microstructural Analysis of Samples Underlaying Thermal Load

### *3.1. Thermal Load Application Method*

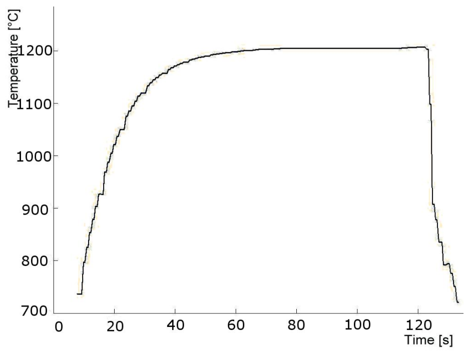
The samples were heated in the device at the temperature of 1165 °C ± 50 °C. This temperature presents thermodynamically counted up temperature of outgoing gases at the regime of the aircraft idle running when the temperature of preheating was in the range of 1000 °C ± 50 °C. A short-period exposition of samples is followed by micro-structural changes of AlSi coating at condition that the surface temperature of the HPT blades could reach the temperature of circumfluent gases. The aim of the experiment was simulating the real overheating of blades without the corroding effect of medium. The temperature loading was measured by Pt-Rh thermocouple and Trendicator II device. The values of thermo-electric voltage were registered and plotted by software MATLAB. There were 4 samples exposed to various temperature-dwells.

### *3.2. Time-Temperature Periods of Samples*

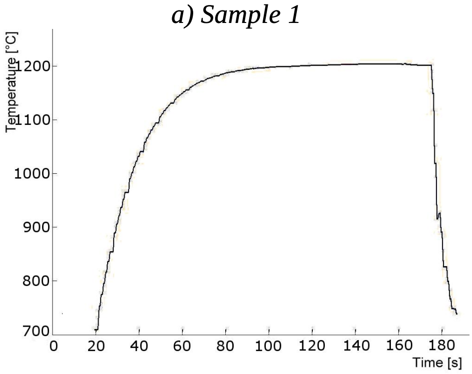
Time-temperature relationships of heated samples under raised dwells are demonstrated in Fig. 5a) to d). In the first case, the heat of the sample reached 1120 °C, the temperature of other samples was 1200 °C. Discontinuous profile of line in Fig. 5d) was caused by interrupting the connection between Pt-Rh thermocouple and heated sample 4. After about 20 seconds total interruption of connection occurred and the sample was cooling down without record.



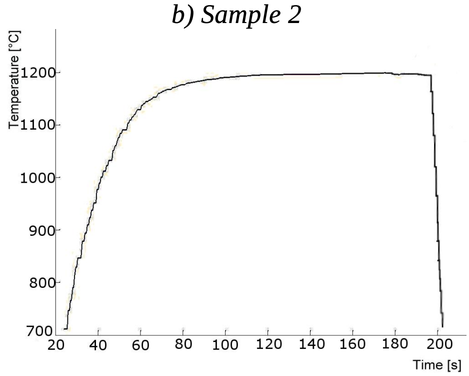

*a) Sample 1*




*b) Sample 2*




*c) Sample 3*




*d) Sample 4*

*Fig. 5 Time-temperature history of investigated samples*

### *3.2. Microstructural Analysis*

Microstructural analysis of samples 1-4 was studied by means of scanning electron microscope (SEM). Changes of AlSi coating of samples are obvious from Figs 6 to 9.

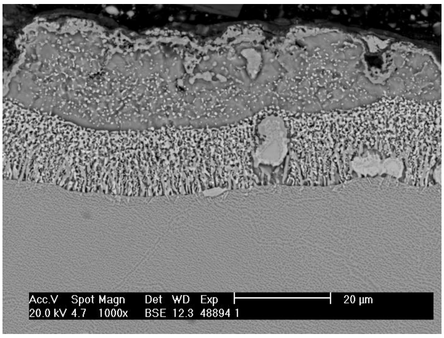



*Fig. 6 Microphotograph of sample 1*

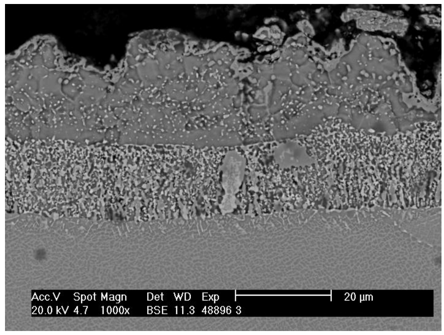



*Fig. 7 Microphotograph of sample 2*

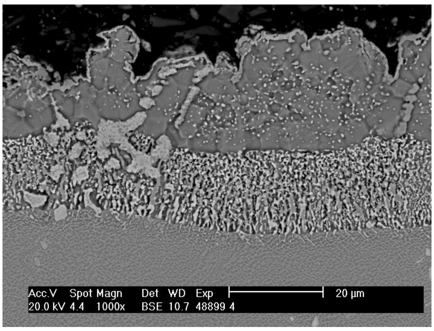



*Fig. 8 Microphotograph of sample 3*

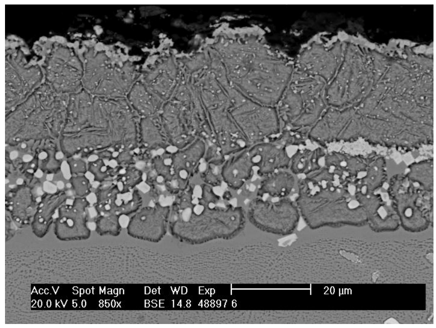



*Fig. 9 Microphotograph of sample 4*

Microchemical analyses in the coating of similar samples affirm the diffusion processes of elements. The most difficult elements for protective behaviour in the aggressive environment are Si and Al. Differences in the silicon and aluminium contents of Al-sublayer were investigated with the aid of EDX analysis. Microchemical changes of these elements in the solid solutions and carbide phases during heating can be visualized by means of a diagram (Figs 10 and 11).
Measurements of the AlSi thickness indicate rising of its average value with dwell (Fig. 12). Since the linear dependence presented in Fig. 12 describes this increase sufficiently, no further analytic solution (e.g. that proposed in [6]) is necessary.

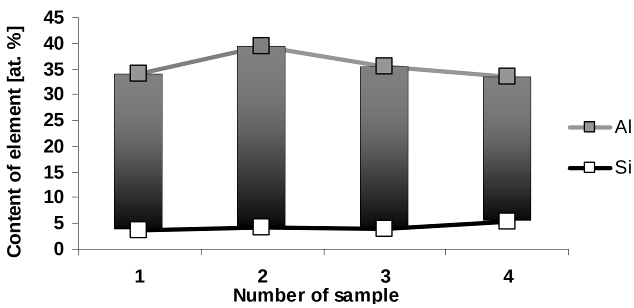



*Fig. 10 Contents of Al and Si element in the solid solution of Al-sublayer.*

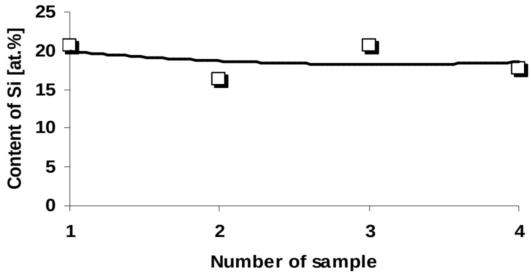



*Fig. 11 Content of Si element in the Si-sublayer.*

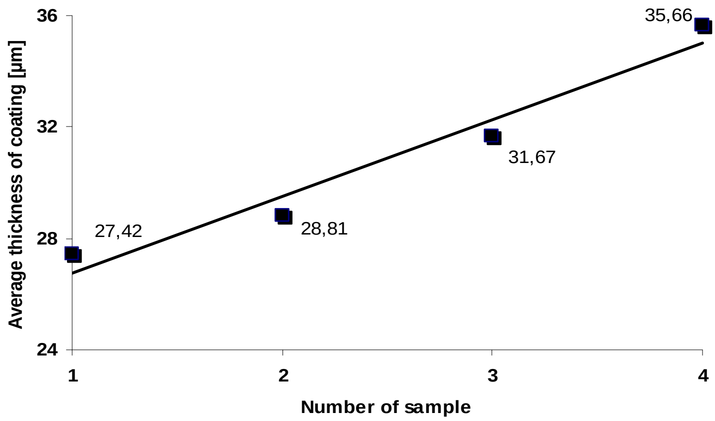



*Fig. 12 Average thickness of AlSi coating*

## 4. Conclusions

- Based on the assessment of the results of silicon contents demonstrated in Figs 10 and 11, it can be concluded that the solution of carbide phases in the Si-sublayer results in the diffusion of Si into increasing content in the aluminide phases of Al-sublayer.
- The same behaviour was observed in the change of contents of Cr, Ti and Co elements. Their loss in the carbide phases of Si-sublayer is proportional to the content rise in aluminide solid solutions of Al-sublayer.

The most significant changes can be observed in the AlSi coating of sample 4 with the dwell 120 seconds at 1200 °C (Fig. 9). Melting of γ´ precipitates occurred in the interface coating-substrate and the phase besides increased contents of Al and Si has the same composition as JS6K alloy. γ-γ´ eutectics occurred on the grain boundaries of both sublayers.

- As far as the thickness of coating is concerned, it does not remain without changes. The average coating thickness is rising with dwell time upon the high temperature. This effect is opposite to degradation of coatings in operation.
- These experiments has revealed that the short dwells time upon the high temperature without mechanical load cause changes of element distribution in phases including corrosive phases on the outer cover of coating. The damage

due to overheating resulting in total loss of coating, as can be seen in working operation, was caused in the initial stage by melting phases. Consequently, the differential thermal expansion between coating and substrate caused spallation of coating. Engine transitions and due to them dynamic forces, as well as the irregularity of the temperature field, have given rise to high stresses and finally deterioration of blades. In addition, aggressive environment, such as grit inducted to the gas-air channel, accelerates the loss of coating by erosion.

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