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COMPREHENSIVE APPROACH TO DETERMINING PARAMETERS FOR REPAIR OF TITANIUM PARTS OF THE GAS-AIR TRACT OF GAS TURBINE ENGINES

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ABSTRACT

The prospects and economic efficiency of titanium alloy products primarily depend on their service life, and this is directly related to the possibility of restoring these parts. The maintainability of gas turbine engine (GTE) parts generally determines their competitiveness. The authors proposed the use of filler materials with a submicrocrystalline structure for the repair of gas turbine engine parts by welding methods. Their optimal chemical composition, manufacturing method, and measures for regulating the structure of such filler materials were established. The optimal parameters of the argon-arc welding mode and post-weld heat treatment were also determined. The mechanical properties of welded joints obtained using experimental filler materials are higher compared to samples obtained using serial filler materials. The macro- and microstructure of welded joints has a significantly smaller number of defects of various origin compared to samples made with serial welding materials. Modeling and calculation of a monowheel using the finite element method was performed to predict the zones and degree of destruction during operation in order to develop an optimal restoration technology. 25 Ref., 2 Tabl., 9 Fig.

KEYWORDS: titanium alloy, welding materials, welded joint, chemical composition, structure, mechanical properties, defects

INTRODUCTION

The viability and cost-effectiveness of titanium alloy components primarily depend on their service life, which is directly related to the refurbishability of these components [1]. A key trend is the use of complex, one-piece (mono-) components made of high-alloy titanium alloys. In the case of monowheels, the main difference between these components and compressors made of discs and assembled blades is the inability to replace damaged sections individually. Therefore, repairing gas turbine components using welding methods is a top priority. Depending on the application of titanium and titanium-based alloy components, the economic feasibility of using titanium is achieved by extending their service life compared to other materials.

During operation, various defects can develop on components, including wear, cracks, corrosion, and phase and structural changes, leading to a loss of their original properties. The nature and location of defects vary depending on the specific type and location of the damage, requiring an individualized approach to repair.

The use of welding methods to restore the performance of complex titanium alloy components is associated with a number of challenges, including changes in the alloy structure as a result of processing or use. Damage occurs during the processing of blanks, from cast to deformed and heat-treated. Structural changes at various stages of manufacturing must be considered when selecting the welding method and modes, as well as the composition of filler materials.

Structural and phase transformations are also possible during the operation of finished components, which is associated with changes in their stress state. Therefore, the effect of the welding thermal cycle on the structure of complex titanium alloys and the stress-strain state of the component is complex and unique to each specific case.

Therefore, in each specific case, the restoration technology must consider the characteristics of the material, changes in its structure and properties, its design, and its stress state. These factors depend on the individual characteristics of the structural material. The range of titanium alloys is quite extensive [2]. The most common alloys effectively used in gas turbine engines are two-phase ($\alpha+\beta$) alloys: VT3-1, VT8, and VT9.

The assessment of the feasibility of restoring a titanium alloy component should be based on the safety margin and the ability to restore the specified properties of the specific component.

Therefore, when considering the possibility of producing a uniformly strong joint of titanium alloys, it is necessary to clearly understand the operating conditions and the mechanisms by which the weld structure is formed, which ensure the desired properties in the alloys. As noted previously, heat-resistant (α+β)-titanium alloys pose the most challenges in terms of welding applications.

Thus, titanium alloys require a specific type of microstructure that provides an optimal combination of the entire range of mechanical properties for the required service life of specific components.

Welded joints of titanium alloys have a number of unique characteristics. Unlike steels, hot cracks do not form in titanium alloys, which is a consequence of the smooth change in mechanical properties at high temperatures. One of the main reasons for this is the insignificant volume change of 0.13–0.27 % during the (α↔β)-transformation of titanium, which is several times smaller than for iron-based alloys [2–4]. Cold cracks, which form due to the stress state and low ductility of the structural components, are a common defect. They are typical for titanium alloys with low ductility (up to 8 %), as well as in alloys with increased impurity content. The use of technological measures, in particular, preheating of welded structures, leads to an increase in the heat-affected zone, which does not solve the problem of improving the mechanical properties of welded joints as a whole [5]. To improve the mechanical properties of difficult-to-weld titanium alloys, a comprehensive consideration of this problem is necessary. Based on an analysis of the work of several authors [6–9], several aspects can be identified that have a primary impact on the properties of welded joints in titanium alloys: chemical composition; structure; technological features and solutions.

A literature review revealed the difficulty of producing titanium alloys with a specified content and uniform distribution of alloying and modifying elements in the ingot.

Literary sources clearly formulate the quality requirements for titanium ingots used to manufacture critically wrought semi-finished products:

- the ingot structure must be free of inclusions, voids, films, and other defects that could migrate to the finished product;
- the content of chemical elements along the ingot height must be uniform, and their distribution within the structural components must have a minimal gradient;
- the level of mechanical properties in different zones of the ingot must be identical and must comply with regulatory requirements. Thus, the difficulties in obtaining deformed complex titanium alloys necessitate the development of a technology for producing alloyed titanium ingots with specified chemical composition and properties, without casting defects 10, 11. Filler materials are used primarily in a deformed state in the form of wire or rods. The technological process of deformation causes difficulties that affect the quality of filler materials and, ultimately, the level of properties of welded joints of titanium alloys [12, 13].

The following requirements can be formulated for the quality of filler metals:

- the filler material structure must be free of inclusions, pores, and other defects that could migrate into the weld;
- there must be no concentrated segregations of alloying and modifying elements, and their distribution within the structural components must have a minimal gradient;
- the amount of impurities must not exceed that of the base metal, and the amount of gaseous impurities must be lower than that of the base metal.

Therefore, to eliminate the noted concentration inhomogeneities, it is necessary to minimize the grain size, which will increase the grain boundary length and, consequently, improve the uniformity of element distribution. The most effective method for reducing the size of filler materials is nano- or submicrocrystalline (SMC) structuring of titanium [14–16]. To obtain bulk nano- and submicrocrystalline materials, various technologies currently exist [17, 18].

Severe plastic deformation (SPD) is the most effective technology for structural metals and alloys, as conventional deformation methods (rolling, drawing, and pressing) ultimately reduce the cross-section of the workpiece and do not allow for high grain refinement. SPD, on the other hand, produces volumetric workpieces suitable for the manufacture of components [19, 20].

Solving the above-mentioned problems requires addressing a range of theoretical and applied materials science challenges. This requires research into the influence of the chemical composition and structure of filler metals on the properties of welded joints of heat-resistant titanium alloys to ensure the required level of properties in the reconditioned components. Structure control must be implemented at all stages of the metallurgical and technological processes (vacuum-arc remelting and intense plastic deformation of filler metal blanks, welding, and heat treatment of the components).

METHODOLOGY

To determine the influence of the chemical composition of experimental titanium alloys on the structure of filler materials, as well as the structure and properties of welded joints of titanium alloys, the following were studied:

- chemical composition of alloys;
- structure and phase composition of alloys;
- fracture surface topography;
- hardness and microhardness of weld metal;
- mechanical properties of welds under static and dynamic cyclic loads;
- resistance of alloy material to crack development under impact loads;
- stress-strain state of restored parts on solid models.

Chemical analysis was performed in various zones of the ingot. The chemical composition of ingots of experimental alloys containing Al, La, Y, B, and filler materials made from wrought titanium alloys (VT2, VT8, VT20), as well as welds, was determined by spectral analysis using a SPECTROMAX instrument (SPECTRO) according to standard methods.

The transition factors of chemical elements (aluminum, lanthanum, yttrium, and boron) were determined by comparing the actual element content in the ingot with the amount of chemical elements introduced into the charge. The following transition factors of alloying elements in the alloy were obtained: $K_{\mathrm{Al}} = 0.66$, $K_{\mathrm{La}} = 0.73$, $K_{\mathrm{Y}} = 0.50$, $K_{\mathrm{B}} = 0.60$.

Yttrium and lanthanum contents were determined by atomic absorption using a Hitache ContrAA 300BU spectrometer. Boron was determined by the spectral optical emission spark method on a Spectra Spectrolab optical emission spark spectrometer.

Impurity contents (nitrogen, oxygen, and hydrogen) were determined using an ELTRA ON900 gas analyzer.

Microanalysis of the elemental contents in the structural components was determined using qualitative and quantitative methods. The distribution of alloying and modifying elements in the structural components of the alloys was determined using a JSM-6360LA multipurpose scanning electron microscope equipped with a JED 2200 energy-dispersive X-ray microanalysis system.

The distribution of chemical elements over the area of the selected micro-section was determined using color-coded mapping, as well as linear analysis [21].

The submicrocrystalline structure in titanium alloys was obtained using severe plastic deformation by screw extrusion [22, 23].

Heating of the samples for severe plastic deformation by screw extrusion between passes was carried out in a chamber electric furnace with an air atmosphere (LAC, Czech Republic) with a maximum permissible operating temperature of 1280 °C.

Welded joints were produced by argon-arc welding with a non-consumable electrode, using a filler metal.

Alloys of standard chemical composition (VT2sv, VT8, VT20) were used as filler materials, and experimental alloys were also smelted: VT2 alloy with the addition of modifiers (lanthanum, yttrium, boron).

The work was carried out in pre-purified argon in a U6872-5306 controlled atmosphere chamber. The required atmosphere was achieved by evacuating the chamber and then supplying argon at a pressure of 0.02 MPa (0.2 atm.).

Welding mode for the samples: filler diameter 1.8–2.0 mm; $I_{\mathrm{w}} = 180$ A; $U_w = 10$ V; $V_w = 0.24$ m/min; tungsten electrode diameter of 1.8 mm.

Welding was performed using identical welding conditions, eliminating the influence of welding conditions on the joint properties. Edge preparation was performed before welding, and weld reinforcement was removed after welding.

After welding, to relieve stress and stabilize the weld structure, the welded joints of the studied (α+β)-titanium alloys were heat-treated in a SNVE-1.3.1/16 vacuum-arc resistance furnace with a vacuum depth of $P = 1\cdot10^{-5}$ mm·Hg. Temperature was controlled using a TXA thermocouple, maintaining the furnace temperature accuracy at ±5 °C.

Metallographic studies of the structures and fractograms of the fracture surfaces were performed using optical microscopes, as well as scanning and transmission electron microscopes. The phase composition of the alloys was studied using energy-dispersive X-ray spectroscopy. Mechanical properties were determined using standard methods [24]. Laboratory and industrial studies were conducted in accordance with existing standards using instruments and equipment that had passed metrological control [25].

To evaluate the application of the developed approaches, tests were conducted on full-scale samples, and solid-state models of the axial monowheel (blisk) blade of the high-pressure compressor of the D-27 turbofan engine were created.

The stress-strain state of the axial monowheel made of VT8 alloy of the D-27 engine was calculated under loads corresponding to engine operation in takeoff mode. Considering that the simulated distance from the wheel rotation axis (*Z*-axis) to the blade airfoil corresponds to the radius of the actual compressor wheel, the calculation sector is loaded with inertial forces from its own mass when specifying the angular velocity. To exclude possible displacement of the calculation model in the axial direction, the displacement of one of the nodes on the front flange is limited in all directions. Linear frequency analysis was used to determine the frequencies and modes of natural vibrations of the structure: analysis type — modal; method — Block Lanczos; number of determined modes — 3; studied frequency range — 0–11000 Hz. Fixation conditions — limitation of displacements along the lateral surfaces of the sector (cutout surfaces). This should be included in the methodology.

The study results were tested in laboratory conditions, as well as at industrial facilities of ZTMC and Motor Sich.

DISCUSSION OF RESULTS

An analysis of literature data, as well as studies of typical damage to gas turbine engine rotor components, reveals that the blade airfoil areas are the most heavily stressed.

Based on the nature of the damage and its location on the component, it can be concluded that repair by cleaning methods is, in most cases, impossible. Welding and surfacing should be considered as the primary repair methods. For one-piece components, ensuring the required level of properties in the repair zone determines the maximum performance of the entire component.

A study of the properties of welded joints obtained using standard filler materials revealed that the mechanical properties of the original base material are up to 30 % lower than the required level. This was due to changes in the type and structure of the weld and the formation of a coarse-lamellar structure with primary β grain sizes of approximately 70–350 μm.

The surface topography of tensile specimens was studied using qualitative fractographic analysis. Analysis of the fracture surface and weld microstructure revealed that the alloys studied were characterized by several structural features with low fracture energy, such as facets and pores. Large cast grains in the weld reduced the material's fracture energy, and their boundaries initiated brittle fracture processes under both static and dynamic loads. It was established that in some cases, pores in the weld, measuring up to 50 μm in size, initiated microcracks. It was concluded that the quality of the filler materials is the primary source of weld defects.

Fatigue limit (σ_{-1}) testing of welded specimens made of VTZ-1 and VT8 alloys revealed that the fatigue limit of the welded joints was more than 30 % lower than that of the base metal. It was established that standard welding methods do not provide mechanical properties of welded joints of heat-resistant titanium alloys at a level 0.9 times that of the base metal. To improve the mechanical properties of welded joints to those of the base metal, it is necessary to develop fundamentally new filler materials that will allow the formation of the required type and size of structural components in the weld.

To ensure the required level of mechanical properties in titanium alloy welds, a specific structure type with a specific size of structural components should be formed. The weld metal structure should be approximated to equiaxed, lamellar, or bimodal structures. To address this issue, it is proposed to introduce modifying elements into the filler materials. The influence of modifying elements on the structure and properties of titanium alloys is determined by the most effective elements: La, Y, and B. To determine the individual and complex influence of these modifiers, the study was conducted using the full-factorial design method.

When selecting the filler material base, we took into account that welding high-strength titanium alloys requires filler metals with reduced alloying element content to prevent brittle fracture of the weld. The most common filler metal used for most titanium alloys is low-alloy titanium grade VT2sv with a low aluminum content. Aluminum, as demonstrated previously, is the most common alloying element, increasing the strength and heat resistance of titanium alloys. During welding, its losses are the highest, so the composition of the standard titanium alloy VT2sv was used as the base metal. This alloy is used for a wide range of structural and heat-resistant titanium alloys [26].

To determine the filler metal composition, we studied the effect of La, Y, and B modifier content on the structure and mechanical properties, determined by the response functions, of welded joints of VT8 titanium alloy. The results for the mechanical properties of the welded joints are presented in Table 1.

Welding of VT8 alloy plates was performed using argon-arc welding with filler materials in the form of rods of experimental compositions. For this purpose, rods up to 2 mm in diameter and 70 mm in length were produced from ingots melted according to the experimental matrix. Welding conditions corresponded to those used for producing welded joints using standard filler materials.

The results of calculating the stress-strain state of the monowheel sector, taking into account the surfacing of the leading and trailing edges for the model units, are shown in Figures 1–3.

As can be seen from the presented data, surfacing using experimental filler materials does not change

Table 1. Mechanical properties of welded joints of titanium alloy VT8 obtained using experimental filler materials

No. experience	X_1	X_2	X_3	Mechanical poperties				
				σ_t, MPa	σ_{-1}, MPa	φ, %	δ, %	*KCU*, kJ/cm^2
1	–1	–1	–1	980	430	64	6	0.40
2	+1	–1	–1	870	300	26	3.7	0.30
3	–1	+1	–1	900	370	50	5.5	0.20
4	+1	+1	–1	770	240	22	3.8	0.18
5	–1	–1	+1	1020	480	70	6.2	0.37
6	+1	–1	+1	880	390	30	4.5	0.30
7	–1	+1	+1	860	380	62	5.8	0.19
8	+1	+1	+1	790	260	27	4.1	0.11
9	0	0	0	1010	480	62	5.9	0.30
10	–1.682	0	0	990	447	69	6.2	0.12
11	1.682	0	0	680	210	22	2.0	0.10
12	0	–1.682	0	1000	470	68	6.1	0.57
13	0	1.682	0	740	220	37	3.0	0.05
14	0	0	–1.682	975	420	55	5.3	0.32
15	0	0	1.682	1070	500	60	5.7	0.28

the distribution of stress fields for all loading conditions. Stress intensity varies within 10 %.

Potential repair zones can be determined based on changes in the distribution of safety factors. The safety factor distribution fields for the welded blisk blade airfoil surface using standard (VT2) and experimental (No. 1 SMK) alloy compositions are shown in Figures 4 and 5. Analysis of the modeling results revealed that the use of experimental alloy

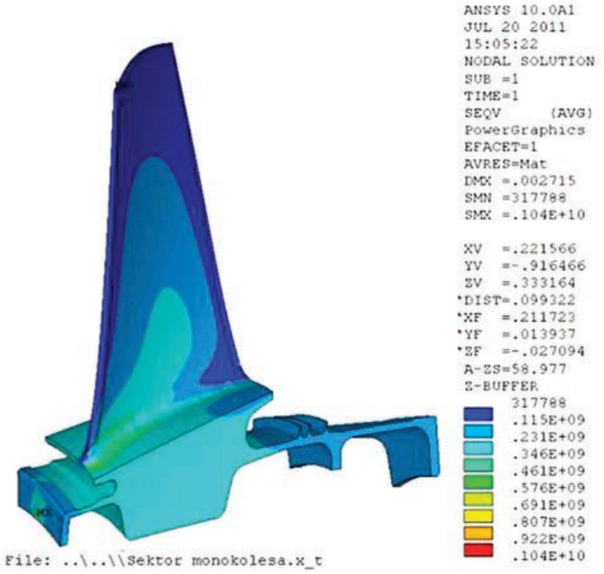

Figure 1. Centrifugal loading. Equivalent stress field (von Mises), Pa

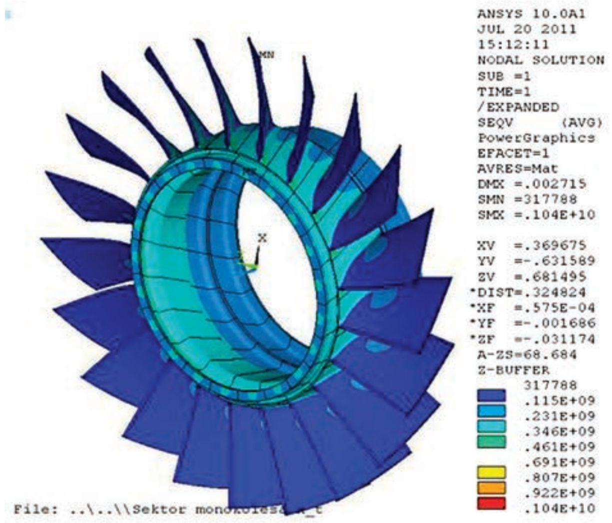

Figure 2. Centrifugal loading. Equivalent stress field (von Mises), Pa.

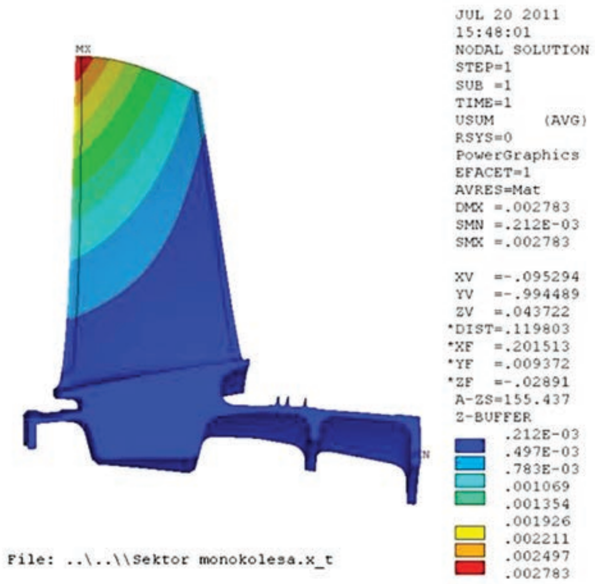

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Figure 3. Centrifugal loading. Total displacement field, m. Elastic modulus of the deposited layer $E = 9.7109$ Pa

No. 1 SMK, due to its higher strength characteristics, significantly expands the potential repair zones for fan blade airfoils.

Since the thickness of the blisk blade airfoil in all sections does not allow for differentiated surfacing on the back and trough, it is assumed that permissible repair zones can be determined by superimposing the safety factor fields for the back and trough (Figure 6).

Based on the obtained results of the stress-strain state modeling and safety factor fields (Figures 4–5), it was concluded that using a differentiated approach based on the use of modified SMK filler metals, the zones of possible repair of the blade airfoil can be significantly expanded, compared to surfacing with standard filler metals.

Analysis of the obtained results revealed that the use of SMK filler metal No. 1 for repairing the blade airfoil under variable loads allows for an increase in repair area by 20–25 %, compared to previously used filler metals. An analysis of the stress state of the unicycle hub revealed that static stresses from centrifugal forces predominate. Gas turbine engine disk materials, in turn, are subject to requirements regulating their ability to resist crack propagation. Therefore, when repairing unicycle hubs, it is necessary to use a filler material that provides high strength properties under static loads and also exhibits high crack resistance characteristics, measured by impact toughness. An analysis of the stress-strain state of the unicycle hub, as well as the strength properties of welded joints obtained by ADS with filler material composition No. 2 of the SMK, revealed that repairs can be performed using the ADS method across virtually the entire disk area. However, commercial filler materials do not provide the required level of impact toughness.

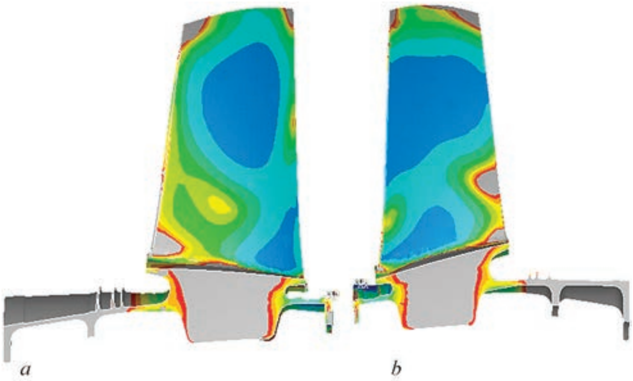

Figure 4. Distribution fields of the KZP for the D27 unicycle blade, restored using the VT-2 additive: *a* — back; *b* — trough

Fan blades made of VT3-1 alloy, one of the most common alloys used in the D-36 gas turbine engine, were selected for full-scale testing. These components were used to develop calculation models to identify potential repair zones. Full-scale experiments allowed the calculations to be verified.

Blades decommissioned due to damage during operation were used for the experiment. Welding, machining, and testing were conducted at Motor Sich JSC. Testing on the full-scale blades was performed on a vibration rig using strain gauges. The tests required welding sections of the blade using a pilot composition and standard filler metal compositions. To ensure consistent testing conditions, blades with damage in the lower portion, i.e., below the anti-vibration platform, were selected. This is because only the upper portion of the blade is used for vibration rig testing.

Blades without damage were tested as a baseline to determine the most critical zone and their service life. According to the results of tests for the fourth bending mode at a stress of $\sigma_{max} = 285$ MPa (amplitude at control point $2A = 7.4$ mm) at a frequency of 1040 Hz, destruction occurred at a number of cycles $N = 7.4 \cdot 10^6$ above the anti-vibration shelf.

To test the reconditioned blades, it was necessary to weld sections of the blade using a test compound

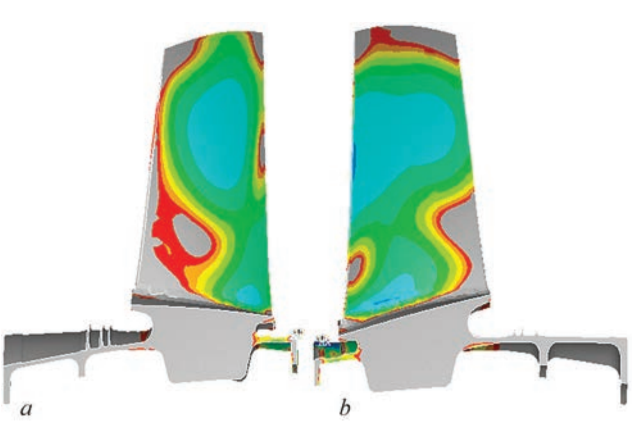

Figure 5. Distribution fields of the KZP for the D27 unicycle blade restored using additive No. 1 SMK: *a* — using VT-2 filler metal; *b* — using experimental filler metal No. 1 SMK

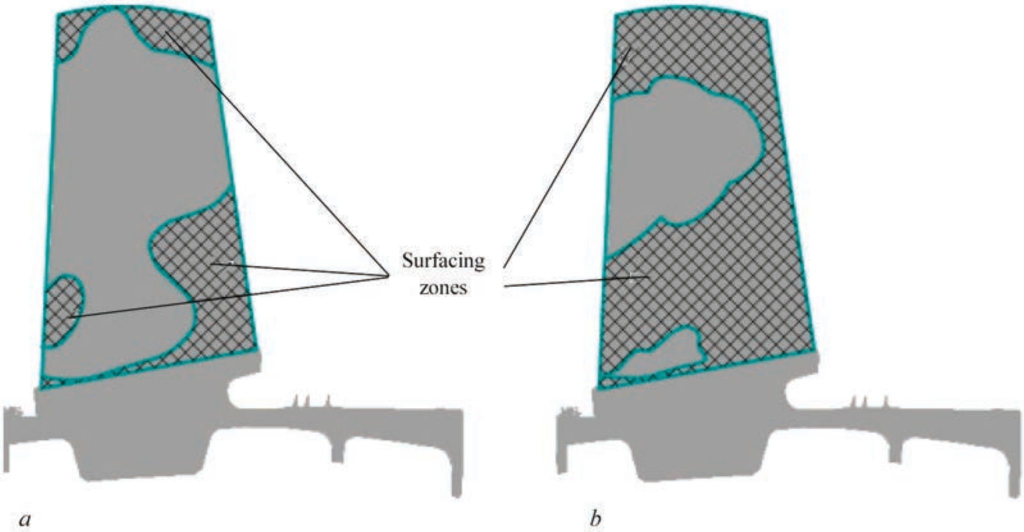

Figure 6. Zones of permissible repair of the blade airfoil made of VT8 alloy for the D-27 engine unicycle

and standard filler metal compositions. Common blade edge damage, such as nicks, was chosen as a model defect. Seventy percent of the damage occurred with nicks ranging in depth from 0.2 to 1.0 mm, and in some cases, their depth could reach 3 mm.

Therefore, a 3 mm deep nick was chosen as the model defect, while the blade airfoil thickness at this depth is approximately 2 mm. The location of the defect on the airfoil was chosen such that the onset and subsequent failure under applied loads occurred along

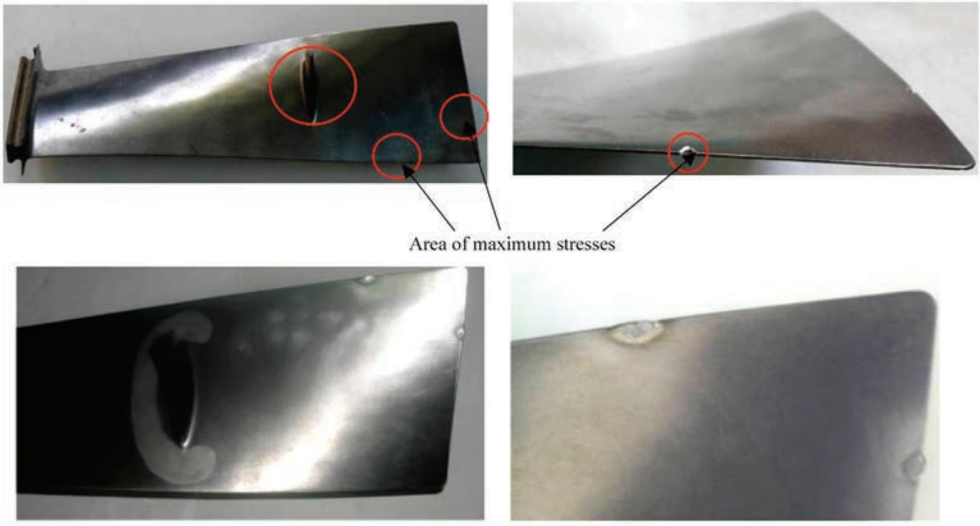

Figure 7. View of a blade restored using the ADS method with experimental and standard additives

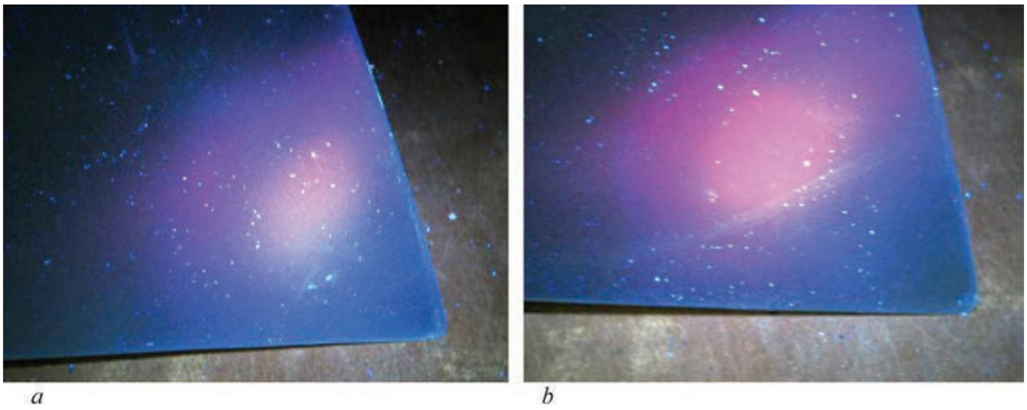

Figure 8. View of a blade restored using the ADS method under fluorescent testing: *a* — blade restored using the standard VT20 filler material; *b* — blade restored using the experimental filler material No. 1 SMK (3.6 % Al; 0.17 % La; 0.02 % B; 0.02 % Y)

Table 2. Durability of VT3-1 alloy blades restored by ADS methods with filler materials of various compositions

Additive material	Durability to the formation of cracks, cycle	The ratio of the durability of the welded blade N_{sv} to the durability of the original blade ($N = 7.4 \cdot 10^6$ at max = 285 MPa)
VT20sv	$5.7 \cdot 10^6$	0.78
3.6 %Al; 0.17 %La; 0.02 %B; 0.02 %Y in a submicrocrystalline state	$7.4 \cdot 10^6$	1

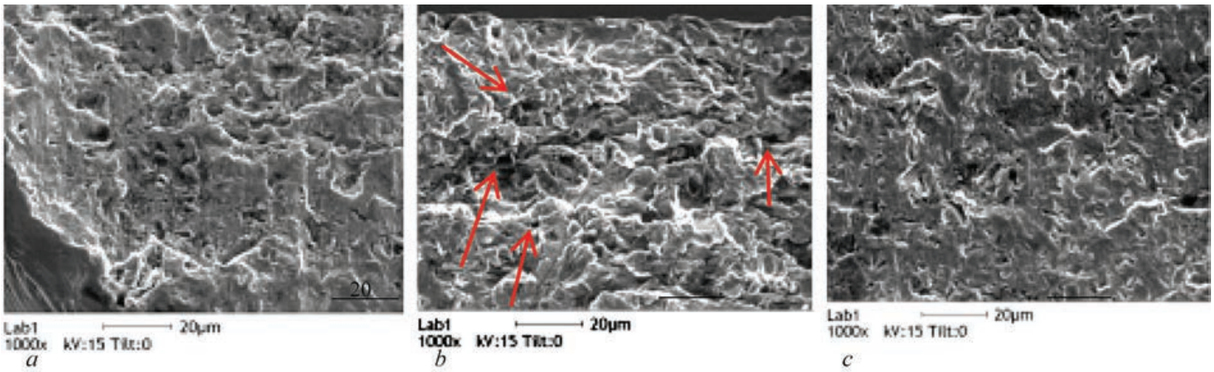

Figure 9. Blade fractograms: *a* — original blade; *b* — reconditioned blade using VT20sv filler metal; *c* — reconditioned blade using SMK pilot filler metal composition No. 1

the weld. This allowed for direct evaluation of the resistance of the weld metal and the heat-affected zone of welded joints produced using various filler metals.

According to vibration test data, when applying mode 4 loads, the onset of failure of undamaged blades corresponds to the nodal cross-section, i.e., in the zone of maximum alternating stress. The location of this test site was determined based on strain gauge measurements. It was in this location that nicks in the form of defects were simulated (Figure 7).

Defects were then ground out in accordance with current regulatory requirements at the plant. After final machining, the samples were heat-treated using the following procedure: annealing at 840 °C for 1 hour, followed by cooling in a furnace. Luminescence testing of the weld zone on the blades was also used to check the quality of the weld (Figure 8). The results showed no defects in the weld.

The results of bench tests on the durability of blades restored by ADS methods with filler materials of various compositions during the fourth bending mode tests with an amplitude of 1074 Hz and a maximum stress of 285 MPa are presented in Table 2.

As follows from the analysis of the presented data, blades restored using the experimental compound had a service life close to that of the original blades. However, the service life of blades restored using the VT20sv filler was, on average, 20 % lower than that of blades restored using the experimental filler materials. Failure onset for all blades occurred in virtually the same zone. This can be explained by the maximum stresses in this section of the blade for specific loading conditions. Continuing testing until blade failure revealed that the failure surface for all blades exhibited a ductile fatigue pattern. In blades produced using the VT20sv filler, the failure mode was less uniform, with crack propagation elements visible. This was likely due to the lower ductility of the weld produced with the VT20sv filler.

As a result of contact and friction during vibration testing, the surface topography formed during fracture was unclear (Figure 9). This complicated the analysis of crack propagation patterns by structural components at high magnifications. Microanalysis of the fracture surface is the most informative. In particular, no areas of brittle fracture or pores were detected on the surface of the original blades (see Figure 9).

For blades produced using SMK pilot filler metal compositions, these defects were virtually absent (see Figure 9, *c*), and individual pores smaller than 5 mm had virtually no effect on the fracture pattern. For blades produced using VT20sv filler metal compositions, pores up to 15 µm in size were present (see Figure 9, *b*). These defects, according to previously presented research results, in the filler metals where the structural imperfections in the filler metals were caused by (pores, chemical inhomogeneity).

Thus, the durability of reconditioned blades is primarily influenced by the weld structure. In turn, the use of experimental SMC additives made it possible to form a weld structure in the VT3-1 equiaxed alloy, close to the structure of the base metal, and to obtain higher-quality welds, which ensured the durability of the restored blades at the level of the original ones.

RESULTS

The tests demonstrated that the durability of reconditioned blades depends on the structure and defects of the weld. Increased durability is a result of the formation of a finely dispersed structure similar to the base metal. In turn, the use of SMC filler metals of the experimental composition allows for higher-quality welds, resulting in reduced pores and weld discontinuities. Thus, the tests conducted on actual blades confirmed the main findings of the study. The following rotor-type components were reconditioned using SMC filler metals: a D36 engine fan blade made of VT3-1 alloy and an axial blisk blade made of VT8M alloy.

Cyclic tests were conducted on full-scale blades using the fourth bending mode, and the stress values acting in the blade were determined. The region and magnitude (285 MPa) of maximum blade stress were established. Computational models for the distribution of stress fields acting in the blade for the fourth bending mode were experimentally validated, and a coefficient for converting the calculated stress values to experimental ones was determined.

It was theoretically and practically proven that the application of a scientific and practical materials science approach increased the repair potential zones by 20–25 % (by area) for a fan blade made of VT3-1 alloy compared to previously used filler materials and also made it possible to repair the hub and about 75 % of the blade part of the axial monowheel made of VT8 alloy.

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КОМПЛЕКСНИЙ ПІДХІД ДО ВИЗНАЧЕННЯ ПАРАМЕТРІВ РЕМОНТУ ТИТАНОВИХ ДЕТАЛЕЙ ГАЗОПОВІТРЯНОГО ТРАКТУ ГАЗОТУРБІННИХ ДВИГУНІВ

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РЕФЕРАТ

Перспективи та економічна ефективність виробів з титанових сплавів насамперед залежать від терміну їх служби, а це безпосередньо пов'язано з можливістю відновлення цих деталей. Ремонтопридатність деталей газотурбінних двигунів (ГТД) загалом визначає їх конкурентоспроможність. Запропоновано використовувати присадочні матеріали з субмікрокристалічною структурою для ремонту деталей ГТД методами зварювання. Встановлено їх оптимальний хімічний склад, спосіб виготовлення та заходи щодо регулювання структури таких присадочних матеріалів. Також визначено оптимальні параметри режиму аргонодугового зварювання та післязварювальної термічної обробки. Механічні властивості зварних з'єднань, отриманих з використанням експериментальних присадочних матеріалів, вищі порівняно зі зразками, отриманими з використанням серійних присадочних матеріалів. Макро- та мікроструктура зварних з'єднань має значно меншу кількість дефектів різного походження порівняно зі зразками, виготовленими з серійних зварювальних матеріалів. Було проведено моделювання та розрахунок моноколеса методом скінченних елементів для прогнозування зон та ступеня руйнування під час експлуатації з метою розробки оптимальної технології відновлення. Бібліогр. 25, табл. 2, рис. 9.

КЛЮЧОВІ СЛОВА: титановий сплав, зварювальні матеріали, зварне з'єднання, хімічний склад, структура, механічні властивості, дефекти

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