Ключевые слова: изостатический графит, изостатическое прессование, фотогальваническая промышленность, термостойкий материал, коксопековая композиция.

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UDC 669.021
DOI: 10.15587/2312-8372.2017.99894

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EFFECT OF SURFACE ROLLING ON MECHANICAL PROPERTIES OF Ti–Al SYSTEM ALLOY

Наведено результати обробки поверхні інтерметалідного сплаву Ti–Al методом прокатки роликами. Прокатку роликами здійснювали при зусиллі 350 Н. Випробування на втому проводились при кімнатній температурі при частоті 60 Гц. Встановлено, що після прокатки поверхні роликами втомна міцність сплаву Ti-45Al-5Nb (ат. %) підвищилась на 4 %, з 675 до 700 МПа. Показано, що поверхнева прокатка зменшує шорсткість поверхні.

Ключові слова: *прокатка поверхні роликами, інтерметалідні сплави, сплави системи Ti–Al, втомні тріщини.*

1. Introduction

Development of aviation technology, especially turbine construction, has put forward ever-increasing demands on structural materials. Therefore, development of new alloys that can work at elevated temperatures, and search for new combinations of elements that improve heat resistance and high-temperature strength, still attracts the attention of researchers.

Today, one of the most important trends in the development of new metal materials with a high level of mechanical properties at temperatures of 600–800 °C is the creation of Ti–Al (γ-TiAl-based alloys) alloys. Interest in this group of materials is based on a unique combination:

- high melting point (1460 °C);
- low density (3.8–4.0 g/cm^3);
- high heat resistance and creep resistance at elevated temperatures;
- high resistance to oxidation.

The specific modulus of elasticity of these alloys is higher than that of titanium and nickel by 50–70 %, and this difference remains at elevated temperatures. According to the specific strength of γ-TiAl alloys in the temperature range $t = 600–850$ °C, depending on the structural state, can exceed all existing structural materials [1–4].

2. The object of research and its technological audit

The object of research is the surface roller burnishing, since for intermetallic alloys of the Ti–Al system, the effect of this hardening method on mechanical properties has not been fully studied so far.

Surface roller burnishing is a method of surface treatment of a material, in which the following effects are possible [5–7]:

- Reduction of surface roughness;
- Occurrence of residual stresses of the first kind;
- Increase in microhardness.

A schematic diagram of the surface roller burnishing is shown in Fig. 1 [8].

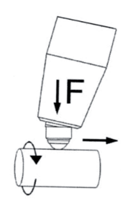


Fig. 1. Schematic diagram of the surface roller burnishing (F – rolling force, N)

In the case of this surface treatment, cold hardening, polishing and the occurrence of compressive stresses in the upper layer occur simultaneously. Together, these three physical effects increase fatigue resistance and reduce or completely prevent the formation of cracks in stress corrosion.

When rolling the surface, the rollers are pressed against the surface of the processed material, which leads to plastic deformation in the surface zone. As a result of deformation, the structure of the surface layers of the material

ISSN 2226-3780

changes, which, in turn, leads to an increase in the mechanical characteristics [9].

The most significant disadvantage of intermetallic alloys is their relatively low plasticity.

3. The aim and objectives of research

The aim of research is determination of the effect of surface hardening on the fatigue properties of alloy Ti-45Al-5Nb (at. %).

To achieve this aim, it is necessary to solve the following tasks:

1. To determine the surface roughness of alloy Ti-45Al-5Nb (at. %) before and after surface treatment.
2. To carry out fatigue tests of the alloy in the initial state and after treatment.
3. To establish a place for the appearance of fatigue cracks.

4. Research of existing solutions of the problem

In [2, 4, 10], the state of research in the field of intermetallic alloys is analyzed. According to the authors of [10], the use of titanium aluminides in the design of aviation turbines will allow to reduce the weight of products by 40 % of the initial mass. It is assumed that γ-TiAl alloys can replace existing materials in the design of a low-pressure turbojet engine (GTE) compressor and thereby improve the aircraft's weight-to-weight ratio [11, 12].

Recently, most research in the field of γ-TiAl has focused on the development of methods for their hardening. Special attention is paid to establishing the influence of surface treatment methods on high-cycle and low-cycle fatigue [13]. For example, the authors of [14] proposed the use of surface rolling by steel rollers and shot blasting to increase the fatigue characteristics of Ti-6 at. %-Al-4 at. % V. It is shown that shot blasting improves the fatigue strength of the alloy by 11 %. It was established in [15–17] that shot blasting or surface roller burnishing is an effective method of surface hardening of titanium alloys. In this case, hardening surface treatment allows to increase the mechanical properties of not only the surface layers, but also the entire material. The author of [14] proposed to use such methods of surface hardening to enhance the mechanical properties of intermetallic-type alloys. When studying Ti-45Al-9Nb-0.2C (at. %), it was found that roller burnishing with a load of 165 N increases its fatigue strength by almost 67 %. Obviously, the surface treatment effect for alloys of different composition and heat treatment differs from these results. That is why the establishment of the effect of hardening surface treatment in combination with thermal treatment on the mechanical properties of the new intermetallic alloy Ti-45Al-5Nb at. % is a promising research.

5. Methods of research

Tests were carried out for alloy Ti-45Al-5Nb at. %. Additionally, the composition of the alloy contained 0.2 at. % C and 0.2 at. % B. Surface rolling parameters were optimized during preliminary studies. It was established that the optimum rolling force for a given alloy is 350 N (Fig. 2).

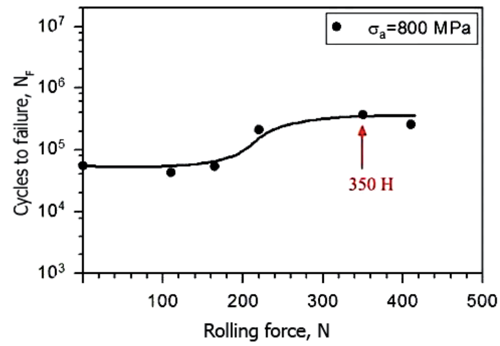


Fig. 2. Optimization of surface roller burnishing parameters for alloy Ti-45Al-5Nb at. %

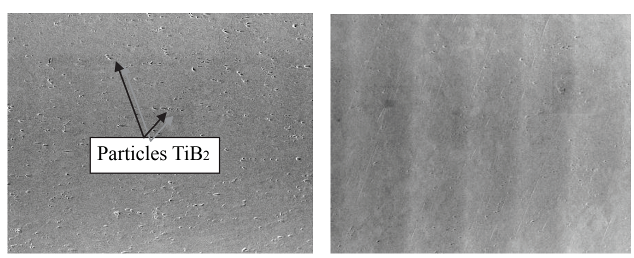
Before the tests, the surface of the samples was electrolytically polished. As a result of this treatment, there were no scratches on the surface, and the surface layers did not contain internal stresses.

Fatigue tests were carried out on «PUPG» machine (Shenk (Germany)), at room temperature and at a cycle frequency of 60 Hz. For fatigue tests, specimens with a diameter of 8.5 mm and a length of 50 mm were made. Surface condition tests were carried out on a scanning electron microscope Tescan TS 5130SB (Czech Republic) at an accelerating voltage of 15 kV.

6. Research results

The surface of alloy Ti-45Al-5Nb at. % in the initial state and after roller burnishing at a load of 350 N is shown in Fig. 3, *a, b*. In the state after electrolytic polishing, the maximum roughness values of the alloy surface are $R_y = 2.4$ μm and boride particles are visible on the surface (Fig. 3, *a*).

After surface rolling, the maximum roughness decreases $R_y = 2.0$ μm. However, the average surface roughness values for both samples are equal ($R_a = 0.2$ μm). On the surface of the samples the bands of the rollers, are clearly visible. The amount of boride particles on the surface of the material is decreased.



a *b*

Fig. 3. The surfaces of alloy Ti-45Al-5Nb at. %: *a* – in the initial state; *b* – after roller burnishing (×50 μm)

The results of the fatigue tests are summarized in Fig. 4. In the initial state, the fatigue of alloy Ti-45Al-5Nb at. % at room temperature is 675 MPa. After surface rolling, the fatigue is increased to 725 MPa, which indicates its hardening effect.

Analysis of fracture fractograms (Fig. 5) of the alloy shows that fatigue cracks in the initial state begin to propagate on the surface of the material, where the level of residual stresses is relatively small.

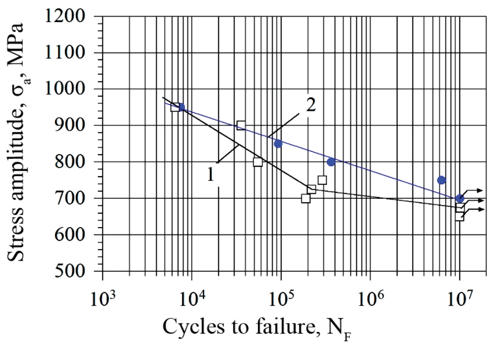
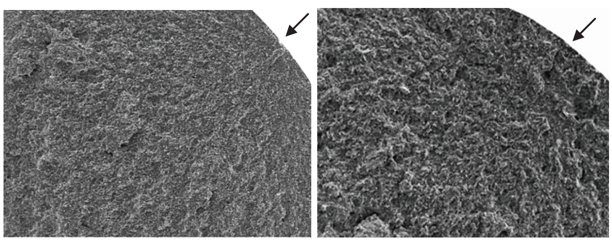


Fig. 4. Fatigue curves of alloy Ti-45Al-5Nb at. %: 1 – in the initial state; 2 – after roller burnishing



a *b*

Fig. 5. Appearance of the fractures after fatigue tests: *a* – in the initial state; *b* – after roller burnishing (×1 mm)

After rolling, fatigue cracks also propagate from the surface of the sample. This indicates that such surface treatment does not fundamentally change the cracking conditions in intermetallic alloys.

The author of [14] found that roller burnishing with a load of 165 N increases the fatigue strength of the intermetallic alloy Ti-45Al-9Nb-0.2C (at. %) by almost 67 %. The obtained results are significantly different from the results given by the authors of [14]. Obviously, the effect of surface treatment depends not only on the processing regime, but also on the composition of the alloys and their heat treatment.

7. SWOT analysis of research results

Strengths. The strongest side of the presented research is the established possibility of hardening intermetallic materials due to deformation of their surface. This principle possibility is proved on the example of alloy Ti-45Al-5Nb at. % and can be extended to a wider group of alloys.

Increasing the fatigue of the Ti-Al system alloys will, to some extent, extend the service life of the gas turbine engine blades. In the designs of existing gas turbine engine (GTE) blades, low-pressure sections are made of nickel alloys of the Inconel type (Ni-Fe-Cr system). The density of such materials, for example Inconel 718, is 8.19 g/cm^3. This is almost 2 times greater than for the investigated alloy. Accordingly, the overall weight of the low pressure compressor section can be reduced by about 40 %. It should be noted that the operating temperatures for intermetallic alloys of the Ti-Al system will also be higher than for the Ni-Fe-Cr system, which will improve the engine efficiency.

Weaknesses. The weak side of the presented study is the absence of a clearly established relationship between the degree of deformation, both the entire material and the surface, and the density of dislocations. It is well known that the plastic deformation of metals and alloys leads to an increase in the dislocation density. However, such data could not be identified for intermetallic materials. Therefore, the authors' further efforts can be directed specifically at establishing the relationship between the deformation degree of Ti-Al alloys and the dislocation density.

Opportunities. Simultaneously with plastic deformation of the surface of materials due to roller burnishing, other surface hardening variants are known. These include: shot blasting, ultrasonic treatment or their combination. The combination of surface hardening with heat treatment is also not fully understood. Therefore, one of the directions of future research is the use of shot blasting with the use of metal and ceramic shot for surface hardening of Ti-Al alloys.

In the most general case, the replacement of nickel alloys in the construction of a low-pressure GTE compressor for intermetallic will reduce the total weight of the turbine and the entire aircraft. Such decrease will definitely lead to decrease in fuel consumption and, accordingly, will increase the range of flights and affect the cost of transportation. A similar situation is typical for road transport. Reduce of the car weight for every 100 kg will reduce fuel consumption by an average of 0.6 l/100 km.

Threats. The wide industrial use of Ti-Al alloys is limited by several factors. The first of these is the complexity of smelting and casting of shaped products made of them. This is due to the large difference in the melting temperatures of Ti (1668 °C), Al (660.5 °C) and Nb (2469 °C) and the need for preliminary preparation of ligatures, which increases the cost of the entire technology. In this case, for the melting of such alloys, it is necessary to use vacuum furnaces, which productivity is less than usual, and the difficulty in servicing is higher.

The second factor is the need to use vacuum units for pressing of turbine blades. Such devices are not yet widespread enough and have a high cost. A similar situation exists in the field of thermal treatment of Ti-Al alloys.

8. Conclusions

1. It is found that the maximum surface roughness of alloyTi-45Al-5Nb (at. %) before the surface treatment is 2.4 μm and particles are observed on the surface, the micro-X-ray spectral analysis of which shows simultaneous presence of Ti and B peaks. This allows them to be identified as TiB_2. After surface roller burnishing, the surface roughness is decreased to 2.0 μm. The number of visible boride particles is decreased.

2. Fatigue tests of alloy Ti-45Al-5Nb (at. %) in the state after electrolytic polishing of the surface and roller burnishing shows that the deformation of the surface contributes to an increase in fatigue from 675 MPa to 725 MPa.

3. When testing the surfaces of alloy fractures before and after surface hardening, it is established that roller burnishing does not fundamentally change the place of crack generation. Both in the initial alloy and after the treatment, the fatigue cracks are generated on the surface of the sample.

ISSN 2226-3780

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УСТАНОВЛЕНИЕ ВЛИЯНИЯ ПРОКАТКИ ПОВЕРХНОСТИ НА МЕХАНИЧЕСКИЕ СВОЙСТВА СПЛАВА СИСТЕМЫ Ti–Al

Приведены результаты обработки поверхности интерметаллидного сплава Ti–Al методом прокатки роликами. Прокатку роликами осуществляли с силой 350 Н. Усталостные испытания проводились при комнатной температуре при частоте 60 Гц. Установлено, что после прокатки поверхности роликами усталостная прочность сплава Ti-45Al-5Nb (ат. %) увеличилась на 4 %, с 675 до 700 МПа. Показано, что поверхностная прокатка уменьшает шероховатость поверхности.

Ключевые слова: прокатка поверхности роликами, интерметаллидные сплавы, сплавы системы Ti–Al, усталостные трещины.

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