ANALYSIS OF THE COEFFICIENT OF LINEAR THERMAL EXPANSION OF SEALING COATINGS OF GAS TURBINE ENGINE PARTS

YELIZAVETA FASOL, VADIM KUBICH

National University "Zaporizhzhia Polytechnic"

The work investigates the effect of yttrium on the temperature coefficient of linear expansion of KNA-82 coatings for the hot path of gas turbine engines (GTE). The coating with a yttrium content of 0.3%, applied by plasma spraying, has the most stable adhesion to the substrate material under cyclic temperature changes. The results can be used to improve the efficiency and durability of the GTE.

Keywords: sealing coatings, temperature coefficient of linear expansion, dilatogram, yttrium-containing ligature, coefficient of efficiency

Introduction. One of the most effective ways to improve the performance of gas turbine engines (GTE) is to reduce radial clearances in the rotor-stator part of the engine, which reduces hot gas consumption. The seals used for this purpose reduce specific fuel losses and increase engine efficiency. The possibility of touching parts due to deformation of the body and rotor during maneuvering of the aircraft and operation of the GTE in non-stationary modes, vibrations and other similar situations can lead to wear and malfunction of the contacting parts. To solve this problem, special coatings are being developed that are adjusted during operation. In particular, the use of KNA-82 coatings alloyed with a complex ligature Co–Ni–Cr–Al–Y, the feasibility of which was proven in [1] and is successfully used at Motor Sich.

In this work, it is proposed to vary the yttrium content in the coating of KNA - 82 within the range of 0.1-0.5%. It is known that appropriate proportions of yttrium contribute to the stabilization of oxide films, improve the adhesion of the applied coatings to the base material, increase the thermal stability of alloys and delay the coagulation of strengthening phases [2]. Segregation of yttrium (Y) at the interface between the oxide film and the coating in Ni–Co–Cr–Al–Y systems helps to reduce the formation of cavities and, thus, improves the adhesion of the α-Al_2O_3 oxide film to the substrate [3].

Coatings must not only have heat resistance properties, but also have high adhesion to the base material. The temperature coefficient of linear expansion (TCLE) is one of the key factors affecting adhesion during service, as thermal stresses are generated in the material when it is heated. These stresses can cause the coating to delaminate from the substrate.

Materials and methodology. As a base material for the research, we chose the serial coating KNA-82, which is currently used in aircraft engines manufactured by PJSC Motor Sich. This coating contains Ni (base), Cr, Si, Al, and solid lubricants (graphite and BN). Yttrium was added in the amount of 0.1, 0.3, and 0.5%. The coating was formed by gas flame and plasma methods. The studies were carried out on a Chevenard dilatometer, using programmed heating to a temperature of 950ºC for 3 hours, cooling in an oven. The size of the standard and the sample is the same: diameter 3.5 mm, length 50 mm. The main purpose of the standard is to compensate for all or part of the thermal expansion of the sample, which makes it possible to record the phase transformation. The coefficient of linear thermal expansion was calculated by the formula (1):

$$a_{ex} = a_r \pm \frac{K_1}{K_2}(a_r + a_q)\frac{d_y}{d_x} \tag{1}$$

where α_r – the average expansion factor of the reference;

α_q – average expansion coefficient of quartz;

K_1, K_2 – optical magnification coefficients of the device along the X and Y coordinate axes;

d_y, d_x – the dimensions of the catheters in mm of a rectangular triangle on the dilatogram in the temperature range where α_{av} is calculated.

Results. The calculated coefficient of linear thermal expansion for all samples ranges from 3×10^{-6} to 17×10^{-6} 1/d and increases with increasing temperature. Based on the results of the study, we constructed graphical dependences in Figs. 1 and 2.

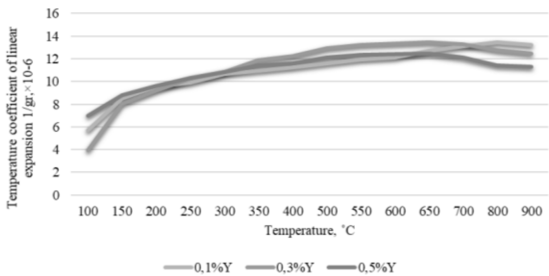

Fig. 1. Dependence of TCLE on heating temperature for samples with a gas flame application method.

As can be seen from Figure 1, for all compositions, a gradual increase in the TCLE up to a temperature of 650...700 °C is observed with a subsequent change in the appearance of the dilatometric curve, indicating a certain decrease in the volume of the material. The coefficient of linear expansion for gas flame deposition with a yttrium content of 0.1% has the largest difference in values and also has extremes. Significant oxidation of the sample after the third heating was also observed. The curves with yttrium content of 0.3 and 0.5% are almost identical, but the curve for the composition with 0.3% yttrium has a fairly wide gradient of values, unlike 0.5%. Let us consider the plasma-coated samples (Fig. 2).

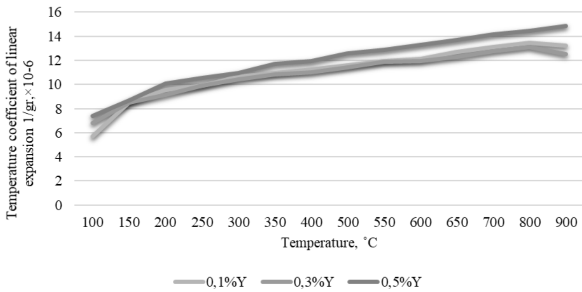

Fig.2. Dependence of TCLE on heating temperature for samples with plasma application method.

For plasma deposition, the curves do not have clearly defined extremes. The TCLE has higher values starting from the reference temperature and up to 900°C. No oxidation of the samples after the third heating was observed in the plasma application, unlike the same in the gas flame application. This can be explained by a more uniform coating and better adhesion. For yttrium content of 0.3%, the best linear dependence and a smaller gradient of coefficient values are observed. Since yttrium is an element of embodiment in the crystal lattice, it can be assumed that with a higher content, the lattice can be significantly distorted. This, in turn, can lead to peeling of the applied coating under gradient temperature changes.

Thus, the results of the study of the temperature coefficient of linear expansion of coatings with different yttrium content and using different methods of application made it possible to establish that the KNA-82 coating with a yttrium content of 0.3% formed by the plasma application method is the most rational and will have a positive effect on the durability of the system in operation.

1. Sotnikov E.G. Improvement of the composition of gas-thermal sealing coatings of turbine parts to improve the efficiency of gas turbine engines: 05.02.01 – "Materials Science" / Sotnikov Yevhenii H. – Zaporizhzhia, 2018. – 193 p. (in Ukrainian).
2. Wu Y., Li Y., Xu Y., Kang M., Wang. Unveiling the mechanism of yttrium-related microstructure inhibiting or promoting high-temperature oxidation based on Ni-Al-Y alloys // Acta Mater. – 2021. – 211. – No. 116879.
3. Ullah A. and Khan A. Temperature effect on early oxidation behavior of NiCoCrAlY coatings: Microstructure and phase transformation // Acta Metall. Sin – 2022. – 35. – P. 975–984.