HEAT RESISTANT CONGLOMERATE TI-AL-SI-CR-N COATINGS FOR TITAN ALLOY-BASED PARTS OF GAS TURBINE ENGINES

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Abstract. When creating advanced GTEs, one of the most important tasks is to increase the heat resistance of GTE blades. One of the basic methods of increasing the heat resistance of blades is application of special coatings. The paper deals with the results of research of Ti-Al-Si-Cr-N based thin heat resistant ion-plasma coatings for titan alloy-based parts of a gas turbine engine (GTE). To carry out the research, three Ti-Al-Si-Cr-N based fusions were taken: conglomerate coatings with different Cr-Ti priority. The analysis of the oxidation process of surfaces in the range of 700-850 ºC with the use of scanning electron microscopy was performed and the key features of the coating fracture process under high-temperature oxidation conditions were identified. The conducted research resulted in the creation of conglomerate coatings with a maximum heat resistance increase efficiency of up to 57 times. Optimum Cr-Ti ratios for obtaining coatings with maximum high-temperature oxidation resistance were determined.

Key words: gas turbine, engine, ion-plasma, coatings, conglomerate.

Introduction

Heat-resistance problems during GTE manufacturing have existed since its invention. Modern GTEs are extremely overloaded units both thermally and mechanically. GTE designers, who are fighting for economic and thrust efficiency, are continuously looking for ways to raise the compression ratio and gas temperature in front of the turbine. All these ways lead to the problem of selecting materials used for manufacturing of turbine parts, a combustion chamber and a compressor (Fig.1). On modern high bypass GTE the temperature behind the compressor reaches and exceeds 500 ºC. The temperature behind the compressor of two circuit turbojet engines *International Aero Engines V2500* with the compression ratio of 32.3, for instance, reaches 576 ºC. On modern *Pratt&Whitney 4000*, *General Electric GE90*, *Rolls-Royce Trent etc.* the temperature of gases entering the turbine reaches 1327º…1477ºC, the compressor compression ratio is 35 and more [1].

Fig. 1. **Stator vanes of GTE-TV2-117A**

Main factors leading to the decrease of GTE resource are as follows:

- dust erosion, which mainly affects compressor blades;
- corrosion;
- high temperature oxidation that mainly affects turbine blades and vanes of last stages of a compressor;
- high-temperature gas corrosion and erosion of combustion chamber components and turbine blades.

Each of these factors has varying degrees of impact on the engine components intended for various purposes.

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For example, erosion is a common problem of helicopter and tank engines, while in marine installations it is very seldom found. Corrosion, by contrast, has a large effect on marine installations. High-temperature oxidation, in its turn, is present in all types of GTE.

The required reliability of compressor blades can be achieved through the use of rather expensive nickel-chromium and other heat-resistant alloys typical of gas turbines. A promising alternative is application of conventional titanium alloys, intermetallic titanium-aluminium alloys or alloyed steel with various compositionally complex protective and thermal barrier coatings [8]. In this case, coatings contain different elements that substantially increase the heat resistance of products at the expense of creating resistant oxide layers or other nitride, silicide compounds on their surface. Most coatings are based on aluminium that forms aluminium oxide on the surface. Chromium, silicon, zirconium as well as such expensive and rare materials as platinum, yttrium, etc. are used as additional elements [9]. These can be both mono- and multilayer coatings; and separate layers can be deposited with the help of different equipment using various techniques – diffusion saturation, vacuum ion-plasma deposition with additional ion-beam activation and electron-beam deposition [10].

Materials and methods

This paper presents the way of improving the heat resistance of GTE elements made of mainly titanium alloys by creating protective coatings based on conglomerate Ti-Al-Si-Cr-N system using the method of vacuum ion-plasma sputtering.

The process of depositing all options of the protective coating was performed on retrofitted NNV-6.6-I1 by using different sources of sputtered materials: two electric vaporizers Ti and Cr with magnetic stabilization of the cathode spot and deposited focus flow in the direction of the substrate, an Al-Si20 % magnetron, a table and samples rotating around their axis (Fig. 2) [2-4].

Feeding of a gas mixture to the magnetron sharply reduces its performance and stability. Therefore, separate feeding of gases is used. Argon is supplied to the magnetron target surface in the amount required for forming a certain thickness of the buffer zone, which partially prevents the penetration of nitrogen. As a result, high performance remains and a nitrogen-free or low nitrogen structure in the area close to the magnetron is ensured. To facilitate the control of sputtering, the pressure of argon is increased up to $3 \cdot 10^{-3}$ mmHg. In this case, a constant stream of argon is established without the intervention of automation. The feeding of nitrogen is adjustable by automation and its partial pressure within the range of $0.4 \cdot 10^{-3}$ mmHg is provided.

Three Ti-Al-Si-Cr-N coatings were selected for the investigation:

- the first option – 149-balanced,
- the second option – 150 Cr priority,
- the third option – 151 Ti priority.

Results and discussion

Currently, the following basic methods are used to improve the performance of GTE parts in severe operating conditions [2-7]:

- development of new, more efficient materials,
- use of various protective coatings,
- application of special methods of turbine blades cooling.

Titanium alloys are successfully used in modern engine building, especially in aviation. They are used for parts of a compressor due to their high specific strength and at the same time low density, high corrosion resistance and heat resistance sufficient to withstand high temperatures of up to 700 ºC.

Nowadays, there are developed new intermetallic alloys based on titanium-aluminium with the density 3.9-4.2 $g \cdot cm^{-3}$ containing 44-65 % of titanium and 35-56 % of aluminium, as well as other alloying elements in the range of 0.1 to 10 %. These alloys have high heat resistance ranging from 700 to 1000 ºC. Therefore, it is possible to use them for manufacturing the last stages of turbines. However, their use is limited by low heat resistance at temperatures higher than 750 ºC.

There are many types of coatings that can considerably increase the heat resistance of titanium alloys. These coatings differ by technologies and sputtered materials. The most widely used coatings are the ones based on aluminium, chromium, silicon, platinum and their compounds with other chemical elements.

This paper presents the way of improving the heat resistance of GTE elements made of mainly titanium alloys by creating protective coatings based on conglomerate Ti-Al-Si-Cr-N system using the method of vacuum ion-plasma sputtering.

For a conglomerate coating it is essential to ensure the simultaneous presence of nitrides and intermetallic compounds of titanium, chromium and aluminium in the layer. The main difference from the scheme of sputtering intermetallic compounds is in the admission of reaction nitrogen gas into the spraying chamber. In the previously described technologies for creating multilayer protective coatings, the conglomerate portion was formed by mixing inert gas argon and nitrogen in appropriate proportions providing the predetermined composition and properties of the coating. Gas mixture was fed from two sides of the chamber. Evaporated material by way of neutral atoms, ions and drops, when moving from the cathode to the surface of the product, undergoes the collisions with gas atoms and ions. At the same time, depending on the contact, the mass is formed corresponding to metal nitride or solid solution, if an interaction with nitrogen occurs. If the ions and metal atoms collide with argon, their energy and temperature are lost. The formation of even a solid metallic phase is possible.

In turn, in liquid or solid state the probability of strong interaction with nitrogen decreases substantially, which leads to the appearance of a metal matrix.

In the modified equipment used for this study the process of obtaining the conglomerate coating has been changed due to the use of magnetron.

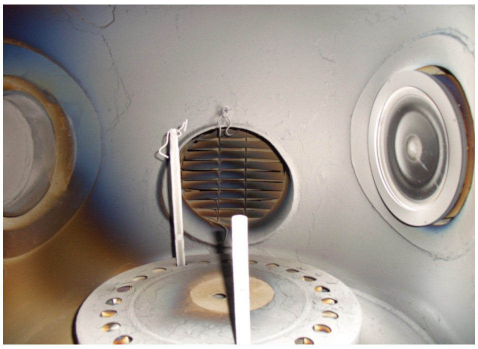


Fig. 2. **Sputtering chamber**

Fig. 3. **Samples after testing:** (149-150-151-basic), 750 ºC

The study of heat resistance was carried out in the furnace atmosphere using the following regime: heating the furnace to desired test temperature, loading the samples into the furnace, 2-hour exposure, unloading and cooling in the air. The tests were carried out at the furnace temperatures of 700, 750, 800 and 850 ºC (Fig. 3-5). Heat resistance was assessed on the basis of the samples weight change after each test cycle (Fig. 6). The protective properties were evaluated by the efficiency coefficient – relation of the reference sample mass gain to the tested sample mass gain at all testing temperatures (Fig. 7).

Fig. 4. **Samples after testing:** (149-150-151-basic) 800 ºC

Fig. 5. **Samples after testing:** (149-150-151-basic), 850 ºC

As a result of the tests, the following features were revealed (Fig. 6-10).

Reference sample. Gradual oxidation is observed at temperatures of up to 700 ºC, which is reflected in preservation of metallic lustre with a change of the surface colour only. The microstructure of the surface does not undergo any significant changes. Further increase in temperature leads to a sharp increase in the oxidation rate; the surface becomes opaque, it also becomes yellowish, which is typical of titanium oxides; micro-relief becomes smooth. At the temperature of 850 ºC, the oxidized layer, which has grown considerably, begins to crumble.

Coating sample 149. Significant oxidation is not observed until the temperature rises up to 800ºC; the surface texture of the coating preserved. Starting with the temperature of 800 ºC, the oxidation rate gradually increases. At the temperature of around 850 ºC the oxide globe formed needle-type areas are present (Fig.8b). The biggest coating efficiency coefficient at 800 ºC is 57.

Coating sample 150. Significant oxidation is not observed until the temperature rises up to 800 ºC; the surface texture of the coating preserved. Starting with the temperature of 750 ºC, the oxidation rate increases (Fig. 9b). At a temperature of around 850 ºC the oxide forms needle-type surface areas. The biggest coating efficiency coefficient at 750 ºC is 48.

Coating sample 151. Significant oxidation is not observed until the temperature rises up to 800 ºC; the surface becomes opaque and the texture of the coating is preserved. Starting with the temperature of 800 ºC, the oxidation rate increases. At the temperature of around 850 ºC the oxide forms needle-type surface areas less than for 150 sample (Fig. 10b). The biggest coating efficiency coefficient at 750 ºC is 48.

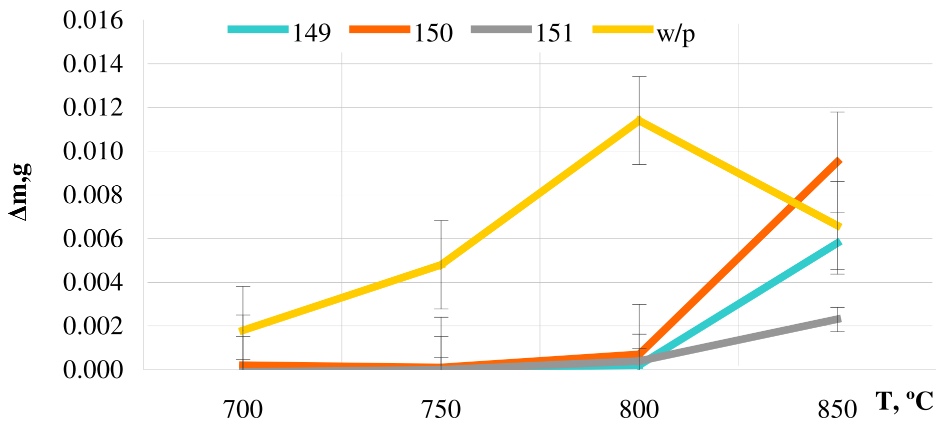


Fig. 6. **Mass gain depending on temperature**

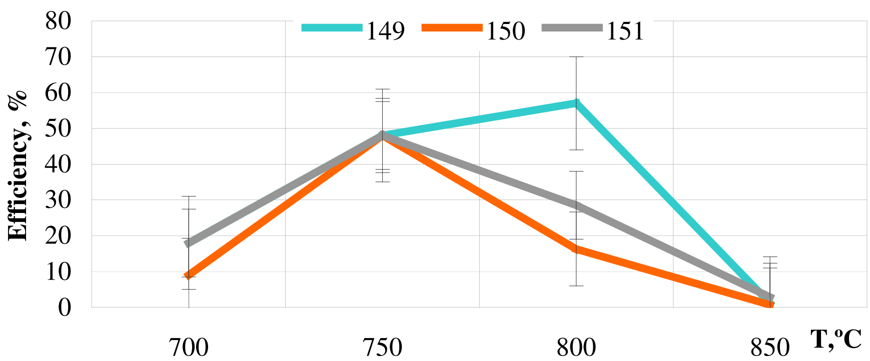
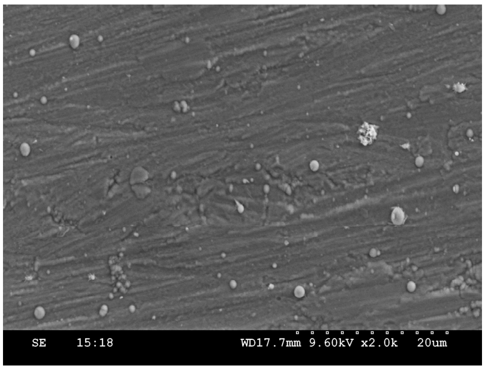


Fig. 7. **Efficiency of coatings depending on temperature**

a)



b)

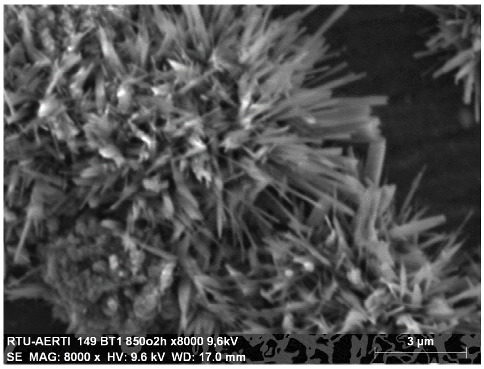
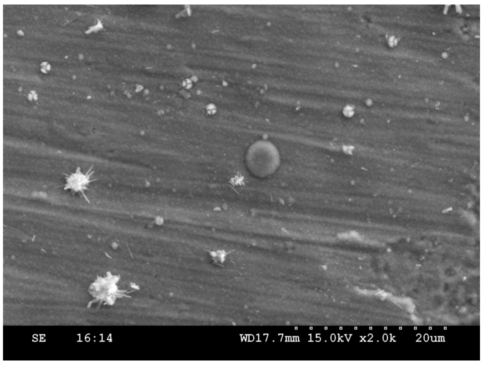


Fig. 8. **Surface of sample 149 after testing:** a – 800 ºC x2000; b – 850 ºC x8000

a)



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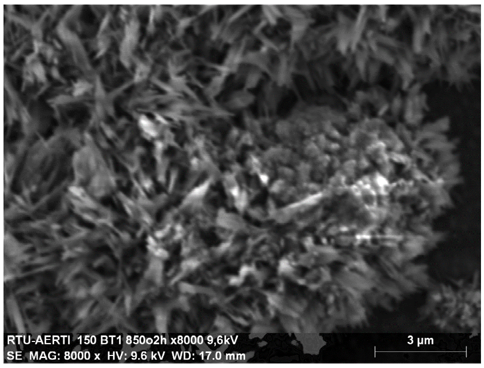
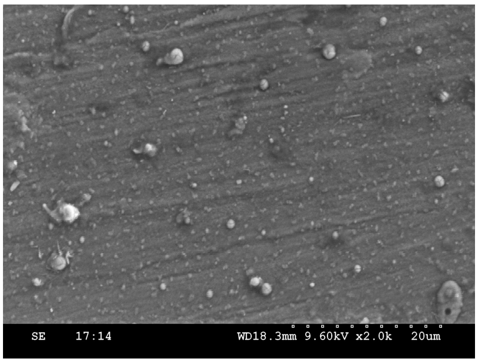


Fig. 9. **Surface of sample 150 after testing:** a – 800 ºC x2000; b – 850 ºC x8000

a)



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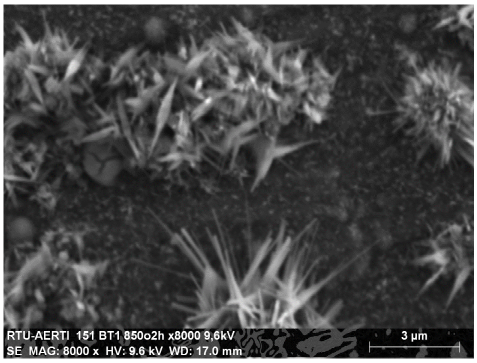

Fig. 10. **Surface of sample 151 after testing:** a – 800 ºC x2000; b – 850 ºC x8000

Conclusions

The results of the research make it possible to conclude the following:

1. The conglomerate coatings based on Ti-Al-Si-Cr-N can be successfully used for protection of titanium alloys from oxidation in mono- or multilayer coatings up to 750-800 ºC – with great efficiency up to 57.
2. The coatings with a balanced ratio of Ti and Cr and with titanium priority have high efficiency in the full range of test temperatures. At the same time, the coating with a balanced content of Ti and Cr has shown a constant efficiency increase of up to 57 within the test temperature range of up to 800 ºC.
3. At a temperature of 850 ºC, catastrophic flaking of TiO2 scale from the uncoated sample was observed, which leads to a sharp decrease of uncoated sample mass and, at this test temperature, does not allow to correctly evaluate the coating efficiency that, in reality, is substantially higher than the one reflected in the efficiency diagram.

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