LASER ABLATION CLEANING OF THE AERONAUTICAL JET ENGINE TURBINE PADDLES

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Abstract

Preliminary results ablation of the laser cleaning was introduced in the article elements of the turbine engine of airplane (blades, guide rings, the chambers of oxidising). Cleaning of these units was realized to obtainment of the metallically fine superficial layer for the chosen melts of Fe – C and on the datum feature Nor, prepare to the processes welds or the spraying thermal of coating barriers thermal TBC_S. The chosen results of the selection of parameters were introduced in the support about steorology and the cleanness of the superficial layer. Various parameters: laser radiation power density, impulse duration, the frequency control and the laser spot lap stage were applied in laboratory experiments. Laser radiation influence effects were estimated on the surface photo, microstructure, chemical composition in microzones investigation basis. The stereoscopic microscopy, electron scanning microscopy (SEM) and the X-ray analysis were used in investigations. Very good cleaning effects are from oxides, accumulations of turbine blades.

In particular, studied elements of aircraft turbine engine, characteristic surface and area topography of heat resistant nickel alloy, tests results of chemical constitution in the characteristic micro-zones of surface layer of high-temperaturecreep are presented in the paper.

Keywords: *nickel based ŻS6K – WI alloy, aeronautical engine paddle, laser ablation cleaning, surface layer topography*

1. Introduction

The issue of surface purity is crucial, especially in modern semiconductors industry and high integration level circuits, optical industry and in industrial technological surface layer shaping processes of various elements (for example in electronics, telecommunication, medicine, galvanic processes, vehicle technique, aviation and many other). Proper technological preparation of various materials surface (metals, composites, ceramics and others) especially in the purity aspect, has crucial impact of adhesion of created coatings (for example galvanic, metallic, sputtered, deposited my PVD methods and many others).

Among applied methods many of them cause ecological and environmental side effects (chemical methods, sand-blasting and many others) polluting environment. Luckily a wide range of modern methods and technologies applied in cleaning process were invented, like electron beam, or laser radiation (ultraviolet, visible, infrared) which allows to clean even the most fragile and delicate surfaces of any kind with great precision and restore primal state, or even may lead to ideal state with no damages [1-9]. During research have been carrying out since 1970's focused on interaction of laser radiation with mater a phenomenon called nowadays laser ablation was noticed [1-4]. Traditional methods of cleaning employing water under high pressure with various abradant additives or chemical compresses with brushing remove buildups in a mechanical way. Competitive methods are usually often applied in production processes chemical removal or with ultrasounds.

To clean very precisely small surfaces of antique items, electronic elements, elements of machines made of various structural materials, application of laser radiation became irreplaceable and in many case it is the only one successful option [3-9].

2. Surface layer laser cleaning

In the particles tearing off process by photons stream, so called phototearing off three major forces are taken under consideration responsible for particles attachment to the surface: van der Waals force, capillary force (electrostatic force. The van der Waals force is the molecular interaction force. Decrease of the distance between particles causes rapid increase of repulsion, nevertheless while distance increases attraction between particles increase, so the particle is strongly attracted to the substrate then. To overcome relatively strong forces of particles adhesion to the substrate, without damaging the surface, laser beam cleaning with photomechanical reaction may be successfully applied [1-9].

As a result of intensive laser radiation absorption in the surface layer (oxides, corrosion, fats, oils, dyes and paints and many others organic and inorganic substances) rapid and strong increase of temperature appears. Plasma is formed from which, as a result of convection and electronic conductivity, starts energy transport towards bulk of the material where laser radiation can not reach. A boundary called ablation front is formed with strong density and temperature gradients. Ablation front separates two areas, where directions of mater motions are opposite. From the area closer to the outer layer heated material “escapes” in the perpendicular direction to the lightened surface.

In the second area matters motions is directed toward result of particles forces) and bulk material. There is only a narrow area of weakly heated matter, condensed by shock wave, propagated as a result of momentum conservation principle, as a reaction of system for very fast matters evaporation. If contaminative layer is very thin, shock wave after reflection from the surface of boundary layer substrate (interfacial) changes direction of the propagation multiplying contaminations tearing off effect.

When the removed layer is thick, transition of the shock wave into acoustic wave takes place causing vibrations of the solid substrate in the irradiated area what causes multiplication of the cleaning effect.

After removal of the accretion, original surface is automatically protected from further damages because interface does not exist any more, so shock wave does not reflect but it is absorbed by the substrate.

Deepness of the ablation front depends from laser radiation wavelength and ranges from 0.3 to 1 micrometer. It means that layer can be removed one after other in totally controlled way. Of course the process occurs after choosing proper parameters of the laser radiation. There is an interesting fact, that we are able to change laser radiation parameters in a fluid way what means fluid control of: duration of the impulse, maximum power density and frequency of the impulse repetition. Supplied power should be high enough to immediately and rapidly create heat flow to the particle or materials substrate what is essential for explosive evaporation of particles and thin layers and so low to not exceed substrate surface damage threshold. Surface cleaning from remaining particles and buildups can be done as well in dry and wet environment [1-9].

3. Purpose and research methods

The main goal of the preliminary research was to define usefulness of the laser cleaning technology (non-tactile method applying mainly laser ablation) of the chosen nickel alloys (mainly ŻS6K-WI – trade label) applied in crucial elements construction of aviator propulsion (mainly turbines paddles) to obtain metallic clean, impurities free surface layer. Applied method should remove all kinds of impurities like: organic and inorganic contaminations, non-metallic inclusions surface oxides from the aviator engine elements and preparing them to spread protective coating on (TBC_S) heat sputtered or formed by CVD method or by others.

Final effect of the planned work will be technological purity increase and enhancement of the surface layer in a significant way, to positively influence the adhesion of modern technological coatings. unique properties of laser radiation are the reason why the laser treatment can be limited to the chosen area without need to mask. Surface which are difficult to reach can be treated as well as highly curved surfaces because the laser method are non-tactile, there is possible to apply them also in toxic and radioactive material treatment. different plasma characteristics (temperature, pressure, time of lasting, chemical composition) formed by devices like laser (CO_2, Nd: YAG, ARF) cause that treatments results are different in every method, what stresses universality of the proposed field of work and determines areas of possible application of every of mentioned above methods. To clean the surface layer of heat-resistant nickel based żs6k-wi alloy from casting impurities, oxides and organic and inorganic precipices comparing investigations of these impurities removal were done by application of laser surface cleaning method using impulse laser renovalaser 2 - ND: YAG with q-modulation and emitted radiation frequency processing. the wavelength was $\lambda = 1.064$ μm. during experiments various power densities ranging from 0.5 to 10 J/cm2 were applied. Exposure time was constant and was set as 10 ns.

In the studies a new generation Nd: YAG laser with ytterbium fibre was also used. In the experiments single laser pulses were applied and the multi-impulse cleaning with varying degrees of covering of the successive pulses was applied. This effect was obtained by using an automated working station (xy table, working with laser) and the station with the laser head Galvo.

For the observation of the purified surface layer a modern set of stereoscopic microscope with the possibility of digital recording was used. Also the scanning electron microscopy (SEM) and EDX to determine the chemical composition of the surface layer before and after laser cleaning were applied. Fig. 1 shows selected elements of turbine engine after laser treatment.

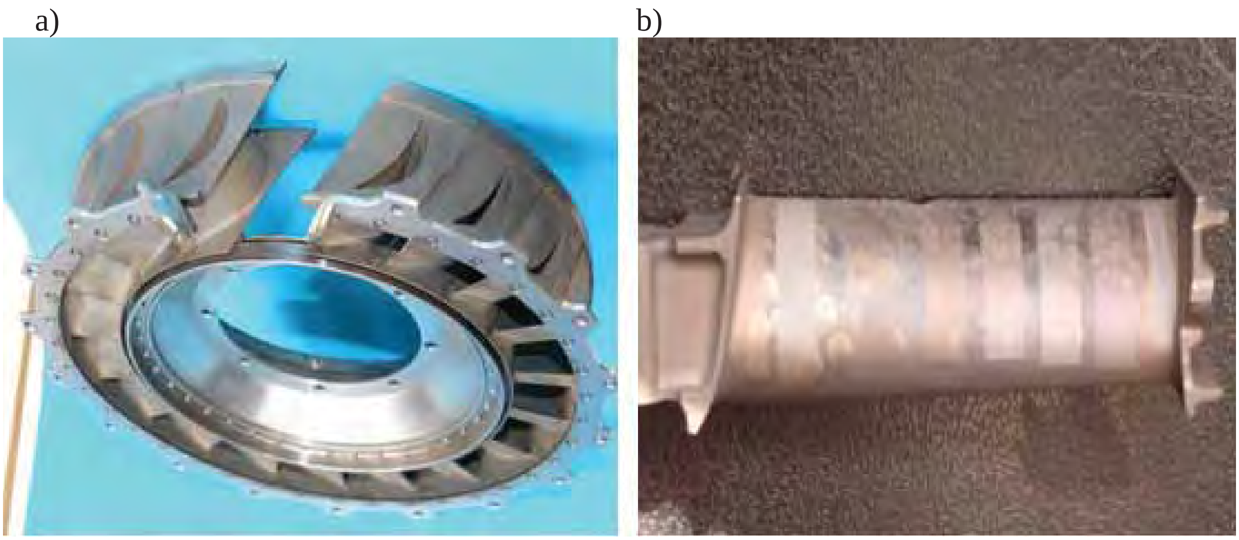

Fig. 1. The studied elements of aircraft turbine engine: a) the turbine blades before cleaning, b) turbine blade laser-cleaned in the laboratory conditions

4. Results

The topography of the contaminated surface layer of the blade made of heat resistant, nickel based alloy ŻS6K-WI is shown in Fig. 2.

The effects of laser cleaning (ReNOVALaser 2 - Nd: YAG with Q-modulation) of the layers is presented in Fig. 1-6. As a result of laser ablation sedimentation and pollution generated in the process of casting and as a result of the human factors impact were removed.

The article presents some characteristic results. In accordance with the established methodology of research, several technological trials of purification of the material provided in the form of cast component that is in the form of the turbine blades, were carried out. By using different energy density and degree of covering very good technological results were achieved. By applying the appropriate laser energy density (up to 1 J/cm^2) no side effects resulting from a surface development or partial melting has been found (Fig. 3). At higher energy densities however, these effects have been clearly increasing (Fig. 4). The resulting melting may have a possible negative effect on the fatigue resistance of the blade material at elevated temperatures.

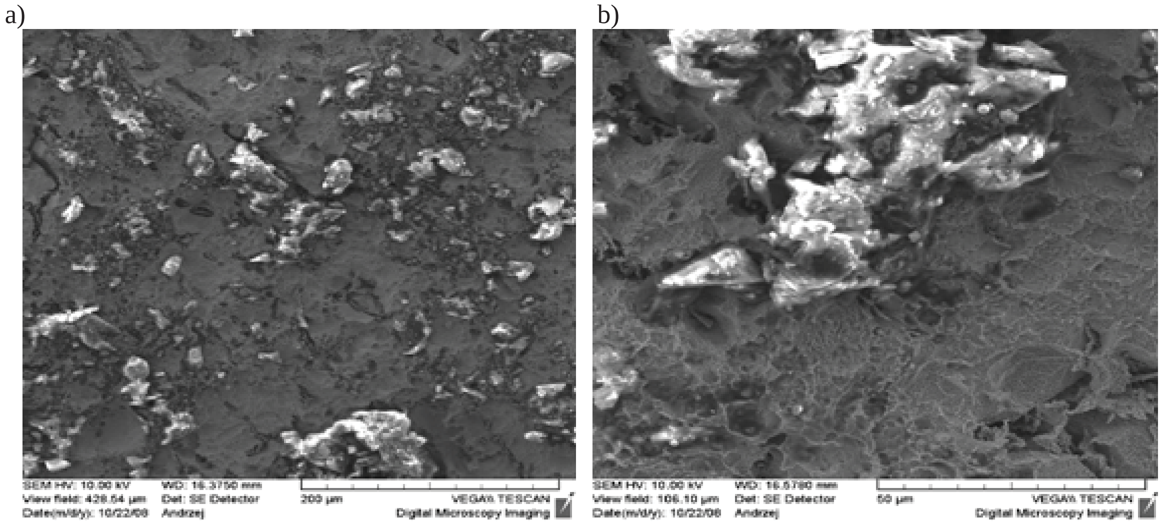

Fig. 2. The characteristic surface topography of heat resistant nickel alloy ŻS6K-WI used in the manufacture of turbine blades of aircraft engines - the material after casting

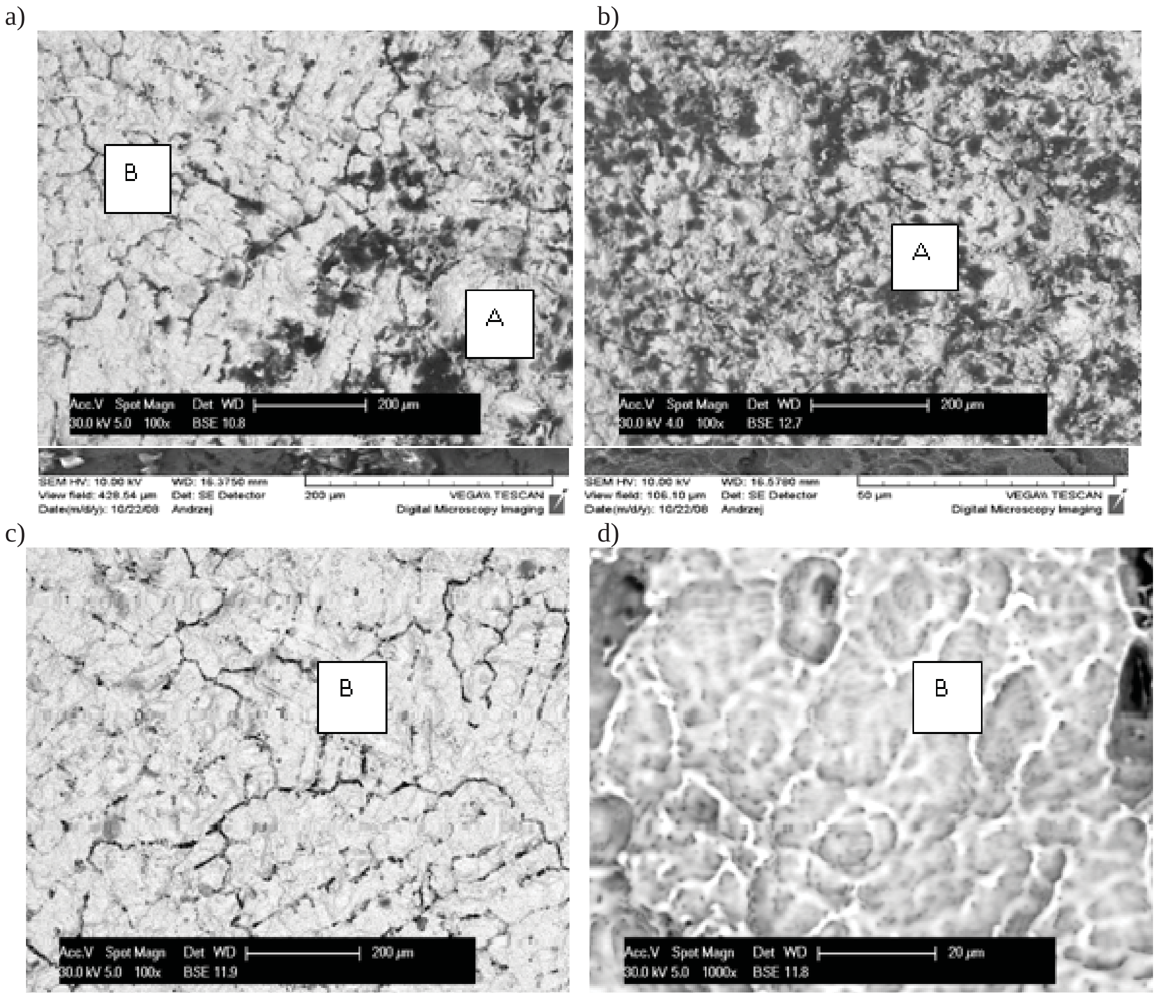

Fig. 3. Characteristic area of the surface layer of heat resistant nickel alloy ŻS6K-WI after casting and laser ablative cleaning: A - a zone before cleaning, B - a zone after cleaning

To eliminate this side effect the efforts should be undertaken to clean the surface layer of blades, for example, by use of smaller wavelengths of radiation (e.g., 532 nm, 355 nm) and / or shorter exposure times (picoseconds) at lower power density. Based on the literature and the author's own experience there is a hope that the use of TEA CO_2 laser radiation will provide the best technical solution that will not cause the surface layer melting of the purified nickel based alloy ŻS6K-WI.

The accuracy of the process was evaluated according to the method, mainly by using scanning electron microscopy (SEM) and X-ray microanalysis. As a result of laser treatment, through the phenomenon of laser ablation, oxides and contamination of organic and inorganic type, resulting from the casting process and the impact of human factors (such as compounds C, Na, Si, Cl, K, Ca, Fe), has been removed – Fig. 5.

The effects of the surface layer cleaning of jet engine turbine blades by using pulsed laser Nd: YAG radiation of 30 Watt with Galvo head, are shown in Fig. 5. By using different power densities and different degree of covering of successive laser pulses, a positive technological effect, that is a removal of impurities occurring in the surface layer without any significant partial blade melting, was achieved.

a) b)

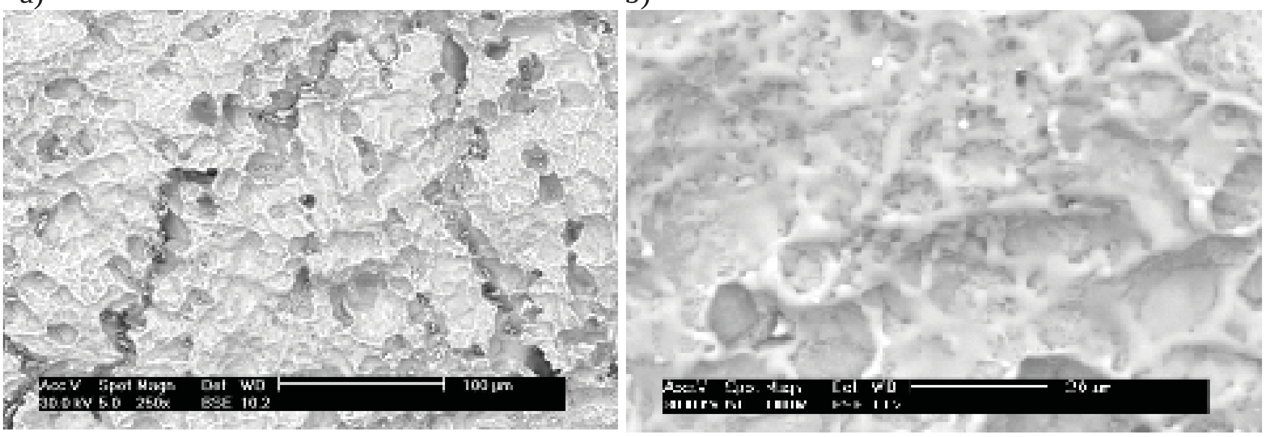

Fig. 4. Characteristic area of the surface layer of heat resistant nickel alloy ŻS6K-WI after casting and laser ablative cleaning - apparent micro partial melting zones

5. Summary

Preliminary studies of ablative laser cleaning of cast aircraft engine turbine blades made of heat resistant nickel based alloy ŻS6K-WI, confirmed the effectiveness of this method. Surface layer of the alloy contains a number of pollutants of organic and inorganic origins, resulting from the same casting process as well as the effects of the human factor impact.

As a result of selective laser treatment, using different processing parameters (energy density, degree of covering), a very good effect of the surface purity, allowing for the production of coatings and protective barriers (aluminidide, TBCS etc.) was obtained, as well as some risks emerging from a partial melting of the surface layer was recognized. These partial melting affect the expansion of the surface area, which may improve significantly the mechanical adhesion, such as barrier coatings, but may also affect the fatigue strength of turbine blades operating at high load, high temperature conditions. Thus when selecting laser treatment parameters one should avoid the partial melting effects of the surface layer, especially in the case of elements operating at variable loads and thermal shocks.

As a result of laser treatment, through the phenomenon of laser ablation, oxides and contamination of organic and inorganic type resulting from the casting process and the human factors impact (such as compounds C, Na, Si, Cl, K, Ca, Fe), has been removed. By applying the appropriate laser energy density (up to few J/cm^2) no side effects resulting from a surface development or partial melting has been found. At higher energy densities however, these effects have been clearly increasing. The resulting melting may have a possible negative effect on the fatigue resistance of the blade material at elevated temperatures. To eliminate this side effect the efforts should be undertaken to clean the surface layer of blades, for example, by use of smaller wavelengths of radiation (e.g., 532 nm, 355 nm) and / or shorter exposure times (pico seconds) at a lower power density. Based on the literature and the author's own experience there is a hope that the use of TEA CO2 laser radiation will provide the best technical solution that will not cause the surface layer melting of the purified turbine blades and other jet engine components cast of heat resistant, nickel based alloy ŻS6K-WI.

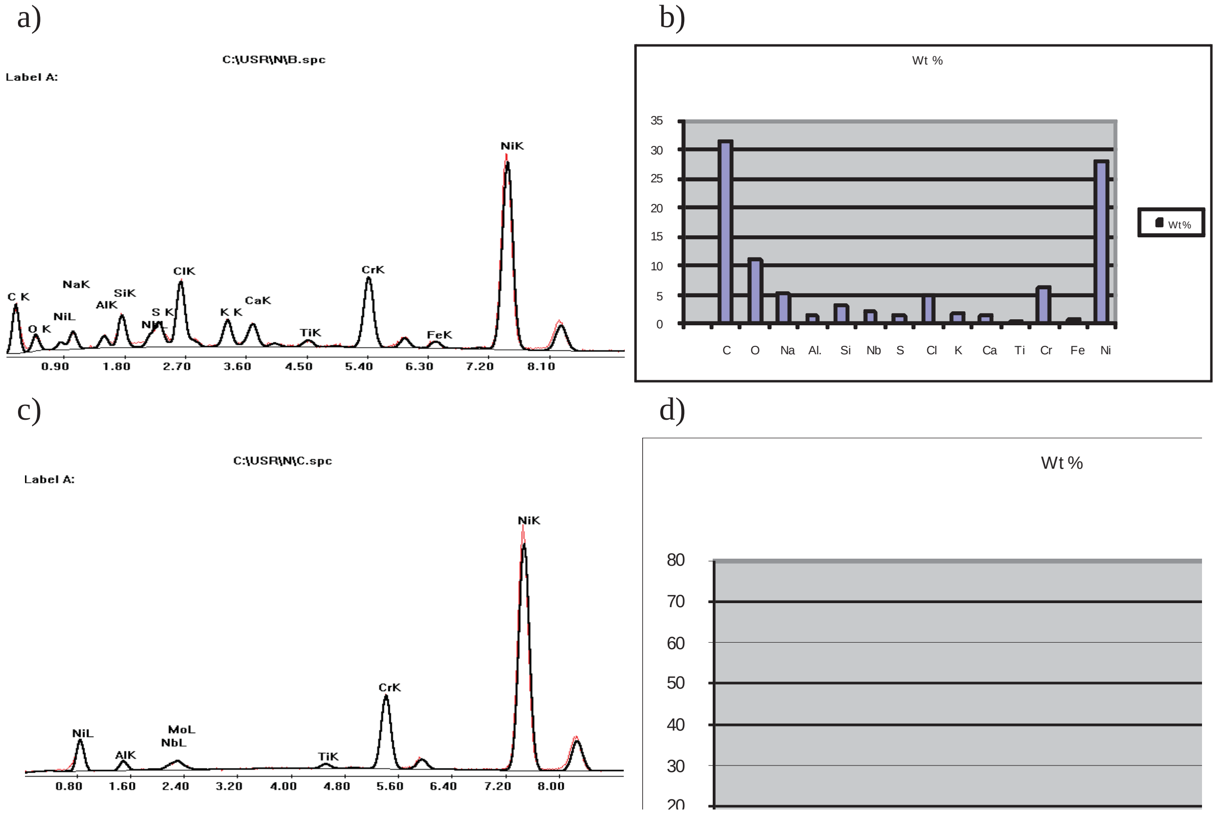

Fig. 5. The tests results of chemical constitution in the characteristic micro-zones of surface layer of high-temperaturecreep resisting nickel alloy: a, b - in the state after casting, c, d in the state after casting and laser cleaning

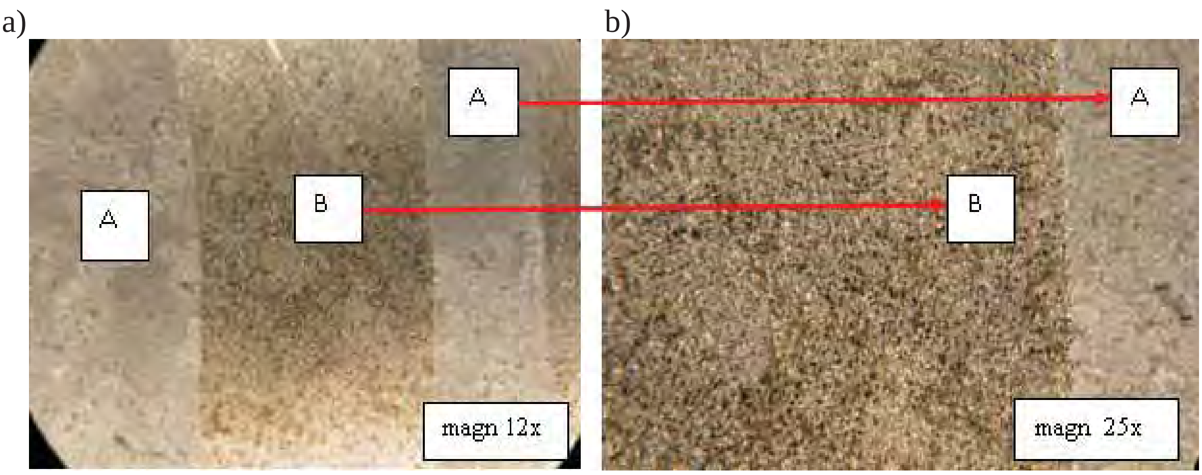

*Fig. 6. Jet engine turbine blade made (cast) of nickel based alloy WI ŻS6K purified by the use of the laser: A - greasy surface, B - purified surface by the use of the radiation of pulsed Nd: YAG laser with power density q = 1.53 * 10^6 W/cm2, and scanning speed v = 5m /s*

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