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ELECTROLYTE-PLASMA PROCESSING OF TURBINE BLADES FOR HEAT-RESISTANT COATING REMOVAL

Possible removal of СДП-1+ВСДП-11 PVD heat-resistant coatings from turbine blades by electrolyte-plasma processing using the existing equipment and different electrolytes is discussed. Metallographic study of electrolyte composition and process parameter impact on blade coating removal efficiency is made. Practical use of discharge panel affecting sharp edge processing rate for preservation of their geometry is established. [dx.doi.org/10.29010/083.6]

Keywords: *rotor blade; heat-resistant coating; electrolyte-plasma processing.*

Introduction

Turbine efficiency and reliable operation largely depends on operational performance and service life of turbine blades. As a result of continuous operation in high temperature conditions different defects occur on the blade surface: dents, cracks, corrosive damages. To extend service life of the blades different restorative solutions determined by both size and type of the blade damage are used. An indispensable step of any repair procedure for turbine blades is damaged coating removal.

For removal of coating residues from blade airfoil surface mechanical, chemical and chemical-mechanical processing methods are currently used in repair of rotor blades [1]. Main problem arising during repair of turbine blades for their restoration is a need for uniform removal of the damaged heat-resistant coating.

The most advanced methods in the context of efficiency, feasibility and residual coating removal control are mechanical, chemical and electrochemical processing methods and their combinations.

For chemical removal of coatings concentrated aqueous solutions of acids are used. Depending on coating composition its chemical attack and removal process can take from several minutes to several hours [2]. It should not be overlooked that etching of coating together with base takes place when using chemical or electrochemical methods of coating removal [3, 4]. Generally, it is hardly possible to completely etch out coating from the blade surface, because it has different thickness of a layer in terms of height and airfoil contour line, so the blade airfoil areas with a thicker or difficult-to-etch layer are mechanically processed.

Thus, it seems appropriate to develop a procedure for post-operation heat-resistant coating removal which would meet the following requirements: etching is independent of the removed layer composition; high rates of coating removal, reduced labour intensity; availability for preparation of coating removal solutions (electrolytes) and their safety. All these features are typical for electrolyte-plasma processing methods for metals and alloys [5].

However, due to complex and exact shape of the turbine blades, rigid geometry tolerances when using electrolyte-plasma processing (EPP), some additional problems arise such as base metal damage on sharp edge and other projected elements.

State-of-the-art

Compressor turbine blades with operating time have damages mostly of airfoil leading edge with СДП-1+ +ВСДП-11 coating (PVD coatings: СДП-1 is Ni-Cr-Co-Al-Y based, ВСДП-11 – Al-Si-Y based). Repair procedure for restoration of blades with such damages, in many cases specifies mechanical removal of the damaged heat-resistant coating layer. This technique depends on skills of the work performer and, at this point of production development, does not always meet quality and economic efficiency requirements.

One of the promising methods allowing to reduce labour intensity in heat-resistant coating removal is electrolyte-plasma processing [3]. As the work shows [6], this method also has some problems related to non-uniform etching of the different areas of the blade surfaces. This is caused by local current density increase in certain zones. Improving chemical composition of process electrolyte used for etching is a subject to be elaborated.

Coating removal work was performed on the existing equipment using the following electrolytes employed in series production as basis: sodium silicofluoride (electrolyte used for removal of casting skin from workpieces), formamide (titanium alloy polishing) and iron chloride (aluminium alloy polishing).

Purpose

Development of trial procedure for uniform and complete removal of residual heat-resistant coatings from repaired blades using electrolyte-plasma processing to reduce labour intensity.

Results

СДП-1+ВСДП-11 coating removal by electrolyte-plasma processing was performed on an experimental equipment using different types of electrolyte employed in series production. New manufactured blade specimens were used as specimens. They were made of ЖС-26 material, total thickness of coating was 0.05 to 0.08 mm on airfoil, 0.025 to 0.04 mm on transition radii and platforms.

Fig. 1 shows appearance of the blade and microslice of reference specimen No. 1, which was not processed.

In the first case, blade specimens No. 1 and No. 3 were subject to electrolyte-plasma processing, where

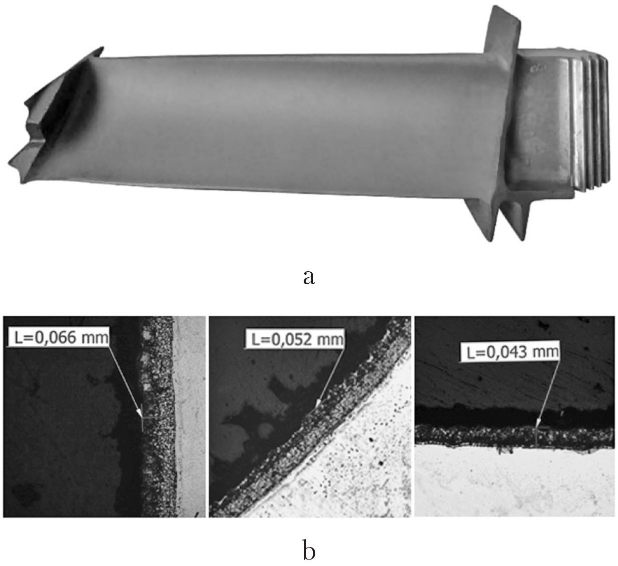


Fig. 1. Blade specimen No. 1 with coating: a – Blade appearance; b – Coating microslice in different zones of the blade

sodium silicofluoride-based electrolyte was used. Processing conditions and chemical composition are given in Table 1.

All the processed blade specimens were subject to metallographic study and measurement of residual coating thickness at reference points according to diagram (Ref. Fig. 2).

Table 1

Processing conditions for Specimens No. 2 and No. 3

Parameters	Specimen No. 2	Specimen No. 3
Voltage, V	320±20	320±20
Current, A	13 to 17	11 to 15
Temperature, °C	78 to 84	78 to 84
Duration, min	5	10
Electrolyte	Sodium silicofluoride, 9%	

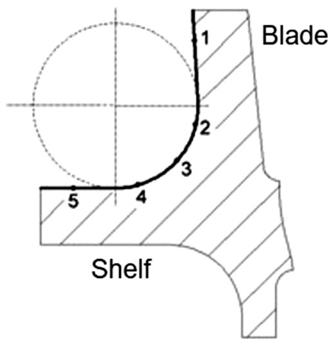
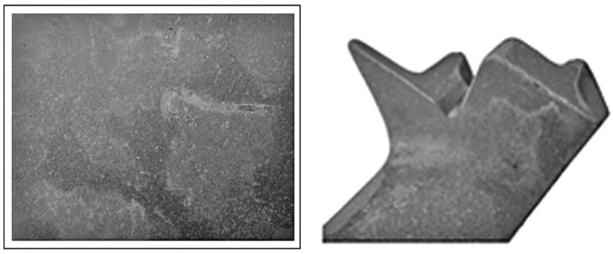


Fig. 2. Arrangement diagram of reference points for coating thickness measurement

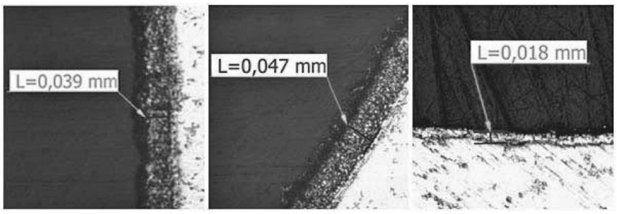
During visual inspection of the blade specimen No. 2 a change in coating colour from matt grey to dark brown with light brown and reddish brown spots is observed (Ref. Fig. 3). Surface roughness is significantly increased. No coating peeling on face ends and zigzag surfaces is found. However, sharp edge blunting is revealed.



a b

Fig. 3. Blade specimen No. 2: a – Processed surface; b – Coating appearance on zigzag surfaces of the blade

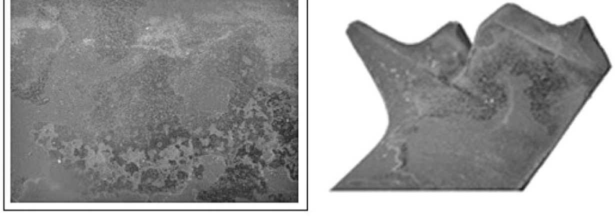
During study of the specimen No. 2 microslice (Ref. Fig. 4) it is determined, that total thickness is reduced only due to ВСДП-11 coating decomposition. However, coating microporosities are local in their occurrence character.



a – point 1 b – point 3 c – point 5

Fig. 4. Specimen No. 2 coating microslices in reference points

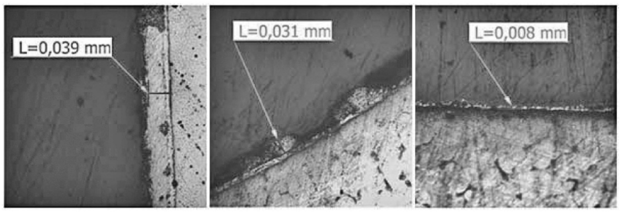
As a result of specimen No. 3 processing (duration of specimen processing is doubled relative to specimen No. 2), blade surface changed its colour from matt grey to dark brown with light brown and reddish brown spots, number and size of spots significantly decreased. Coating peeling at face ends and on blade zigzag surfaces is not observed, though decomposition of protecting coating on sharp edges of zigzag surfaces is detected (Ref. Fig. 5).



a b

Fig. 5. Blade specimen No. 3: a – Processed surface; b – Coating appearance on zigzag surfaces of the blade

Specimen No. 3 microslice (Ref. Fig. 6) shows local sites of coating decomposition to base metal without damage to the latter.



a – point 1 b – point 3 c – point 5

Fig. 6. Specimen No. 3 coating microslices in reference points

Specimen No. 4 is processed using formamide-based electrolyte (Table 3) with complete specimen immersion in electrolyte (formamide is used for titanium alloy polishing). A feature distinguishing this procedure from the previous one is flowing electrolyte feed, which is indispensable for the procedure. Also it requires special tooling creating a uniform electrolyte flow in the clearance between tooling and blade over entire processed surface, which is difficult to put into practice due to complex geometry of the blade.

Processing conditions and chemical composition are given in Table 2.

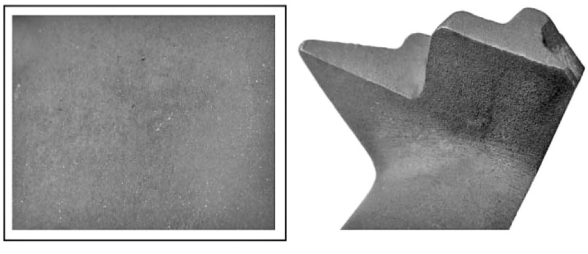
Fig. 7 shows blade specimen No. 4 after processing in formamide-based electrolyte.

Table 2

Processing conditions for Specimen No. 4

Parameters	Specimen No. 4
Voltage, V	30
Current, A	42
Temperature, °C	33 (flowing)
Duration, min.	0.5
Electrolyte	Formamide

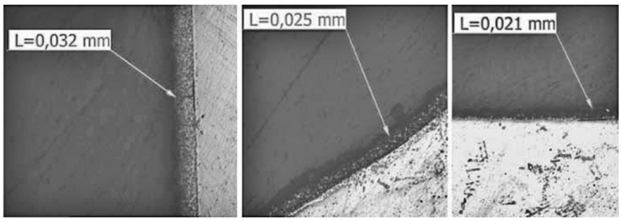
Change in colour from matt grey to lustrous silvery is visually observed.



a b

Fig. 7. Blade specimen No. 4: a – Processed surface; b – Coating appearance on zigzag surfaces of the blade

Micrographic investigation of the specimen No. 4 coating section (Ref. Fig. 8) shows most uniform removal of heat-resistant coating, absence of local pickling tints, as well as the most considerable loss in blade geometry on airfoil sharp edges and zigzag surfaces.



a – point 1 b – point 3 c – point 5

Fig. 8. Specimen No. 4 coating microslices in reference points

Based on the performed experiments, we obtained thickness values of residual coating on blade flowpath surfaces, measurement data are given in Table 3. It is important to note efficient processing of specimen No. 3, where maximum removal of both ВСДП-11 and СДП-1 coating takes place. Specimen No. 2 does not provide the required removal quality but this specimen has a minimum damage on zigzag surfaces.

Table 3

СДП-1+ВСДП-11 Coating Thicknesses

Measurement point No.	Coating thickness, mm			
	Reference specimen, No. 1	Specimen No. 2	Specimen No. 3	Specimen No. 4
1	0.066	0.040	0.039	0.032
2	0.060	0.035	0.037	0.033
3	0.052	0.031	0.031	0.025
4	0.047	0.026	0.016	0.022
5	0.043	0.022	0.008	0.02

Due to tooling complexity and significant perturbation of turbine blade geometry, specimen No. 4 processing option is useless.

Based on the results obtained and Table 3 data, it is decided to continue experimental works using sodium silicofluoride-based electrolyte and extending processing duration up to 10 min, as well as to develop and implement auxiliary tooling which includes discharge panel.

During EPP this panel is in immediate proximity to sharp edges of the blade (1 to 2 mm). However, discharge energy is distributed between the panel and blade surface, which reduces rate of material decomposition in adjacent zone. Employing discharge panel decelerates processing of sharp edges and small radii of airfoil leading and trailing edges.

Discharge panel arrangement diagram is given in Fig. 9.

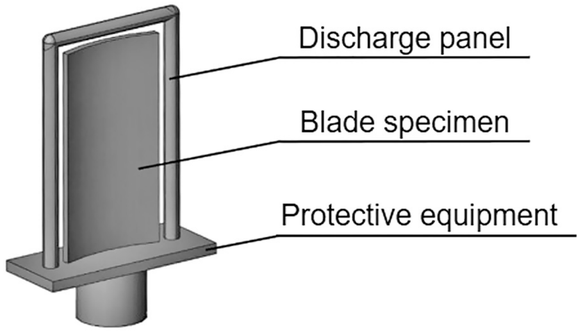


Fig. 9. Arrangement diagram of discharge panel relative to blade specimen

Using this discharge panel with the existing tooling used in previous experiments, specimen No. 5 is processed in sodium silicofluoride-based electrolyte.

Processing conditions for specimen No. 5 and chemical composition are given in Table 4.

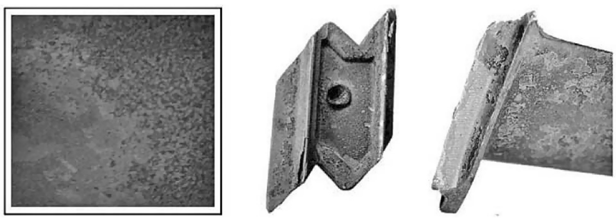
Table 4

Processing Conditions for Specimen No. 5

Parameters	Specimen No. 5
Voltage, V	315 to 345
Current, A	14 to 20
Electrolyte	Sodium silicofluoride, 9%
Temperature, °C	68 to 72
Duration, min	5

Fig. 10 shows blade specimen No. 5 after processing in sodium silicofluoride-based electrolyte using discharge panel with tooling.

As can be seen in Fig. 10, auxiliary panel allows correct distributing of electrolyte over all surfaces, at the same time makes it possible to monitor coating decomposition on blade zigzag surfaces.



a b

Fig. 10. Blade specimen No. 5: a – Processed surface; b – Coating appearance on zigzag surfaces of the blade

Metallographic study of the blade processed according to option No. 5 shows complete decomposition of coating, diffusion zone, and base metal on zigzag surfaces (Ref. Fig. 11).

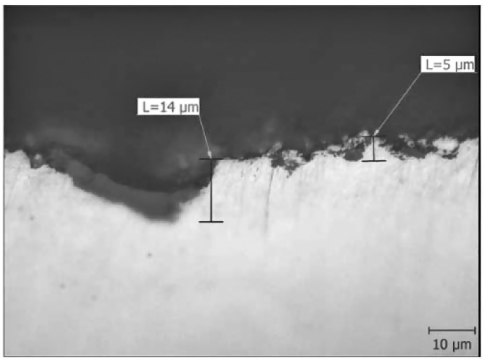


Fig. 11. Microslice of specimen No. 5 coating in point 1

Electrolyte-plasma processing of blades according to option No. 5 with auxiliary panels produced maximum positive effect, yet further experiments with processing duration and tooling did not allow improving the obtained result.

Besides the aforesaid, an additional problem occurred related to discharge panel rapid wear caused by its rapid deterioration. In most cases this same factor did not allow rather accurate monitoring of coating etching degree during processing, resulting in local damages of base metal of the blade.

The obtained results allow to make a conclusion about a need to select a new electrolyte composition which would consider chemical composition of СДП-1 and ВСДП-11 coatings (in both coatings there is a content of aluminium) and nuances of electrolyte-plasma processing.

The result of selection is iron chloride—based electrolyte (this electrolyte is used in series production for polishing of aluminium parts), so it is used for decomposition of aluminium and its compounds as part of coating.

Using iron chloride-based electrolyte, specimen No. 6 is processed.

Processing conditions for specimen No. 6 and chemical composition are given in Table 5.

Fig. 12 shows blade specimen No. 6 after processing in iron chloride with discharge panel.

During visual inspection of the processed specimen No. 6 a local peeling and lifting of coating from the base metal is observed.

High rate of protective coating decomposition is due to high concentration of electrolyte, at the same time rapid damage of the blade sharp edges occurs. In order to obtain uniform processing over entire surface of the blade, aggressiveness of solution was reduced to concentration of 5 to 6% (Ref. Table 7). Processing condition and chemical composition for specimen No. 7 and chemical composition of electrolyte are given in Table 6.

Table 5

Processing conditions for Specimen No. 6

Parameters	Specimen No. 6
Voltage, V	310 to 330
Current, A	14 to 22
Electrolyte	Iron chloride, 9%
Temperature, °C	72 to 78
Duration, min	0.5

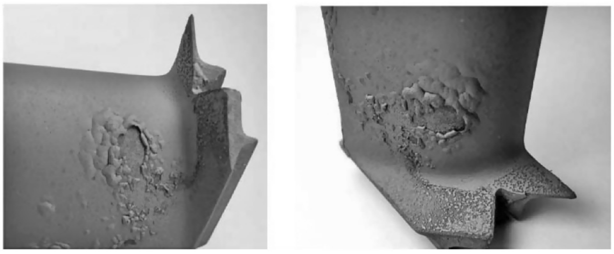


Fig. 12. Blade specimen No. 6 after processing in iron chloride

Table 6

Processing conditions for Specimen No. 7

Parameters	Specimen No. 7
Voltage, B	310 to 330
Current, A	14 to 22
Electrolyte	Iron chloride 5 to 6%
Temperature, °C	72 to 78
Duration, min	5

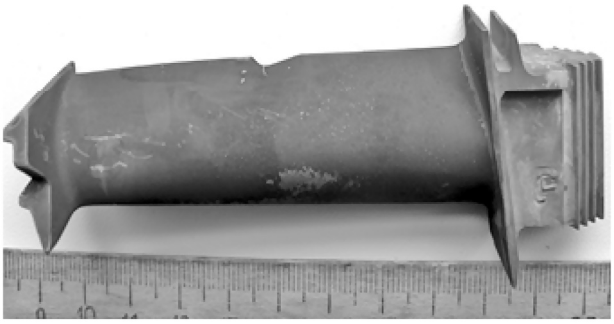
During visual inspection of specimen No. 6 it is established that blade surface is mostly of dark grey colour with a light grey spot from airfoil pressure side (Ref. Fig. 13).

Micrographic investigation of section shows that СДП-1+ВСДП-11 coating has a non-uniform decomposition around airfoil perimeter, resulting in porous structure (Ref. Fig. 14 and 15).

The obtained result proves that the processing failed to decompose heat-resistant coating on flat surfaces of the specimen. However, coating on blade sharp edges is 80% decomposed.

Conclusions

Possible removal of СДП-1+ВСДП-11 PVD heat-resistant coating from turbine blades by electrolyte-plasma processing is discussed. For purposes of prob-



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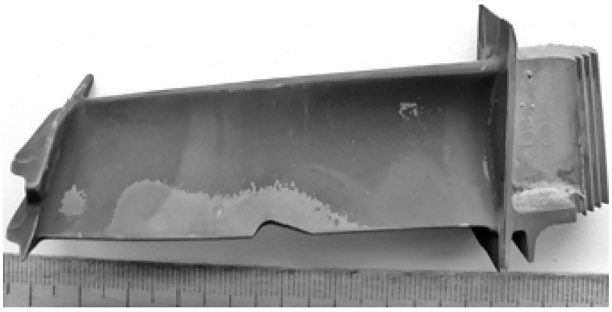
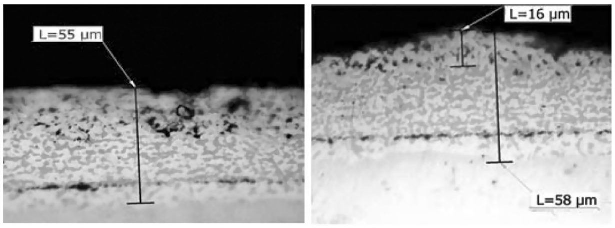


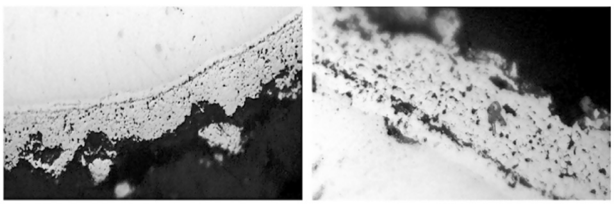
b

Fig. 13. Blade specimen No. 7 appearance:
a – from suction side; b – from pressure side



a b

Fig. 14. Blade specimen No. 7 coating microslice:
a – from suction side; b – from pressure side



a b

Fig. 15. Blade specimen No. 7 coating microslice:
a – leading edge, b – trailing edge

lem solution, electrolytes based on sodium silicofluoride, formamide and iron chloride are proposed for use.

Based on types of blade geometry perturbation during EPP, auxiliary discharge panels are designed and developed. These discharge panels ensure coating removal uniformity and protect blade airfoil sharp edges from deterioration.

It follows from findings that in case of formamide-based electrolyte a complete removal of heat-resistant coatings of any thickness is achieved. To provide this procedure, a special tooling with complicated design ensuring uniform flow of electrolyte over entire surface of the blade is required. For this reason the procedure is difficult to put into practice for blades with complex curved surface.

The most efficient and promising solution is using sodium silicofluoride and iron chloride-based electrolytes. When they are used, a high rate and satisfactory coating removal uniformity are observed. These electrolytes are most efficient in removing small coating thicknesses (up to 20 µm), as well as in case of incomplete removal of heat-resistant layers, if applicable.

Based on findings it is decided to continue improvement work on heat-resistant coating removal procedure using sodium silicofluoride- and iron chloride-based electrolytes.

References

[1] Kulikov I. S. Elektrolitno plazmennaya obrabotka materialov [Electrolyte plasma treatment of materials] / I. S. Kulikov, S. V. Vaschenko, A. Ya. Kamenev, – Minsk: Belaruskaya nauka, 2010. 132 s.

[2] Eliseev Yu. S. Himiko-termicheskaya obrabotka i zashitnyie pokryitiya v aviadvigatelestroenii [Chemical-thermal treatment and protective coatings in aircraft engine building] / Yu. S. Eliseev, N. V. Abraimov, V. V. Kryilov – M.: Vyisshaya shkola, 1999. 525 s.

[3] Bybin A. A. Zakonomernosti udaleniya vneshney I vnutrenney zon zharostoykogo alyuminidnogo pokryitiya s dlitelnoy narabotkoy pri remonte lopatok TVD [Removal Patterns for external and internal zones of heat-resistant aluminide coating with continuous operating time during HPT blade repair] / A. A. Byibin, R. R. Nevyantseva, E. V. Parfenov // Vestnik UGATU. – 2008. – № 1(26). S. 127–130.

[4] Lesnikov V. P. Tehnologiya vosstanovitelnogo remonta turbinnyih lopatok GTD [Reconditioning repair procedure for GTE turbine blades] / V. P. Lesnikov, V. P. Kuznetsov, A. V. Korotkih // Aviatsionno-kosmicheskaya tehnika I tehnologiya. – 2004. – № 7(15). S. 236–239.

[5] Spravochnik po elektrohimicheskim i elektrofizicheskim metodam obrabotki [Electrochemical and electrophysical processing techniques reference guide] / G. L. Amitan, I. A. Baysupov, Yu. M. Baron, V. A. Volosatova. L.: Mashinostroenie, 1988. 719 s.

[6] Budinovski S. A. Udalenie zharostoykih pokryitiy s poverhnosti pera lopatok turbin v vodnyih malokontsentrirovanyih rastvorah neorganicheskih kislot [Heat-resistant coating removal form turbine blade airfoil portions in low concentration solutions of inorganic acids] / S. A. Budinovski, S. A. Muboyadzhan, A. M. Gayamov // Tehnologiya metallov, – 2006. – № 11. S. 40–45.

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ЭЛЕКТРОЛИТНО-ПЛАЗМЕННАЯ ОБРАБОТКА ЛОПАТОК ТУРБИНЫ С ЦЕЛЬЮ СНЯТИЯ С ИХ ПОВЕРХНОСТИ ЖАРОСТОЙКОГО ПОКРЫТИЯ

Рассмотрена возможность снятия жаростойкого конденсационного покрытия СДП-1+ВСДП-11 с лопаток турбины путем применения электролитно-плазменной обработки (ЭПО) на существующем оборудовании с использованием различных электролитов. Проведены металлографические исследования влияния состава электролита и технологических параметров на эффективность снятия поверхностного слоя покрытия лопаток. Установлена эффективность применения разгрузочного экрана на скорость обрабатывания острых граней с целью сохранения их геометрических размеров. [dx.doi.org/10.29010/083.6]

Ключевые слова: лопатка рабочая; жаропрочное покрытие; электролитно-плазменная обработка.

Литература

[1] Куликов И. С. Электролитно плазменная обработка материалов [Текст] / И. С. Куликов, С. В. Ващенко, А. Я. Каменев. – Минск: Беларуская наука, 2010. 132 с.

[2] Елисеев Ю. С. Химико-термическая обработка и защитные покрытия в авиадвигателестроении [Текст] / Ю. С. Елисеев, Н. В. Абраимов, В. В. Крылов – М.: Высшая школа, 1999. 525 с.

[3] Быбин А. А. Закономерности удаления внешней и внутренней зон жаростойкого алюминидного покрытия с длительной наработкой при ремонте лопаток ТВД [Текст] / А. А. Быбин, Р. Р. Невьянцева, Е. В. Парфенов // Вестник УГАТУ. – 2008. –№ 1(26). С. 127–130.

[4] Лесников В. П. Технология восстановительного ремонта турбинных лопаток ГТД [Текст] / В. П. Лесников, В. П. Кузнецов, А. В. Коротких // Авиационно-космическая техника и технология. – 2004. – №7(15). С. 236–239.

[5] Справочник по электрохимическим и электрофизическим методам обработки [Текст] / Г. Л. Амитан, И. А. Байсупов, Ю. М. Барон и др. Под общ. ред. В. А. Волосатова. Л.: Машиностроение, 1988. 719 с.

[6] Будиновский С. А. Удаление жаростойких покрытий с поверхности пера лопаток турбин в водных малоконцентрированых растворах неорганических кислот [Текст] / С. А. Будиновский, С. А. Мубояджян, А. М. Гаямов // Технология металлов, – 2006. – № 11. С. 40–45.