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PATON TURBINE TECHNOLOGIES

Paton Turbine Technologies LLC (PTT), being the assignee of «Pratt & Whitney-Paton» (PWP) marked its twenty-fifth anniversary in 2018.

At the start of 1990s, United Technologies Corporation (UTC), one of USA largest financial-industrial groups, addressed B.E.Paton with the initiative to create a scientific-research center for further advance of scientific developments in the field of EB-PVD technology, started earlier at PWI under the leadership of such well-known scientists as B.E. Paton, B.O. Movchan, I.S. Malashenko, V.O. Timashov, and oth.

The main specialization of the established Joint Venture consisted in improvement and adaptation of the production of thermal barrier coatings (TBC) for the world market (Figure 1). TBC application is one of the ways to improve the service life of components of the turbine hot section and more efficient operation of gas-turbine units (GTU). In combination with internal cooling, TBCs provide a lowering of temperature on the base alloy surface, and, hence, allow raising the turbine inlet gas temperature, thus increasing its efficiency, and also promote protection from external erosion impact and prevent metal degradation under the impact of the external gas environment, thermal and residual stresses. International experience of the last decades, particularly in the aviation industry, confirmed the rationality of application of electron beam physical vapour deposition (EB-PVD) in vacuum, in order to produce thermal barrier ceramic coatings with a columnar rather dense structure of formed crystallites. This is exactly the structural feature that ensures a fatigue life margin of the ceramic coatings at varying thermal cyclic loading in operation (Figure 2).

The process of formation of electron beam thermal barrier coatings on a heat-resistant bond coat was mastered at PWI. Further successful development of the technology led to formation of a regular thermally grown oxide layer (TGO) on the boundary with the metal interlayer during ceramics deposition. It was developed and certified due to the efforts of Ukrainian and USA specialists of Pratt & Whitney-Paton.

At the start of its activity, Ukrainian-USA Joint Venture Pratt & Whitney-Paton entered into production and intellectual cooperation with Pratt & Whitney Company, which together with British Rolls-Royce Company and USA General Electric belong to the «big three» of aircraft manufacturers.

Just one year after the Company was established, manufacture of high-tech electron beam equipment for the USA partners began in Kiev, which was stage-by-stage placed and upgraded in the USA and Singapore.

In 1998, EB-PVD ceramic coating was first deposited on blades of the first stage of PW 4000 aircraft engine, some series of which were designed for Airbus A300-600, Airbus A310-300, Boeing 747-400, at RC Pratt & Whitney-Paton in Kiev. Now the Company achievements include formation of coatings on the components of CF-6 aircraft engines, produced by GE Aviation for Airbus A300/310/330, Boeing747, Boeing 767; CFM-56 produced by CFM International (joint

Figure 1. General view of the Company production facilities: *a* — coating shop, *b* — shop for repair of gas turbine engine components

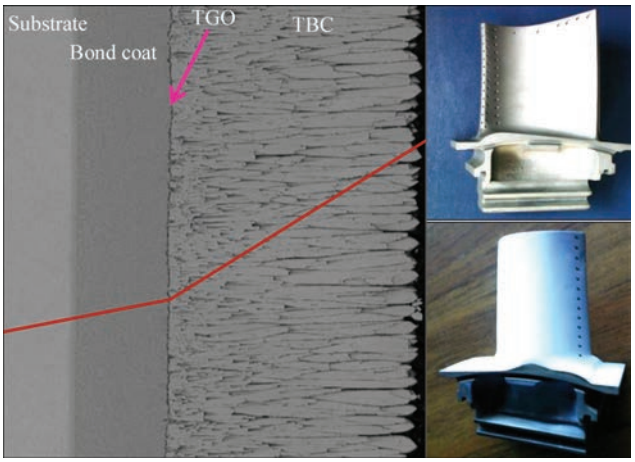

Figure 2. Thermal barrier coating and appearance of blades with metal and ceramic coatings

venture of Safran Company and USA General Electric) for Airbus A319/320/321 and Boeing 737. Over the last thirteen years the coatings were successfully deposited on more than 280 thou blades and 18 thou rings of additional power units APU 131-9 Honeywell.

Another important page in the history of PTT development is long-term cooperation with Siemens Industrial Turbomachinery AB Division (Swedish Branch) on deposition of thermal barrier coatings on blades of SGT 800 turbine (nominal power of 47/53 MW). By the level of pollutant emissions into the atmosphere at 50 to 100 % load it was noted by experts as the best among the medium-power generating turbines. The active cooperation phase started in the first quarter of 2006, and during this time EB-PVD metal and ceramic coatings were deposited on more than 60 thou blades of SGT 800 turbines of four different generations. Here, the production efficiency was higher than 99.8 %. And now Paton Turbine Technologies, as a leader in thermal barrier coating sector, is developing and testing original coatings for a new generation of single-crystal blades of 1-st stage of the modified SGT 800 turbine, which will be marketed this year.

At present thermal barrier coatings on various types of base alloys and metal layers are produced at PTT by EB-PVD method. Today TBC are deposited on a wide range of blades and vanes, made from high-temperature nickel alloys of equiaxial, directional crystallization and single-crystal alloys of different generations, for instance, MAR M-247, CMSX-4, PWA-1484, Rene-5, CM-186LC, IN-939, ZhS-32, ZhS-36, etc. Used as bond coats are metal layers of MeCrAlY (+Hf, Si) systems, formed by the methods of EB-PVD, high-velocity flame spraying in an oxygen-containing atmosphere (HVOF), plasma spraying in low vacuum (LPPS); aluminide NiAl and platinum-aluminide (Pt, Ni)Al coatings (Figure 3).

In addition, the majority of them are now produced in Kiev. Development strategy of Paton Turbine Technologies reflects targeted diversification for creation of a production complex, which helps producing various types of coatings or their systems. These coatings are used for the components of hot section of turbines in gas turbine engines. The composition and method to produce metal coatings are selected, depending on their functional features, and base alloy type of the component to be coated. It is important to note that testing coated samples for thermal cyclic fatigue showed that some systems of thermal barrier coatings provide the fatigue life of more than 3700 thermal cycles at maximum temperature of 1100 °C.

Our Company experienced periods of ups and downs, and 2014 was a quite serious challenge, when USA partners withdrew from RC «Pratt & Whitney-Paton» and its assignee — Paton Turbine Technologies Company was organized on its base. Owing to the support of PWI and Institute directorship personally, as well as maximum interest of the new PTT partner in the development of Paton Turbine Technologies, the Company received an impetus for further growth, and reaching new horizons, both in commercial production and in mastering advanced technologies.

At present, owing to the knowledge, creative approach and proper organization of production, the EB-PVD units manufactured at Paton Turbine Technologies/Pratt & Whitney-Paton, continue operating successfully to fulfill the aviation industry orders in the USA and Singapore. International cooperation with Siemens Industrial Turbomachinery AB, Honeywell, Meyer Tool, Inc., and Kawasaki Heavy Industries, Ltd. Companies continues to develop. For international positioning of the Company, it is important to note that PTT is included into the data base of Siemens Industrial Turbomachinery AB as a qualified and approved supplier (SIT Approval Supplier Data Base (ASD) SQ).

The high level of the Company was confirmed by ISO 9001, AS 9100, ISO 14001, FAA, and NADCAP certificates, which are revalidated on a regular basis.

The Company purposefully maintains a high level of production organization, which was established by USA partners. In 2009 Pratt & Whitney-Paton reached the Silver Level in ACE system (Achievement of Competitive Excellence) within the United Technologies Corporation, and Paton Turbine Technologies continues maintaining the operation of all the key elements of the system up to now.

Stable and confident development of Paton Turbine Technologies is also reflected in the Company personnel policy. Over the last three years, 67 workplaces

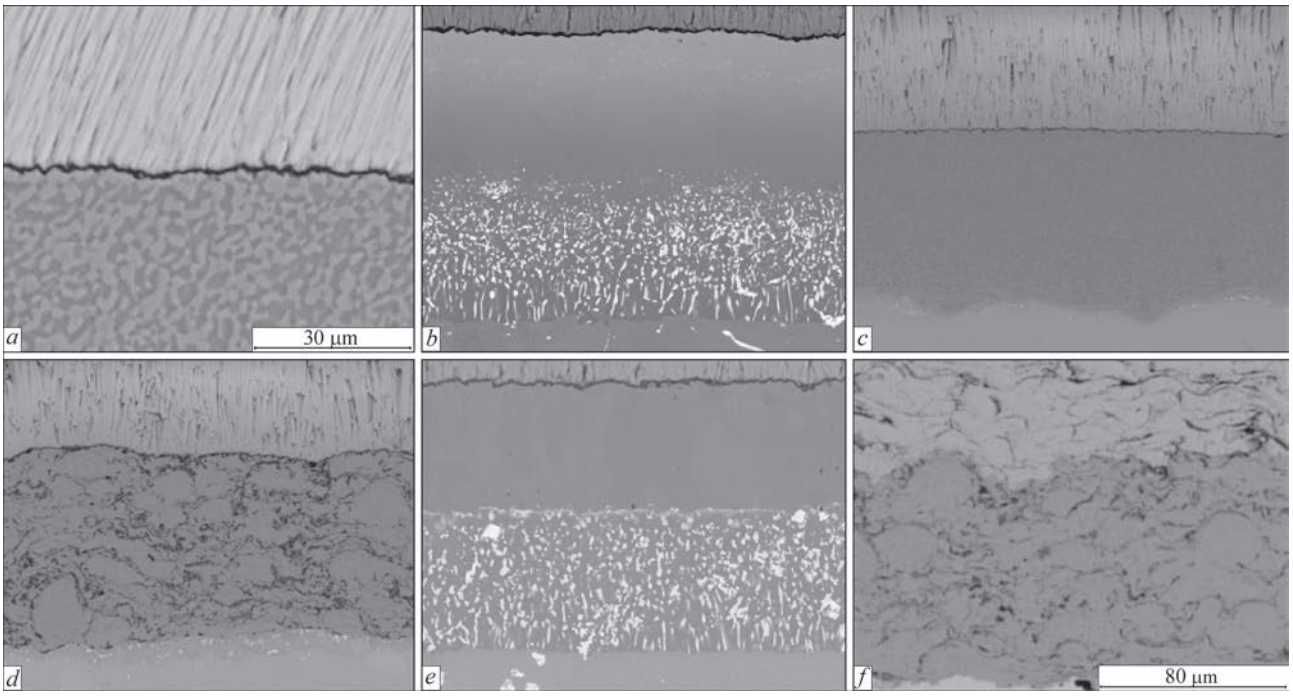

Figure 3. Different types of bond coats in thermal barrier systems of coatings produced by EB-PVD: (*a*–*e*) and APS: *a* — EB-PVD; *b* — PtAl; *c* — LPPS; *e*, *f* — HVOF; *e* — NiAl

were additionally created (more than 50 % Company growth, compared to 2014). Here, the number of employees with higher education is more than 2/3 of the Company total staff. A significant rejuvenation of the workforce took place.

During development of EB-PVD coating technologies more than 25 different patents were granted over the twenty-five year history. Here, the patented technologies have been and are currently used in actual production. Paton Turbine Technologies/Pratt & Whitney-Paton developed and registered Company Specification both for metal PWP-400 (18 coating types) and for ceramic coatings — PWP-100.

Together with development of «traditional» areas, the scientific and technical units of Paton Turbine Technologies continue investigations in the field of creating fundamentally new types of protective coatings. To the Company's credit are the new types of advanced MeCrAlY coatings, produced by EB-PVD of the coating alloy with addition of alloying elements. Development of ceramic coatings was continued in the application of new materials, based on a mixture of REM oxides. Such materials have the heat conductivity below that of standard ZrO_2-Y_2O_3 ceramics. Application of EB-PVD of such materials allows producing new generation ceramic coatings, which is exactly realized in PTT.

Focusing on the realities of the market of protective coatings for aircraft engines and industrial gas turbines, alongside EB-PVD of MeCrAlY type coatings, the Company began actively developing and using other methods of protective coating deposition. Platinum-aluminide coatings are widely used as a metal bond coat for GTE first stage blades. These coatings are a separate group of platinum-modified aluminide coatings.

Our Company achievements already include thermal barrier coatings deposited on platinum-aluminide coatings of the Customer for the aircraft engine blades, the fatigue life of which exceeded 1000 thermal cycles. Starting from 2018, a platinum electroplating section was set up and has been operating in the Company. It is fitted with competitive Ukrainian equipment. This year we will finish setting up the laboratory and will commission the production section for gas-phase aluminizing, based on available equipment, upgraded in the Netherlands. This will widen PTT production line as to producing aluminide and platinum-aluminide coatings for foreign and Ukrainian partners. It is important that the result of long-term study of the properties and features of forming platinum-aluminides was the developed at Paton Turbine Technologies optimum composition of the coating, which, as the bond coat, ensures formation of reliable thermal barrier systems with sufficient service life, both on equiaxial crystallization alloys, and on single-crystal alloys of different generations (Figure 4).

As alternative and less expensive methods of coating deposition, Paton Turbine Technologies production complex developed and introduced coatings produced by the methods of HVOF and APS (air plasma spray). Processes of thermal spraying are widely

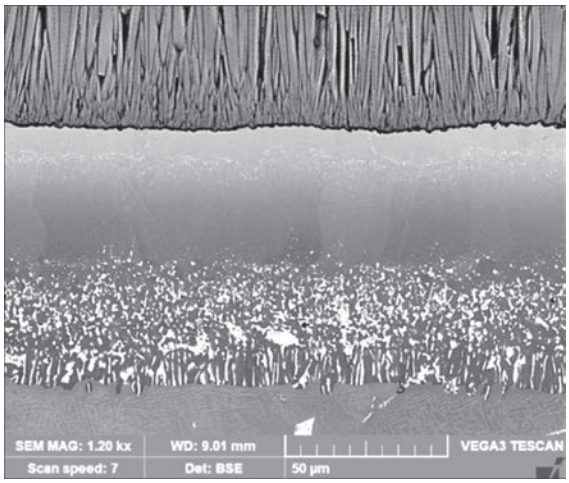

Figure 4. Structure of platinum-aluminide coatings formed as a bond coat in the system of thermal barrier coating deposited by EB-PVD

applied for deposition of thermal barrier coatings and bond coats for components of engines and land gas turbines. These deposition technologies are popular from the viewpoint of cost, as well as due to the simplicity and repeatability of the process. HVOF process allows forming rather dense coatings of NiCoCrAlY (+HF, Si) system (with less than 2 vol.% porosity), which due to the features of the lamellar structure and alloying complex demonstrate good resistance to high-temperature oxidation and thermal stability, that allows applying them both as independent protective coatings, and as bond coats for thermal barrier coatings, deposited by APS method (Figure 5). In terms of cost, APS-coatings, which are produced in air or shielding atmosphere, are more profitable in commercial use for components of industrial and power turbines, and provide a fatigue life of more than 1000 thermal cycles. TBCs deposited by this method have low heat conductivity.

APS unit was also used for development of a method of producing abradable ceramic coatings of ReSZ system: they are used in the turbine flow section to minimize the radial gap above the blades, in order to reduce the gas losses and increase the turbine effectiveness. These coatings have sufficient erosion and corrosion resistance, heat resistance, proper porosity (>20 %), etc. In the case of the blade interaction with the casing, the coating protects the blade and the casing from serious damage, improves the turbine efficiency and reduces fuel consumption.

It should be noted that Paton Turbine Technologies performs new developments, aimed at further progress of modern technologies, their adaptation in production not only for the aerospace industry, but also for other sectors, in particular, transport engineering, metallurgy, and chemical industry.

At present, producing wear-resistant coatings is in great demand with different customers in the market. Using the HVOF unit, PTT started really applying the method of high-velocity thermal spraying of wear-resistant, corrosion-resistant and antifriction coatings of the type of WC, Cr, C_2, Mo, PG-10N-01, etc., for rotation products and on flat abradable surfaces (Figure 6).

In 2006 Pratt & Whitney-Paton began developing a new direction, namely repair of gas turbine engine components. Now, a separate shop is functioning in the production complex, which performs comprehensive repair of both serial batches of aviation products, and of individual components. Advanced methods of blade repair include welding and brazing to extend the operating life of blades of turbines and gas-turbine units as a whole. At reconditioning products after service most attention is given to high-temperature brazing in vacuum. Diffusion brazing of high-temperature nickel alloys as to its technological capabilities is equivalent to argon-arc welding and provides the required physico-mechanical properties of the joints.

The entire repair cycle includes the operations on product cleaning, removal of used coatings, machining and heat treatment, operations of cladding,

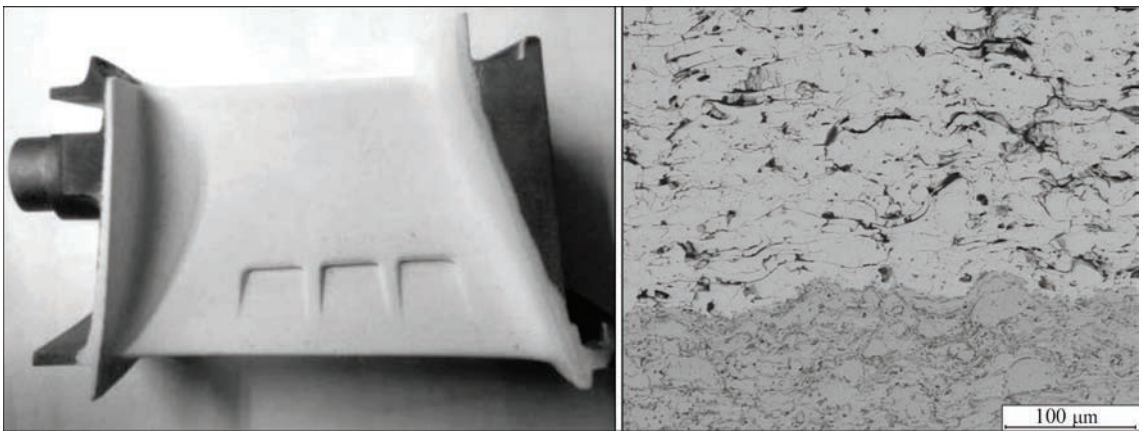

Figure 5. Blade with thermal barrier coating, produced by the methods of HVOF/APS and structure of the interphase between the metal (HVOF) and ceramic (APS) layers of TBC system

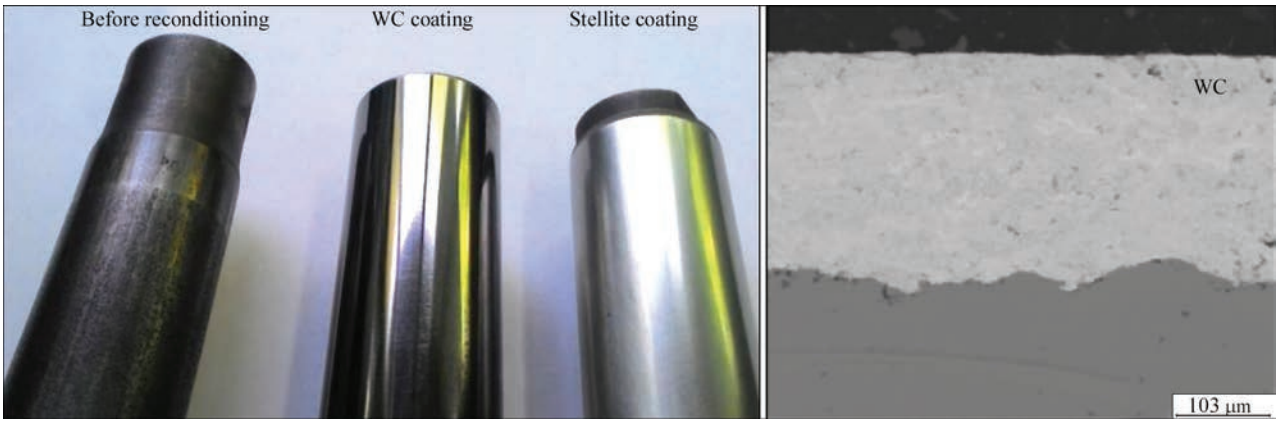

Figure 6. General view of the shaft after operation and reconditioning with deposition of wear-resistant coatings of WC and Stellite type, and microstructure of WC coating

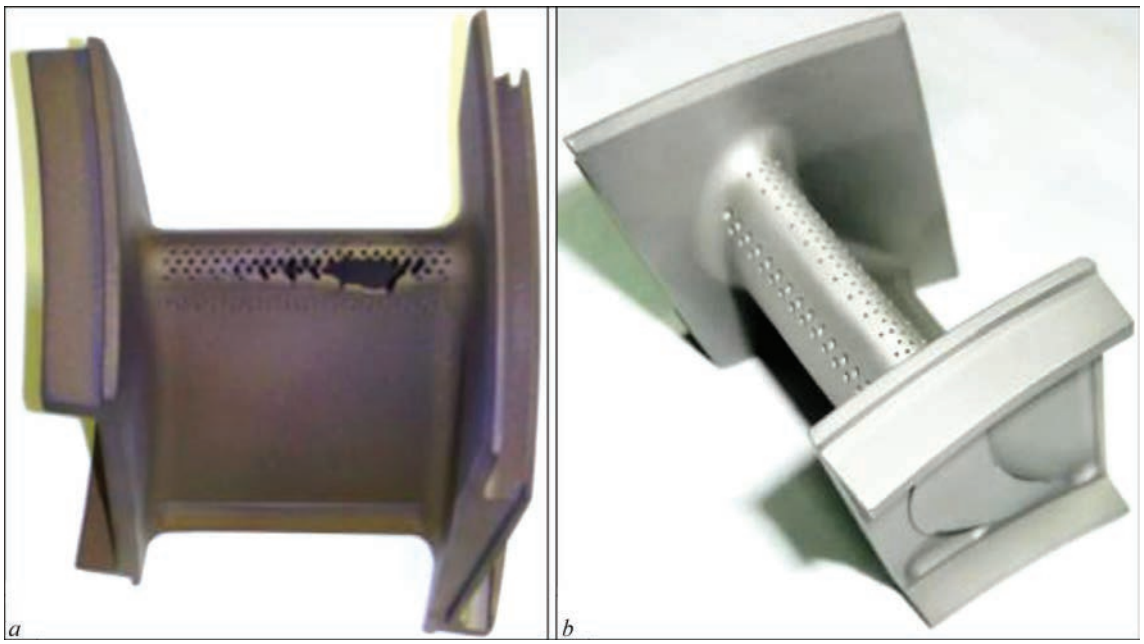

Figure 7. General view of the nozzle blade after operation with burn-out on the leading edge (*a*) and after reconditioning for further operation (*b*)

brazing, restoration of the dimensions and profile, coating deposition, hardening, etc. The main attention is given to combining higher strength and low-temperature ductility of the repaired areas, and ensuring heat resistance of base alloys of the reconditioned products. Paton Turbine Technologies

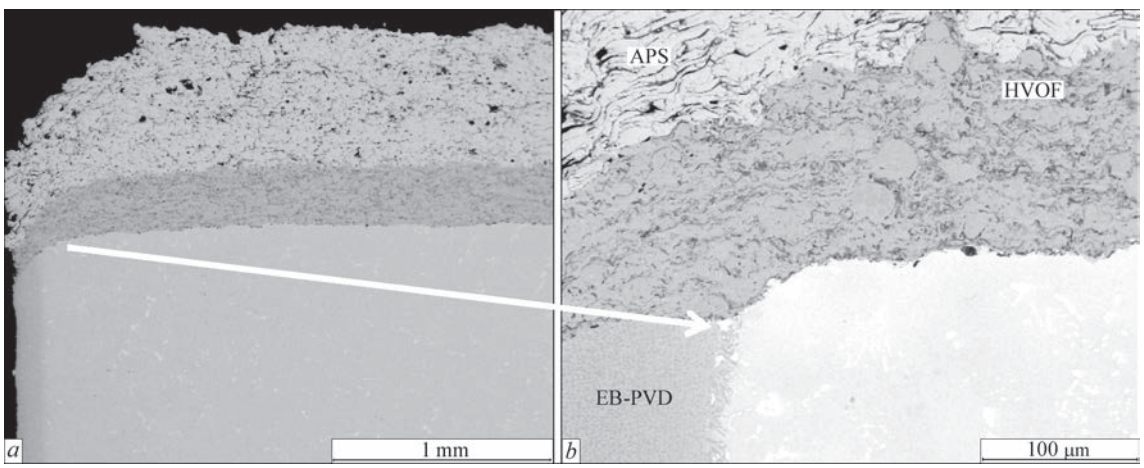

Figure 8. Combining various coating types on the tip of power turbine airfoil: *a* — fragment of airfoil; *b* — joint line of two types of protective and thermal barrier coatings

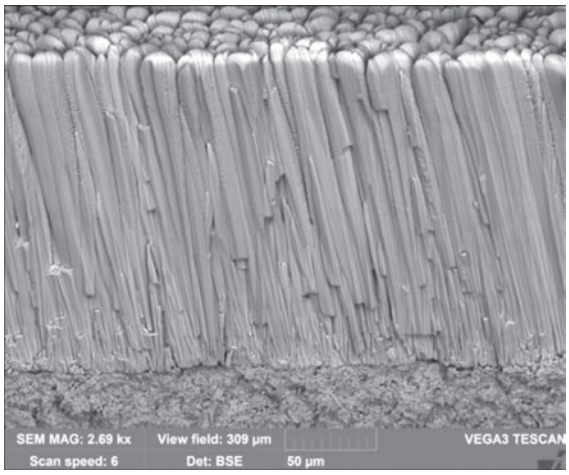

Figure 9. Classical columnar structure of thermal barrier coating produced by EB-PVD

performs reconditioning of components of RD-33, AL-31, D 30KP, D 36, TVZ-117, DSU GTDE-117 aircraft engines and industrial gas-turbine units, GTK 10-4, GTK 10I, MS 3002, DR-59, etc.

In order to repair burns-through, mechanical and corrosion-erosion damage, crack «healing» and restoration of the dimensions of blades, segments and other gas turbine components, multilayer preforms or composite filler metals are now used, which ensure optimization of the processes of formation of sound strong welds with sufficiently high physico-mechanical characteristics. The new mastered cladding and brazing technologies allow repairing the casting and service extended developed defects (cracks, burns-through, fusion, degradation, etc.) of the components of GTE hot section (Figure 7).

Having the knowledge, skills, experience and production capacity, PTT now conducts the entire complex of reconditioning of gas turbine engine components after service, and performs the full cycle of repair and deposition of various types of coatings, required for this product type (Figures 8, 9). This method includes expert assessment, fault detection, a set of thermomechanical operations, and testing. Thus, customer requirements are satisfied in «all inclusive» format, i.e. the entire reconditioning process is in one place.

Paton Turbine Technologies LLC is an example of successful adaptation and introduction of the achievements of fundamental science into production, development of modern technologies, and moving forward, while taking into account the urgent needs of the society.