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Laser repair hardfacing of titanium alloy turbine

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ABSTRACT

Purpose: of this paper: work out repair technology of worn abutments of aircraft jet engine blades forged of titanium alloy WT3-1.
Design/methodology/approach: The study were based on the analysis of laser HPDL powder surfacing of titanium alloy plates using wide range chemical composition consumables of titanium alloys and mixtures of pure titanium and spherical powder of WC indicated that very hard and highest quality deposits are provided by powder mixture of 40-50%Ti+60-50%WC.
Findings: It was found that it is possible to achieve high quality deposits, free of any defects. HPDL technology can be used to repair worn turbine blade.
Research limitations/implications: It was found that it is possible to repair the worn areas abutments of blades of zero compression stage of aircraft engine turbine by HPDL laser surfacing with using composite powder mixture of 50%Ti+50%WC as an additional material.
Practical implications: The technology can be applied for repair worn abutments of aircraft jet engine blades.
Originality/value: Repairing worn abutments of aircraft jet engine blades.
Keywords: Hardfacing; titanium; Turbine blade; Spherical tungsten carbide; High power diode laser

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1. Introduction

Aircraft jet engine parts are working in very complex environment under very strong mechanical dynamic loads, erosion and friction wear and high temperatures. Due to very strict rules of maintenance of jet engines all parts are subjected precise quality control and defects are detected two options are used; worn parts are scraped and replaced by new one or repair process is employed. Because of very high cost of jet engines spare parts and high quality repair process many jet engines maintenance companies decide to repair worn parts by application of modern laser cladding technology [1-4]. One of the most efficient regeneration method described in many publications is high power diode laser (HPDL) powder surfacing and alloying. Various laser powders surfaced on new or worn working surfaces of components provides specific properties such as high abrasive wear resistance, erosion resistance, corrosion resistance, heat resistance and combinations thereof. Laser powder surfacing technique allows to control the portion of the substrate material in deposit in range from 5% to 100% making it possible to achieve required utility properties in the first layer [1,3-5,13].

The aim of present study is to work out repair technology of worn abutments of aircraft jet engine blades forged of titanium alloy WT3-1, Tables 1 and 2, Figs. 1 and 2. It is high-temperature creep resisting titanium alloy of martensitic diphase Tiα + Tiβ, which can work at temperatures up to 450°C [7-13]. The basic problem of weldability of diphase Tiα + Tiβ titanium alloys is high sensitivity on influence of interstitial elements carbon, hydrogen, nitrogen and oxygen. These elements enter the crystal lattice in monoatomic form, then migrate to interstices of the hexagonal close-packed titanium lattice what inhibits plastic deformation and result In a substantial loss of ductility and hydrogen embrittlement. When contamination exceeds certain level welding stresses may cause weld metal cracking. Titanium alloy deposits cracking can be avoided by very strict preventing carbon, hydrogen, oxygen and nitrogen pick up protection of molten weld metal and welding zone by inert gases shielding and precise cleaning of the hardfacing area. Shield of hardfaced area must be maintained until the deposit and surrounding area have cooled below 250°C [7-13]. To provide highest quality of repair hardfacing of worn abutments of aircraft jest engine blades forged of titanium alloy WT3-1, laser hardfacing process was selected and studied.

2. Experimental

Blades of zero compression stage of aircraft engine turbine are forged structure made of titanium alloy WT3-1, Tables 1, 2 and 3, Figs. 1 and 2. Every blade has two abutments which faces are worn due to strong metal-metal wear during turbine operation under dynamic load, Fig. 3. Study of worn areas of blades abutments has shown that they are worn on the depth of 0.3 up to 3.0 [mm]. Metallographic examinations of blades abutments revealed deposits composite structure of Cu-Ti-Ni-Zr alloy matrix with massive tungsten carbides WC of dimensions in the range 40 [µm] to over 200 [µm] and the average thickness of deposits is 0.65 [mm], Figs. 4 and 5 (a, b). Measurements of hardness distribution on the cross section and the face area of the abutments deposits indicated that it is in the range 45-48 HRC and 550-630 HV0.1, Figs. 6 and 7. High oxygen content in the deposit matrix indicates that oxy-fuel surfacing technology was used in production process of blades in Russian factory. Due to very high cost of spare parts of Russian aircraft engines it was decided to work out high quality repair surfacing technology of worn titanium alloy turbine blades. Research of the laser surfacing process was carried out on the automatic stand equipped with AUTOMATION numerically controlled table and the HPDL DL020 ROFIN SINAR high power diode laser, Figs. 8, 9. The studies used Ti+WC welding powder and a titanium alloy plate. The tests were carried out with beam size of 1.8×6.8 [mm], beam focal length of 82.0 [mm] and focusing on the surface of the plate. Powder was injected into the focal point through concentric powder feed and shielding gas nozzle with diameter of 1.6 [mm]. Preliminary tests of laser HPDL powder surfacing of titanium alloy plates using wide range chemical composition consumables of titanium alloys and mixtures of pure titanium and spherical powder of WC indicated that very hard and highest quality deposits are provided by powder mixture of 40-50%Ti+60-50%WC, Figs. 10 to 13. Surfacing powder was composed of the titanium matrix Amperit 155 titanium powder of grain size 45-75 [µm] and spherical tungsten carbide powder of dia. 100-150 [µm] in volume proportion of 50%Ti+50%WC.

Fig. 1. Blades of zero compression stage of Russian aircraft engine turbine made of titanium alloy WT3-1, Tables 1 and 2

Table 1.
Chemical composition of WT3-1 titanium alloy

Basic alloying elements wt. %			Max content of impurities wt. %				
Al	Mo	others	Fe	C	H	N	O
5.5-6.5	2.0-3.0	Cr 0.8.2.3. Si 0.2.0.4 Cu max. 1.4	0.2-0.7	0.08	0.015	0.05	0.20

Table 2
Mechanical properties of WT3-1 titanium alloy

R_m [MPa]	$R_{0.2}$ [MPa]	A5 [%]	HRC
1040.1180	-	14.20	38-40

Table 3.
Chemical composition of Amperit 155 titanium powder used for laser HPDL surfacing

Typical composition wt. %								
Ti	Ni	Fe	B	Si	C	Mg	O	H
approx. 98	-	0.3	-	0.1	-	max 0.2	max 0.4	max 0.1

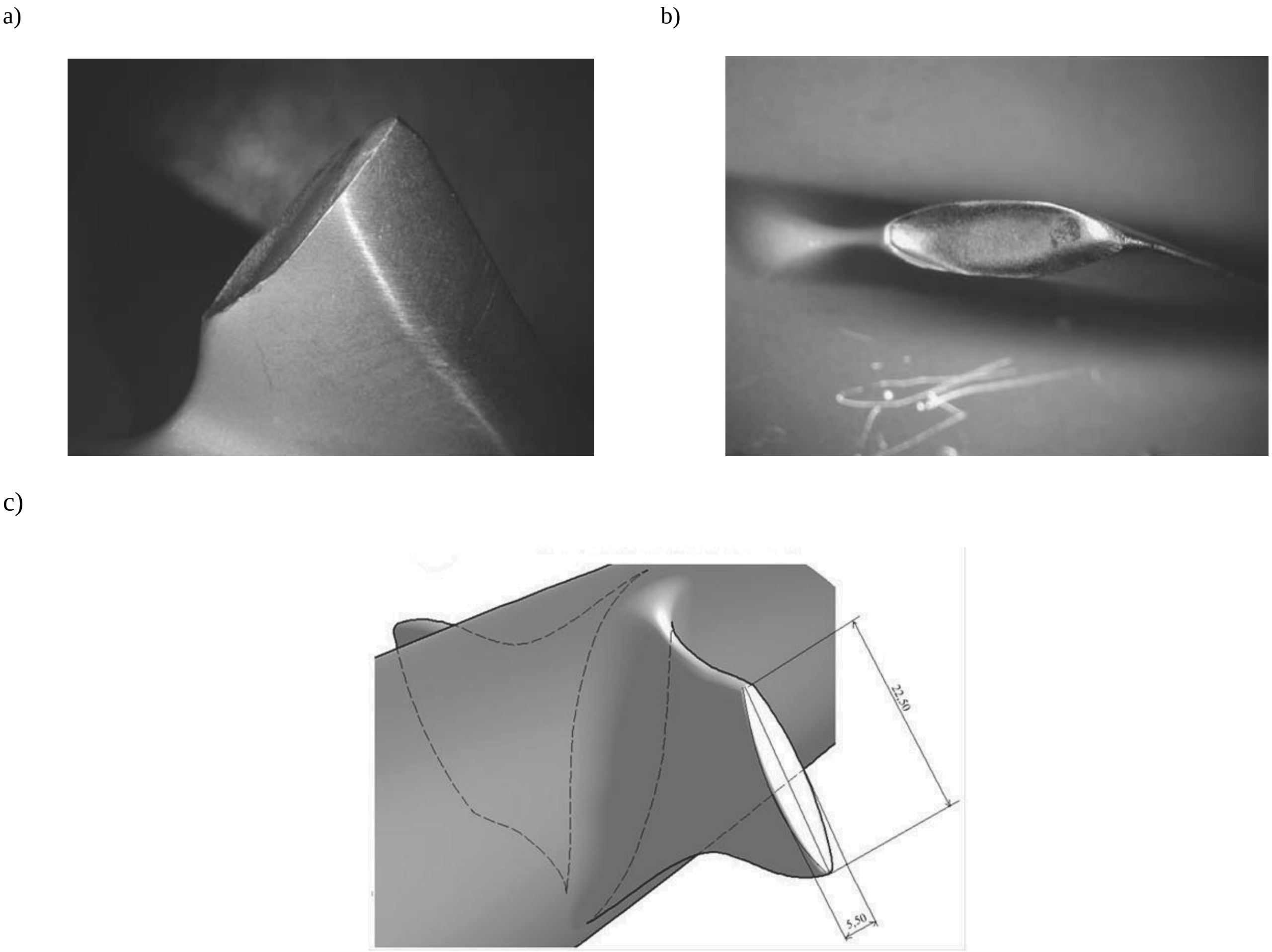


Fig. 2. A view of worn butt face of the abutment of the WT3-1 titanium alloy turbine blade (a,b,c)

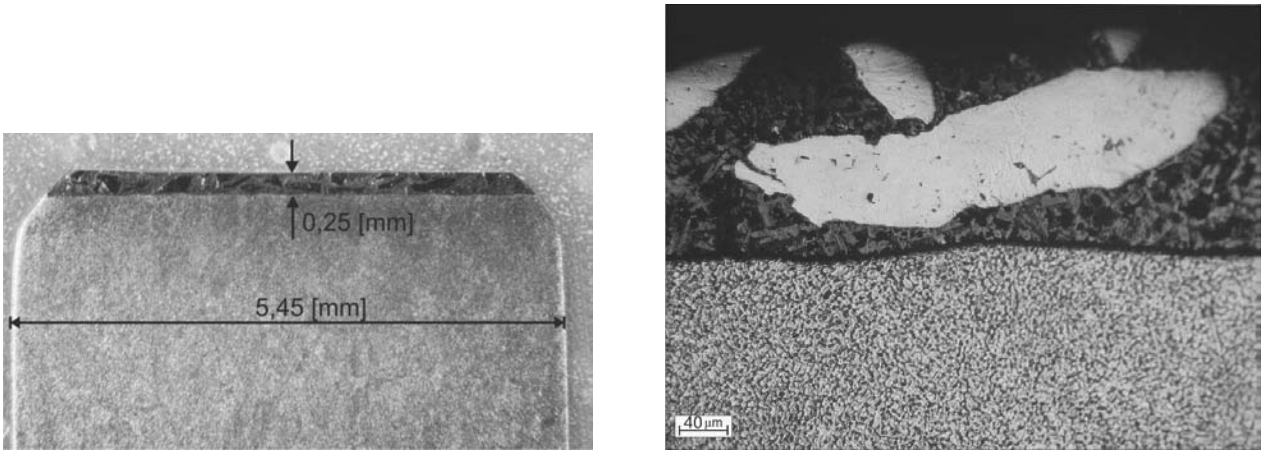
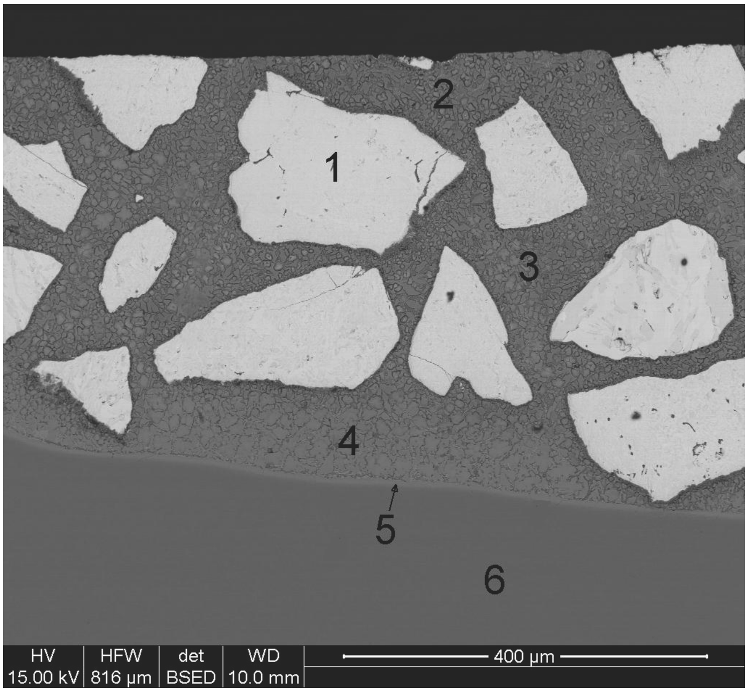
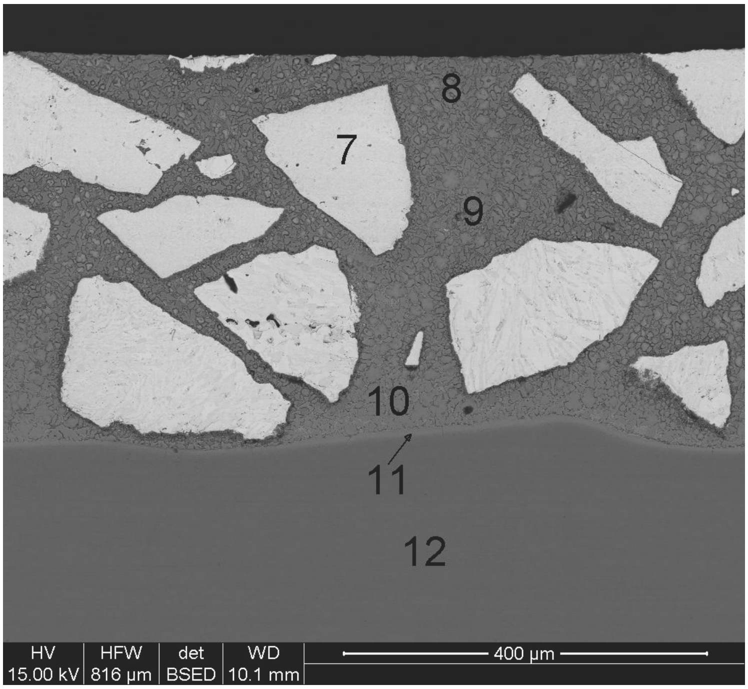


Fig. 3. Macro and microstructure of the partially worn deposit of the abutment of WT3-1 titanium alloy turbine blade (a,b)



Element	Composition wt. %					
	area 1	area 2	area 3	area 4	area 5	area 6
C	0.6	0.9	0.4	0.4	-	-
O	-	21.9	23.6	9.7	-	-
Al	-	0.3	0.3	1.4	2.7	7.1
Si	-	-	-	-	-	0.6
W	99.4	12.8	8.9	5.9	9.2	-
Zr	-	4.3	5.0	9.5	7.6	-
Mo	-	1.5	1.3	1.3	1.9	2.5
Cl	-	1.3	1.0	-	-	-
Ca	-	1.3	0.7	-	-	-
Ti	-	21.7	25.0	52.6	68.9	88.5
Cr	-	-	-	-	0.6	1.3
Ni	-	4.2	5.8	6.5	3.8	-
Cu	-	29.8	28.0	12.7	5.3	-

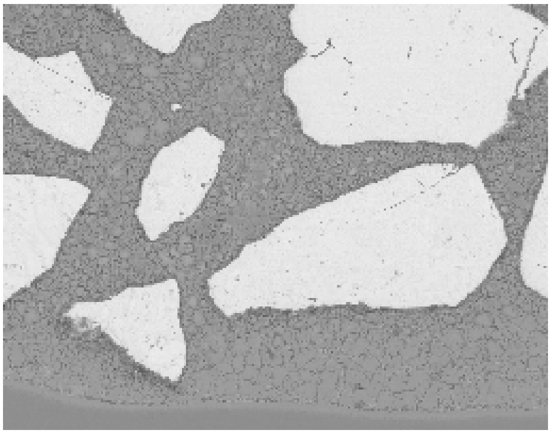
Fig. 4. EDXS scanning microscopy microstructure of the partially worn deposit of the abutment of WT3-1 titanium alloy turbine blade and results of scanning microanalysis of selected areas of the deposit, Fig. 3



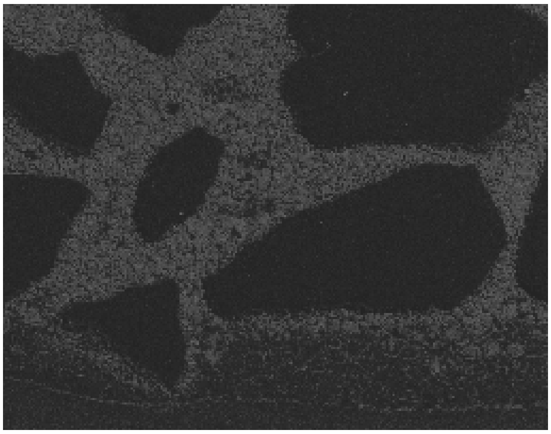
Element	Composition wt. %					
	area 7	area 8	area 9	area 10	area 11	area 12
C	0.7	1.0	0.4	0.4	-	-
O	-	21.4	19.0	12.2	-	-
Al	-	0.3	0.4	1.4	2.8	7.1
Si	-	-	-	-	-	0.6
W	99.3	10.8	9.0	6.0	10.1	-
Zr	-	4.2	9.0	9.8	6.4	-
Mo	-	-	-	-	-	2.7
Cl	-	1.4	0.8	-	-	-
Ca	-	0.7	0.5	-	-	-
Ti	-	21.8	28.7	51.0	72.0	88.2
Cr	-	-	-	-	-	1.4
Ni	-	4.1	5.8	6.4	3.5	-
Cu	-	34.3	26.4	12.8	5.2	-

Fig. 5a. EDXS scanning microscopy microstructure of the partially worn deposit of the abutment of WT3-1 titanium alloy turbine blade and results of scanning microanalysis of selected areas of the deposit, Fig. 3 and distribution of alloying elements

a) SE

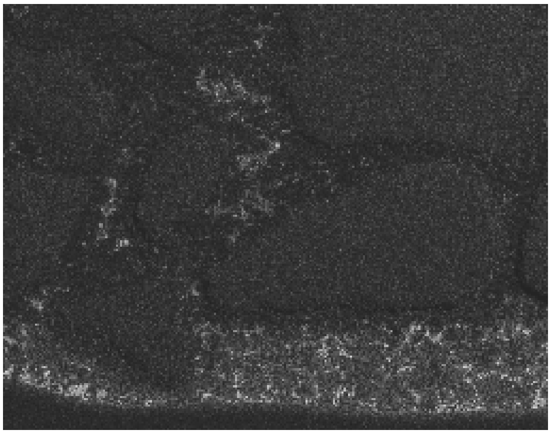


b) oxygen

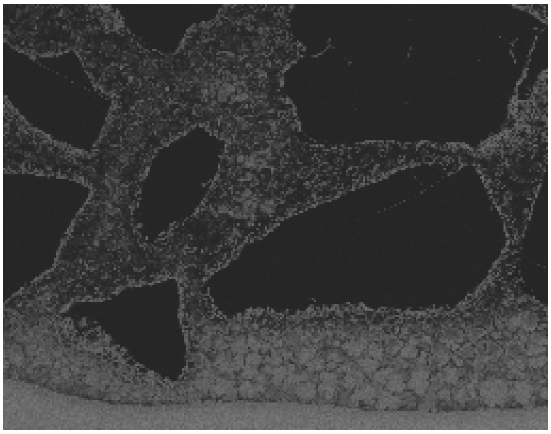


c) tungsten

d) cyrkonium



e) titanium



f) copper

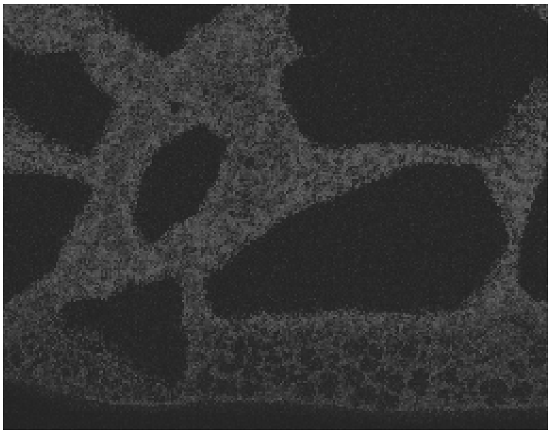


Fig. 5b. Distribution of alloying elements of WT3-1 titanium alloy turbine blade

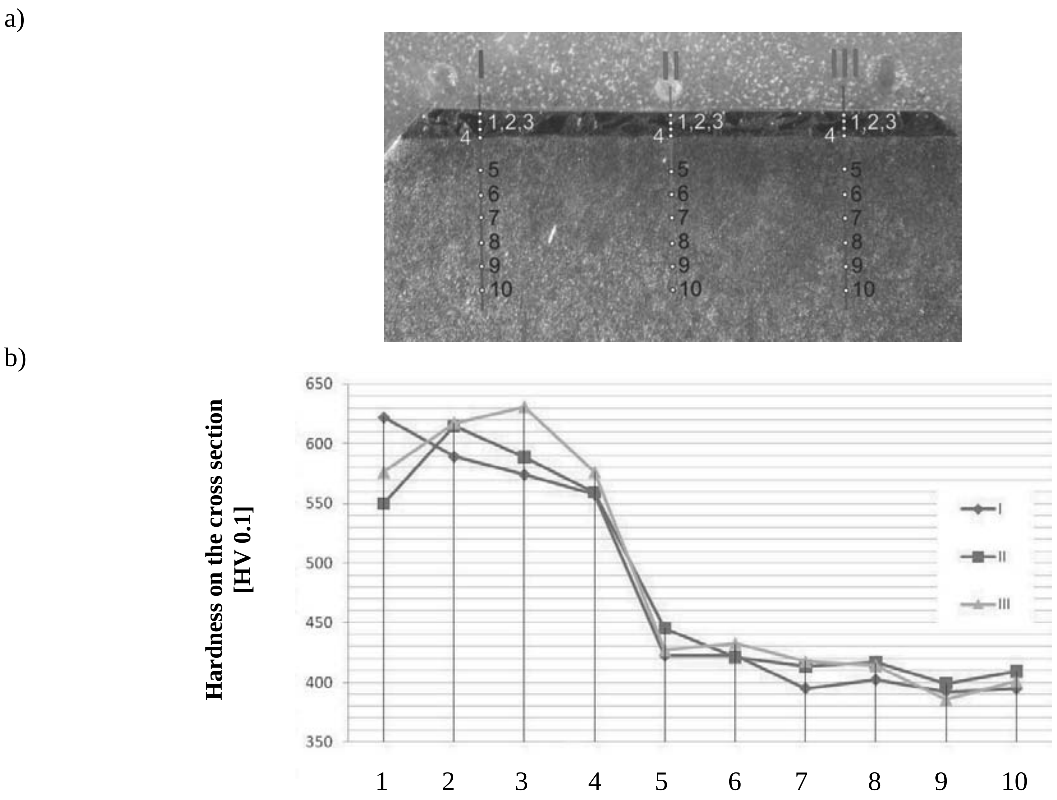
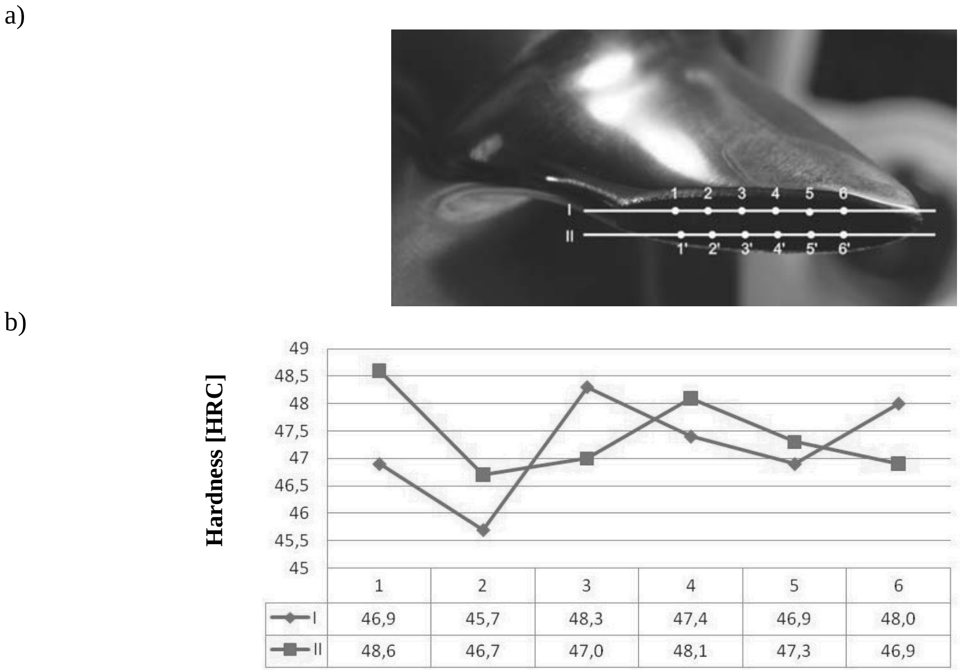


Fig. 6. Results of HV 0,1 hardness measurements on the cross-section of the partially worn deposit of the abutment of WT3-1 titanium alloy turbine blade



	1	2	3	4	5	6
I	46,9	45,7	48,3	47,4	46,9	48,0
II	48,6	46,7	47,0	48,1	47,3	46,9

Average
hardness
47.2 [HRC]
47.4 [HRC]

Fig. 7. Results of HRC hardness measurements on the butt face of the abutment of the partially worn deposit of the abutment of WT3-1 titanium alloy turbine blade

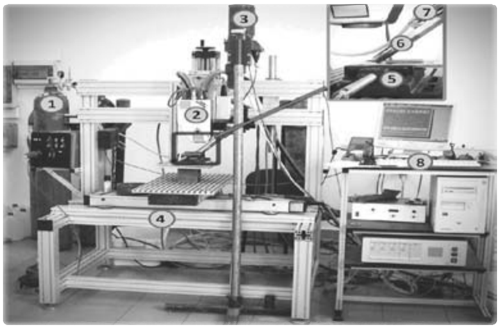


Fig. 8. Laser HPDL surfacing experimental CNC stand equipped with diode laser ROFIN SINAR DL 020: 1 - shielding and powder feeding gases containers (argon), 2 - HPDL laser head, 3 - powder feeding system, 4 - CNC positioning control system ISEL AUTOMATION, 5 - fixture of titanium alloy WT3-1 plate to be hardfaced, 6 - powder feeding nozzle of dia 2.0 [mm], 7 - shielding gas nozzle, 8 - stand control system

Comprehensive study of influence of laser HPDL powder surfacing parameters on the quality of deposits indicated that it is possible to achieve high quality deposits, free of any defects, Table 4, Figs. 11 to 13. Proper selection of surfacing parameters (laser beam power, travel speed, powder feed rate) allows to adjust the shape and dimensions of the deposits, Figs. 10-12, Table 4. Metallographic examinations of deposits proved high quality of deposits and uniform distribution of spherical WC inclusions in titanium matrix, Fig 16. Controlling the laser surfacing parameters, especially the laser beam power density and the powder feed rate it is possible to control the hardness of the surface layer in a wide range. The average hardness of the face area of deposit is in the range 54-60 HRC and it is 15-30% higher than the hardness of the deposit prior the regeneration Fig. 7, Table 5. The average micro hardness on the cross section of deposits is in the range 413-460 HV0.3, Table 6.

Because the width of the blade abutment is 5.5 [mm] and the allowable wear is in the range 0.3-0.5 [mm], using HPDL surfacing process it is possible to repair worn areas of blade abutment.

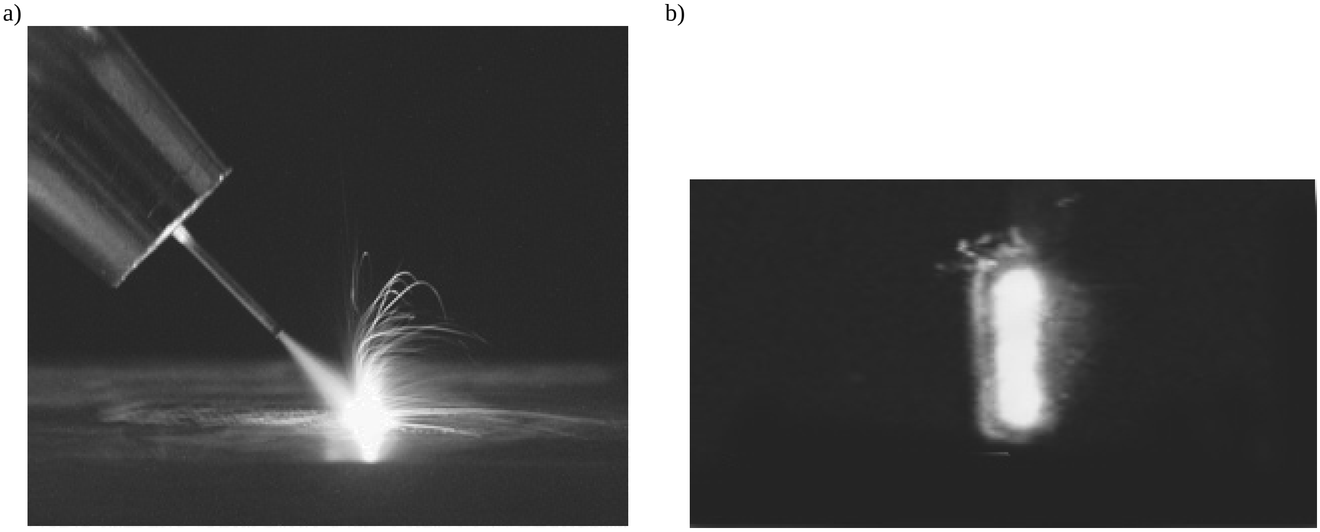

a) b)

Fig. 9. A view of powder laser HPDL hardfacing process with side powder feeding system (a) and thermovision image of the laser beam focused on the surface of the titanium alloy plate to be hardfaced (b)

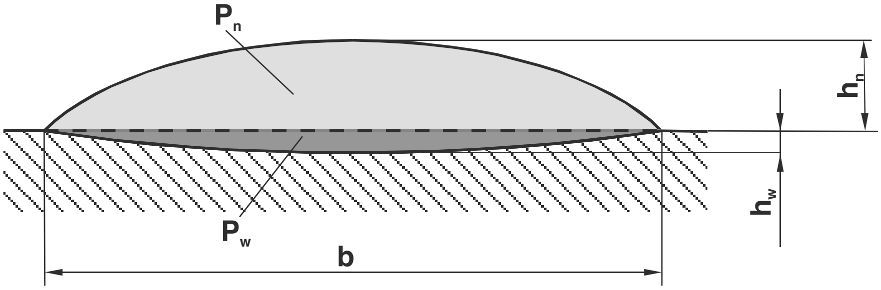


Fig. 10. Basic dimensions of bead-on-plate deposit, dilution - $U = \frac{P_w}{P_n + P_w} \cdot 100\%$, Table 4

Table 4.
The influence of laser HPDL composite powder mixture of 50%Ti-50%WC laser hardfacing parameters on the quality, dimensions and dilution of „bead-on-plate" straight deposits on titanium alloy WT-20 plate 6.0 [mm] thick, Figs. 10 and 11

No of deposit	Laser beam power [kW]	Travel speed [mm/min]	Powder feed rate [g/min]	b [mm]	h_n [mm]	h_w [mm]	Dilution [%]	Quality of the deposit
N1	1.2	200	8.72	6.12	0.21	0.38	64	unacceptable
N2	1.4			6.22	1.04	0.52	33	unacceptable
N3	1.6			6.30	0.49	0.70	59	unacceptable
N4	1.4		14	6.15	0.61	0.53	46	high
N5	1.6			6.42	1.01	0.63	38	unacceptable
N6	1.8			6.38	0.76	0.81	52	high
N7	2.0			6.43	0.48	0.97	67	high

Remarks: Focal length 82 [mm], laser beam spot - 1.8×6.8 [mm]. Dia. of powder feeding nozzle 2.0 [mm]. Dia. of shielding gas nozzle - 12.0 [mm]. Shielding gas argon flow rate - 15.0 [l/min]

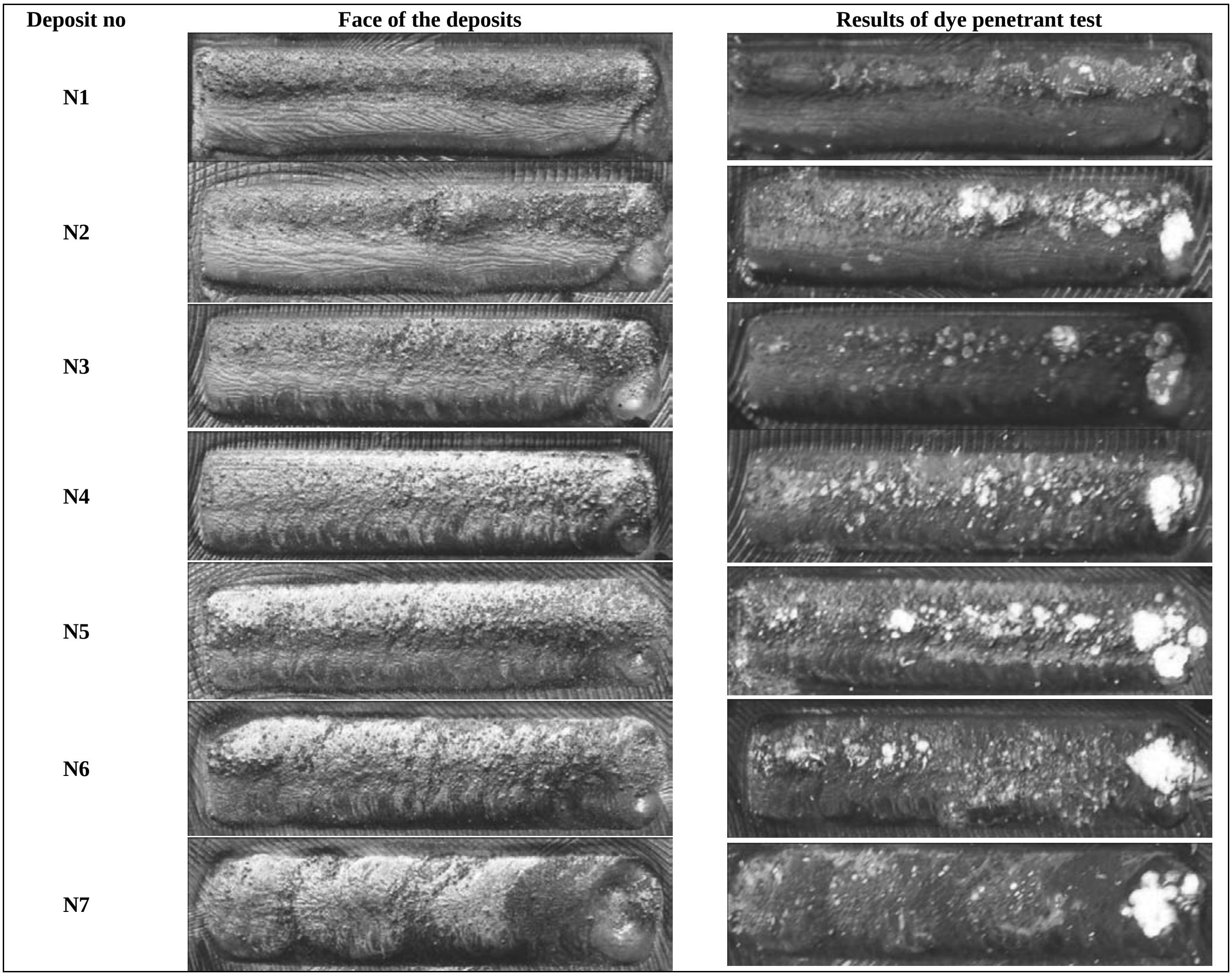
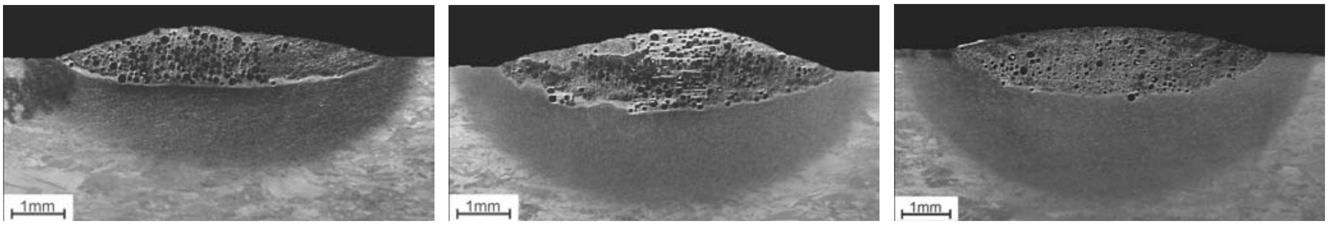


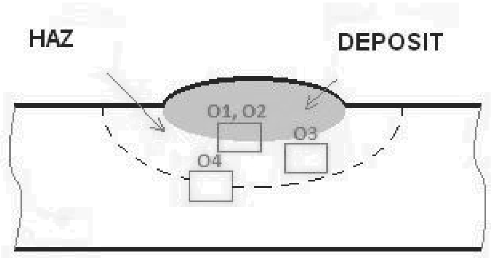
Fig. 11. A view of faces of as surfaced „bead-on-plate" deposits and after dye penetrant tests, Table 4



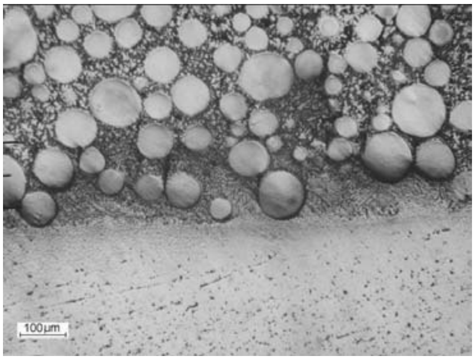
N4 N6 N7

Fig. 12. Macrostructure of „bead-on-plate" deposits, Table 4, Fig. 9

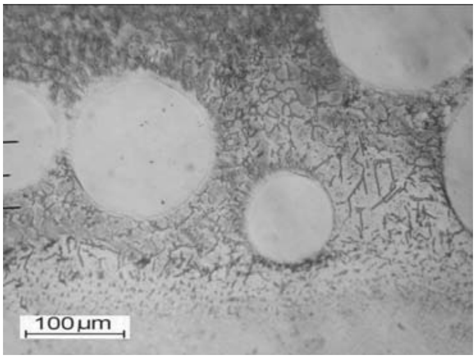
Layout of microstructure observation areas of N7 deposit



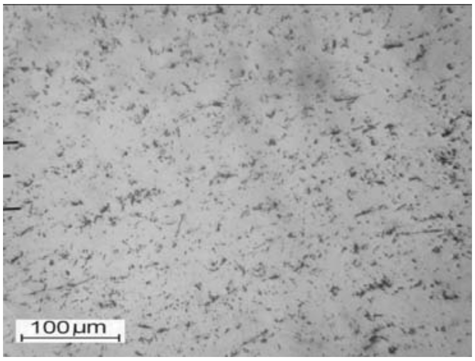
O1 observation area



O2 observation area



O3 observation area



O4 observation area

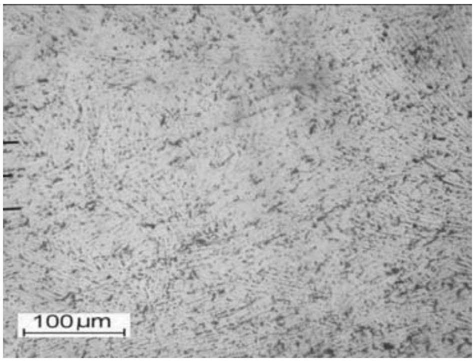


Fig. 13. Microstructure of N7 „bead-on-plate" deposit, Table 4, Fig. 10

Table 5.
Results of HRC hardness measurements of the face of „bead-on-plate" deposits of laser HPDL composite powder mixture of 50%Ti-50%WC laser hardfaced, Table 4, Figs. 9 and 10

Deposit no	N1	N2	N3	N4	N5	N6	N7
Average of 6 measurements [HRC]	57.6	60.2	56.3	58.4	56.1	53.9	54.2

Table 6.
Results of HV0,3 micro hardness measurements on the cross-section of „bead-on-plate" deposits of laser HPDL composite powder mixture of 50%Ti-50%WC laser hardfaced, Table 4, Figs. 9, 10 and 11

Deposit no	N1	N2	N3	N4	N5	N6	N7
deposit [HV0.3]	432	438	453	462	426	413	424
HAZ [HV0.3]	372	361	381	349	356	379	384

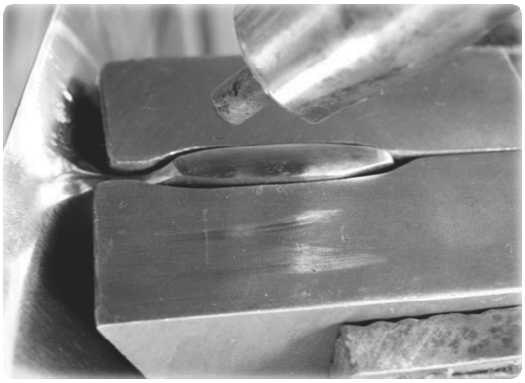
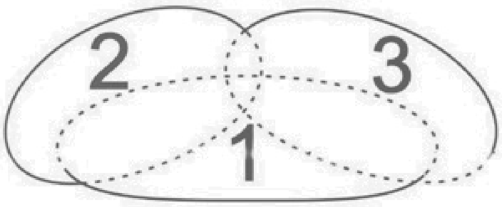


Fig. 14. A view of fixture used for automatic laser HPDL composite powder mixture of 50%Ti-50%WC laser repair hardfacing of worn butt surface of abutment of WT3-1 titanium alloy turbine blade, Figs. 1 and 2



Deposit no	Laser beam power [kW]	Travel speed [mm/min]	Powder feed rate [g/min]
1	1.4	200	14.00
2 ,3	1.2		8.72

Fig. 15. Sequence of laser HPDL surfacing of straight beads and parameters of HPDL composite powder mixture of 50%Ti-50%WC laser repair hardfacing of worn butt surface of abutment of WT3-1 titanium alloy turbine blade, Table 4

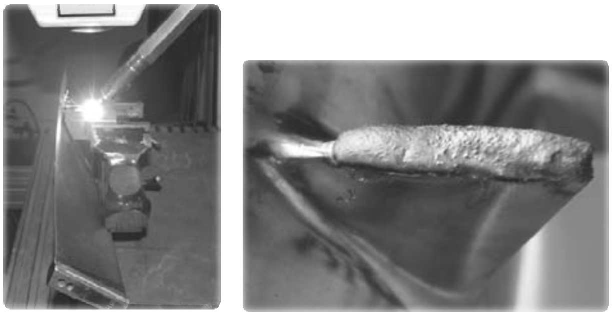


Fig. 16. A view of automatic HPDL composite powder mixture of 50%Ti+50%WC laser HPDL repair hardfacing of worn butt surface of abutmant of WT3-1 titanium alloy turbine blade and ate repair deposit

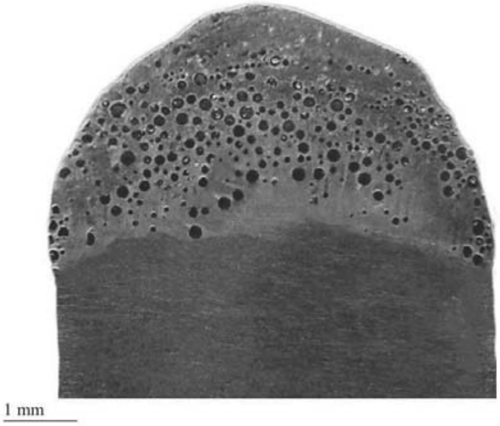


Fig. 17. Macrostructure of the laser HPDL repair deposit of worn surface of abutment of WT3-1 titanium alloy turbine blade, Fig. 14

3. Conclusions

Extensive tests have demonstrated that the HPDL laser surfacing with use of the Ti-WC cermet powder allows to obtain high quality deposits, free of external and internal defects, characterized by high hardness in relation to the base material, Table 4, Figs. 11 to 13. Metallographic examinations of deposits proved high quality of deposits and uniform distribution of spherical WC inclusions in titanium matrix, Fig 16. Summarizing the results of the study can be concluded that it is possible to repair the worn areas abutments of blades of zero compression stage of aircraft engine turbine by HPDL laser surfacing with using composite powder mixture of 50%Ti+50%WC as an additional material.

Worn butt surface of blades of WT3-1 titanium alloy turbine blade before regeneration process (HPDL surfacing) have to be sanded and cleaned. Three deposits was made according to Fig. 15. After hardfacing and removing the excess of the deposit the thickness of the layer is 0.7 mm which corresponds with assumption about the thickness of the working layer, Figs. 14-17.

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