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Problems and perspectives of the use of intermetallic alloys as a material for details of gas turbine engine

The article is devoted to problems and perspectives of using intermetallic alloys as a material for gas turbine engine parts. It is shown that one of the most promising directions for the development of new generation aircraft engines is the use of intermetallic alloys based on aluminides of titanium and nickel in the construction of a compressor and turbine.

The current stage in the development of aviation engineering in general and engine construction in particular is characterized by significant advances in the field of design, manufacturing technology, testing and theory of control of gas turbine engines (GTE). New design and technological solutions used in the fifth generation GTE have significantly improved their tactical and technical characteristics. The main trends typical for the development of the GTE of the new generation are the use of advanced cooling systems, monocrystalline turbine vanes, disks of powder materials, integral structures of compressor disks with vanes, alloys based on metal intermetallics, composite materials, as well as gas-dynamic perfection of all elements of the flowing part [1].

One of the most promising areas for improving the aviation engines of the new generation is the use of intermetallic alloys based on titanium and nickel aluminides in the design of the compressor and turbine. For example, alloys based on titanium aluminide have a number of advantages over titanium alloys, namely, they are characterized by a lower specific gravity, high mechanical properties, high-temperature strength and heat resistance [2]. At the same time, the main drawbacks of such alloys are the high cost of obtaining due to energy-consuming and labor-intensive phase synthesis TiAl and Ti_3Al, as well as low plasticity and complexity of the formation of aerodynamic surfaces of parts of the GTE due to poor machinability. Solving these problems will allow successful application of alloys of this class in the design of existing and advanced aviation gas turbine engines.

Currently, scientists use different methods of obtaining intermetallic alloys. Among them, it is possible to distinguish the smelting of ingots of intermetallic alloys with the use of plasma arc and induction heating sources, electroslag melting and the method of electroslag melting in an inert atmosphere under "active" fluxes, and methods of powder metallurgy [3-5]. The drawbacks of these methods include the high consumption of electrical energy, which leads to an increase in the cost of alloys, as well as a large chemical heterogeneity of the material. For example, the technology for producing a cast alloy Ti- (47-52%) Al- (1-2%) (V, Mn) includes a preliminary melting, 3-5 re-melting (for homogenization) melted by an tungsten electrode in an argon atmosphere, and then final melting in a vacuum with a pouring in copper crystallizers [4].

Recently, a broad research has been obtained for the method of obtaining intermetallic alloys by electroslag remelting [5]. This technology is not significantly different from traditional, developed by Paton Institute of Electric Welding. In accordance with the method of obtaining intermetallic alloys by electroslag remelting, the anode rod, consisting of two ingots of the necessary high purity metals, drops to a molten slag bath containing titanium chips and calcium fluxes. Under the influence of an electric current, rod passes remelting with obtaining the necessary intermetallic compound. The drawbacks of this method can be attributed to high energy costs, the complexity of equipment, the difficulties caused by the control of the protective atmosphere, the liquation of the obtained material.

Among the most promising methods for obtaining intermetallic alloys, the method of self-propagating high-temperature synthesis (SHS) is considered. SHS is an effective method for obtaining a wide class of materials and represents a highly exothermic interaction of chemical reagents in the condensed phase flowing in the combustion mode [6]. One of the options for conducting the SHS process is to heat at a given speed to a temperature at which the volumetric self-heating of the system begins at the expense of the chemical reaction, and the SHS is in the mode of a volumetric thermal explosion (thermal spontaneous combustion). High-temperature synthesis in the mode of thermal spontaneous combustion is most often used for systems with a relatively low exothermic effect of the chemical interaction reaction of reagents, in particular, systems for the synthesis of intermetallics. In such systems, the adiabatic reaction temperature is low, which means they cannot burn at room temperature. For the synthesis of intermetallics, it is necessary to increase the synthesis temperature at the expense of preheating of the burden for synthesis in the mode of thermal spontaneous combustion. The most common method of synthesis in the mode of thermal spontaneous combustion is linear heating with constant speed in a wide range of speeds: from 0.5 to 2000 K/min. This method synthesizes the largest number of materials. In the first place, these are intermetallics (mainly metal aluminides) and composites on their basis.

The use of alloys on the basis of titanium aluminides as a material for the details of the GTE is substantiated: considering the level of physical and mechanical properties of alloys based on titanium aluminides, they can effectively be used as a material for high pressure compressor rotor parts as well as low pressure turbines in the GTE design. In this case, for example, being substitutes for iron-nickel alloys of the type EP718-VAR, currently used for the manufacture of vanes of high pressure compressors, whose operating temperature can be about 550 °C and nickel-based alloys of the type EI-437B, used for the manufacture of compressor discs, the main effect of The use of intermetallic alloys is to reduce their mass, which contributes to both reducing the mass of the engine as a whole and reducing the level of dynamic loads on its rotor [7].

Given the principal differences in the production of alloys based on intermetallic materials by means of SHS synthesis against traditional methods, as well as the perspectives of this method from an economic point of view, it is very interesting to study the processes of structuring the products of synthesis and their mechanical properties obtained under non-stationary temperature conditions for use as a material for obtaining structural materials for details of the GTE.

It was established that doping of γ-TiAl alloys with niobium (7 ... 8% by weight) and an increase in the degree of plastic deformation under conditions of extrusion at a load of 100 MPa can significantly reduce the grain size in the final product (up to 10-12 μm) and create a two-level structure with nanolamel colonies with a distance up to 500 nm. The theoretical calculations have been carried out using the Hall-Petch model, which showed that the Ti-Al-Nb alloy with nano-structures of lamellae has a limit strength up to 1800 MPa (Fig. 1), which is 3 times more than in Ti-Al alloy [8, 9].

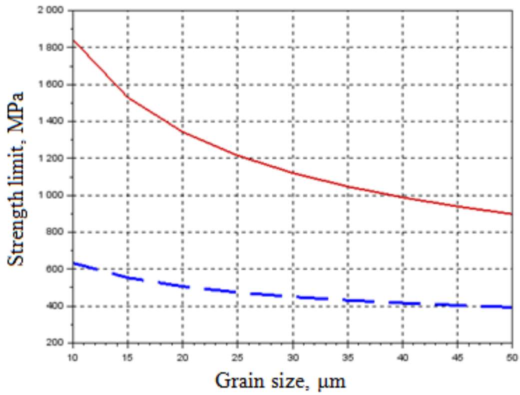

Fig.1. Dependence of the strength limit σ on the grain size *d*

Conclusion

Considering the level of physical and mechanical properties of alloys on the basis of titanium aluminides, they can effectively be used as a material for high pressure compressor rotor parts, as well as low pressure turbines, in the GTE design. The main effect from the use of intermetallic alloys is to reduce their mass, which contributes to both reducing the mass of the engine as a whole and reducing the level of dynamic loads on its rotor.

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References

1. Белоконь Ю.А. Получение интерметаллидных титановых сплавов для деталей компрессора газотурбинных двигателей на основе метода самораспространяющегося высокоскоростного синтеза / Ю.А. Белоконь, Д.В. Павленко, С.Н. Пахолка // Вестник двигателестроения. – 2016. – №. 1. – С. 72-80.

2. Имаев В. М. Современное состояние исследований и перспективы развития технологий интерметаллидных γ-TiAl сплавов / В. М. Имаев, Р. М. Имаев, Т. И. Оленева // Письма о материалах. – 2011. – Т. 1. – С. 25-31.

3. Рябцев А. Д. Исследование возможности получения титан-алюминиевого сплава методом электрошлакового переплава в инертной атмосфере под «активными» кальцийсодержащими флюсами / А. Д. Рябцев, А. А. Троянский // Проблемы специальной электрометаллургии. – 2000. – № 1. – С. 3-5.

4. Ахонин С. В. Особенности получения слитков сплавов на основе алюминидов титана в электронно-лучевых установках / С. В. Ахонин, А. Ю. Северин, В. А. Березос [и др.] // IV Міжнародна науково-практична конференція «Титан 2016: виробництво та використання в авіабудуванні. – Запоріжжя: АТ «Мотор Січ», 2016. – С. 24-28.

5. Протоковилов И. В. Магнитоуправляемая электрошлакавая плавка интерметаллидных сплавов на основе титана / И. В. Протоковилов, Д. А. Петров, В. Б. Порохонько // IV Міжнародна науково-практична конференція «Титан 2016: виробництво та використання в авіабудуванні. – Запоріжжя: АТ «Мотор Січ», 2016. – С. 32-36.

6. Амосов А. П. Порошковая технология самораспространяющегося высокотемпературного синтеза материалов / А. П. Амосов, И. П. Боровинская, А. Г. Мержанов. – М. : Машиностроение-1, 2007. – 567 с.

7. Куликовский Р. А. Перспективы промышленного применения алюминидов титана в авиадвигателестроении / Р. А. Куликовский, С. Н. Пахолка, Д. В. Павленко // Строительство, материаловедение, машиностроение: сб. научных трудов. – Вып. 80. – Дн-вск. : ПГАСА, 2015. – С. 369-372.

8. Belokon, Y. The investigation of nanostructure formation in intermetallic -TiAl alloys / Y. Belokon, A. Zherebtsov, K. Belokon // 2017 IEEE International Young Scientists Forum on Applied Physics and Engineering (YSF-2017). – 2017. – P. 311-314.

9. Sereda, B. The influence of deformation process at titan aluminides retrieving by SHS-compaction technologies / B. Sereda, I. Kruglyak, A. Zherebtsov, Y. Belokon' // Metallurgical and Mining Industry. – 2011. – No. 7. – P. 59-63.