Investigation of the thermal characteristics of a metal-anisotropic composite contact pair

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Abstract. The tendency to use various composite materials in the production of aircraft components and assemblies determines the relevance of the study of the anisotropic properties of these materials. Ceramic-matrix composites used in aviation rocket and space technology can be assigned certain anisotropic properties already at the production stage. The anisotropy of the material has a significant effect on the thermal characteristics of metal - ceramic-matrix composite contact pairs. This paper presents the results of numerical modelling of the thermal properties of contact interaction with the participation of an anisotropic ceramic matrix composite. It is shown that a change in the orientation of the fibers of the composite matrix with respect to the direction of the heat flux significantly changes the contact thermal resistance.

Keywords: contact interaction, thermal contact resistance, composite materials, anisotropic properties, numerical modelling.

1. Introduction
Improving the efficiency of components and assemblies of aviation technology is closely related to the use of new materials. As metal (steel, aluminum, titanium, heat-resistant alloys) replaced wood in the production of aircraft, so nowadays in the production of aircraft, composite materials are increasingly used, which can provide the necessary operational reliability and strength characteristics while reducing the weight of the structure.

Composites based on carbon-ceramics have a high potential that can be used to obtain high efficiency of assemblies and parts made from it [1, 2]. The advantages of ceramic-matrix composites (CMC) include low specific mass, high heat resistance, chemical inertness and corrosion resistance [3,4]. With the help of a certain orientation of the layers of the reinforcement matrix used in the product part, you can define certain characteristics of it. The artificially created anisotropy, which depends on the orientation of the fibers in the material, determines the direction and magnitude of resistance to tension, compression, or shear. In this case, during production, it is necessary to arrange the fibers taking into account the high elastic modulus across the layers of the composite material and the low Poisson's ratio. The influence of anisotropy on the value of the thermal conductivity coefficients and the strength characteristics of the product, depending on the direction of laying the matrix fibers, largely determines the features of the use of such materials. Quite a lot of works are currently devoted to the study of the use of these features [5-11].

2. Problems of providing thermal interaction in contact
In the simplest version of replacing metal parts with parts made of composite materials, the main characteristics of the sample are reproduced. Manufacturing of a composite structure allows maximum use of all the advantages of its constituent raw materials [12]. Designing the strength characteristics of a composite structure consisting of differently oriented matrix layers with different characteristics in directions is much more difficult in practice than designing a metal structure. At the same time, the use
of specially designed numerical modeling tools allows us to solve the problems arising in the design [13, 14]. To implement the method of numerical modeling of the characteristics of a ceramic-matrix composite, taking into account its anisotropic properties, the ANSYS software package was used in this work. This software package allows not only to calculate the strength characteristics of the material, but also to check the manufacturability of the product, i.e. check the potential for its manufacture, as well as develop a technology for laying processes.

The existing technologies for the manufacture of products from a ceramic-matrix composite do not allow to ensure adequate reproduction of geometric parameters and the necessary strength indicators in the production of large-sized structures. Therefore, at present, combined structures are used, combining elements from CMC and metal. This study is devoted to the question of interaction of such different materials at the points of contact. The modern practice of using parts made of a ceramic matrix composite in one design simultaneously with structural metals and high-temperature alloys creates the problem of taking into account the anisotropic properties of the composite during their contact interaction. This problem becomes especially important for high-temperature connections. In this case, the thermal conductivity of the ceramic-matrix composite part directed along the normal to the contact surface is of fundamental importance, because it is it that largely determines the temperature gradient in the contact area. A high temperature gradient can cause the appearance of cracks, leading to the subsequent destruction of parts [15].

The surface temperature in the contact zone depends on many components: thermal and mechanical properties of the interacting materials, profiles and roughness of the contacting surfaces, the presence or absence of an intercontact medium. When the heat flux passes through the contacting surfaces, the temperatures at the interface will be equal only if the contact occurs over the entire surface area, i.e. if the contact is perfect [16,17]. Real contact between two surfaces is almost never perfect. The temperature gradient arising at the point of contact is characterized by the value of the thermal contact resistance (TCR) [18].

3. Results. Investigation of the effect of anisotropy properties of the CMC on the TCR.

To study the influence of the anisotropy of the thermal and mechanical properties of interacting materials, the contact connection of the pair “stainless steel—ceramic-matrix composite (CMC)”, represented by samples with the arrangement of fibers 0 °, 45 ° and 90 ° relative to the normal to the contact area, was considered.

The very ideology of using composite materials is based on the ability to set the mechanical and thermal properties of the material in any chosen direction during design [12,15].

The study was carried out for three options for the arrangement of reinforcing fibers. Experimental samples - "tablets" were cut from the blanks in mutually perpendicular directions - X, Y, Z, where X is the direction of laying the reinforcing material, Y is the transverse direction in the plane of the layer, Z is the "third" direction (along the thickness of the sample).

When carrying out the calculations, the approved method for calculating the TCR [19-21] was used, consisting of:

- removal of profilograms of contact surfaces,
- building a 3-dimensional geometric model of the contact,
- construction of a 3-dimensional computational grid model.

When carrying out the calculation, the condition for taking into account the properties of an anisotropic material becomes fundamental. This condition was implemented when setting properties in the ANSYS software by rotating the coordinate system of the reinforcing fibers relative to the main coordinate system.
At the initial stage of the calculation, a mechanical analysis of the contact is carried out, in which the magnitude of the displacement of the surfaces relative to each other and the field of the arising equivalent stresses are determined. For the analysis, we used CMC with a roughness of 2.07 μm and stainless steel with a roughness of 0.82 μm. The range of the compressive load and the direction of the heat flux (the heat flux is directed from stainless steel to the ceramic-matrix composite) were set as the boundary conditions for the formation of contact areas.

According to the mechanical analysis data (obtained deformed geometry), thermal analysis is carried out, the results of which are the temperature field of the contact pair. Figures 1 and 2 show the distribution of the temperature field of the contacting surface of the CMC taking into account the orientation of the fibers for a compressive load of 1 MPa at a temperature in the intercontact zone of 200°C and 800°C, respectively.

As can be seen from the presented figures, the temperature field is less uniform when the fibers are oriented with a reinforcement angle of 90°.

The calculation results show that an increase in temperature in the contact zone leads to a smooth decrease in the value of the thermal contact resistance, Figure 3.
Figure 3. Dependence of TCR on temperature at compressive pressure P = 0.2793 MPa.

To assess the quality of the results obtained, they were compared with the known analytical dependences shown in Figure 4.
4. Discussion
It can be seen that the results obtained for reinforcement angles of 0° and 45° are in good agreement with the results of calculations carried out using the analytical dependence of Mesnyankin [18]. Significantly different data on the value of TCR for a reinforcement angle of 90° can be explained by the anisotropic properties of CMC - high thermal conductivity in the direction parallel to the line of contact of materials and low in the perpendicular direction. Such conditions of heat transfer prevent the propagation of the heat flux deep into the material.
An analysis of the results obtained from the analytical dependences of Shlykov [16] and Malkov [17] showed that these dependences are not applicable to the assessment of the TCR of contact pairs with the participation of composite materials.

5. Conclusions
The study showed that in the case of contact interaction of anisotropic composite materials, it is necessary to pay close attention to
- evaluation of the roughness of the contacting surfaces;
- the shape and structure of the reinforcing matrix of the product;
- technologies for laying out the fibers of the reinforcing matrix.
The results of the calculations performed within the framework of this study make it possible to obtain the temperature field of the contacting surface of the CMC for each separately taken direction of reinforcement of the part.
The use of the anisotropic properties of the material in the design, strict adherence to the technology of laying out reinforcing fibers will make it possible to produce products with the necessary specific characteristics.

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