

## Thermal stability of protective coatings produced on nickel based superalloy

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### Manufacturing and processing

#### ABSTRACT

**Purpose:** In this paper the results of high temperature cyclic oxidation tests of the protective diffusion coatings were presented. One of the main purposes of this work was to produce three different types of protective coatings by three different methods, i.e. slurry method, vapour phase aluminizing (VPA) and chemical vapour deposition (CVD), applied on nickel based René 80 superalloy substrate.

**Design/methodology/approach:** The high temperature cyclic oxidation tests were carried out in 23h cycles at constant temperature 1100°C using Carbolite CWF 1300 chamber furnace. The samples were removed outside and were weighted after each cycle. The microstructure investigations of all kinds of the coatings were conducted by the use of light microscope (Nikon Epiphot 300) and a scanning electron microscope (Hitachi S-3400N). In the analysis influence of each method have been taken into consideration, i.e. especially influence of the kind of process on microstructure, coating thickness, chemical composition, first of all aluminium content (in outer  $\beta$ -NiAl layer so-called additive layer, diffusion layer and substrate). For the chemical composition examination x-ray energy dispersive (EDS) method was applied using Thermo equipment.

**Findings:** It was found that the best high cyclic oxidation resistance of coating was obtained using CVD method (the maximal increase of samples weight after 28th cycle was observed, whereas in case of the slurry sample after 3rd and VPA after 5th).

**Research limitations/implications:** The research results will be used in the future in order to increase coating thickness, aluminium content and to produce Pt, Pd, Zr, Hf and Si modified aluminide coatings.

**Practical implications:** The CVD method will be used to coat internal passages of turbine blades, for example to produce modified aluminide bond coats on single crystal nickel based superalloys.

**Originality/value:** Chemical vapour deposition is an unique method which is a "pure method" and allows to coat hardly accessible locations/areas.

**Keywords:** Metallic alloys; Corrosion; Erosion; Thin and thick coatings; Surface treatment; Slurry; Vapour phase aluminizing; Chemical vapour deposition; Protective coatings; Aluminide coatings; High temperature oxidation

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## 1. Introduction

The development of modern aircraft engines is being determined with increasing the permanence of elements of the hot section of the aircraft engine what results from the aspiration to increasing the gas temperature on the inlet into the turbine, of increasing compression, of reducing the specific consumption of air and the fuel. These tendencies forced into using protective coatings what in consequence was transferred for developing new methods of producing protective diffusion layers e.g. As a result of many examinations they stated, that with very good oxidation resistance high-temperature aluminide coatings are characterized, on the base aluminides of nickel (binary phase diagram Ni-Al). The need to coat internal cooling passages led to the introduction of the more modern methods of aluminizing from - oldest technology pack cementation until after the most modern method of CVD. Diffusion aluminide layers (often modified through the introduction of other elements, e.g. platinum, chromium, silicon, zirconium and of hafnium) produced may be different methods [4]. In the CVD method two basic processes, i.e. the low-activity and high-activity process of aluminizing are distinguished. Coatings produced in the high-activity (of Al) process (the gas precursor is being produced from granules Al-Cr about the all sorts chemical composition) can be standalone protective coatings (high concentration of aluminium in outer layer) or after the low-activity process to create the so-called coating "bond coat" up to ceramic coating forming TBC (Thermal Barrier Coating) [8-10]. The oldest of the methods of coating elements of aircraft engines is the process of „pack cementation”. The mechanism of the formation (during this process) of diffusion aluminide coatings has been described by Goward et al. [2]. This method consists in putting covered parts in the mixture of active powders (Al, Cr, the Si, Ti, not) at 800-1000°C for ca. 10 hours. Mixture contains ca. 15 wt % aluminium, 3 wt% of halide of aluminium ( $AlX_n$   $n < 3$ , on the base of chlorine, fluorine or bromine) and 82 wt% of the filler ( $Al_2O_3$ ). The composition of mixture can be modified. A possibility of putting coatings simultaneously on a lot of blades is an advantage of this method. It is cheap method - compared with modern processes of aluminizing (VPA, CVD). The necessity of direct contact with the substrate coated with is a disadvantage of that method. The application of coatings in places where access is difficult (internal passages of turbine blades, cooling channels) becomes impossible. Another disadvantage is the large volume consumed powder and late recycling what is making this method harmful to the environment. The “Slurry” method is other aluminizing process and consists of putting on the element water or of organic layer of suspension containing powders of aluminium, silicon, chromium or platinum. Suspension can be put by the dipping, spray or with brush. The diffusion process is proceeding as the same as at putting the coating with method "pack cementation" [1,2,5]. It has been demonstrated that the thickness of the suspension imposed on element has significant roles on the formation of the microstructure and the thickness of aluminide coating [5]. The  $\beta$ -NiAl bevel will be received if a thin layer of suspension is put. However putting a thick layer of suspension will cause the formation of two zones: outer rich in aluminium phase  $\beta$ -NiAl and internal rich in nickel phase  $\beta$ -NiAl. Homogenization of the microstructure shall be obtained by again annealing at 1080°C for 2 hours. The content of aluminium in

diffusion layer amounts ca. 31 wt%. Long-standing research carried out by the company Pratt & Whitney, Rolls-Royce, and Sermatech International showed a very good properties of aluminide coatings modified with silicon produced by “slurry” method. Engines worked in the marine environment showed sustainability by around 10 000 hours more using layers of modified silicon. The technological process coating method „slurry” is as follows: the layer of suspension is being put on the covered element which after drying is being subjected to the heat processing (diffusion annealing) [5]. This process is being conducted in the atmosphere of protective gasses (Ar, He) at 850-1100°C for 2-20 h. After heat treatment coated elements shall be cleaned with residues of the suspension with method of the sandblasting or hydro-grinding. Another annealing at 1080°C for 2 hours makes it possible to obtain homogeneous microstructure. On account of the tendency to the sedimentation one should still mix suspension up in the container. “Slurry” method allows to obtain high quality of the coating. This technology is characterised by smallest consuming applied materials and the lowest cost of coating and the heat treatment. This is one of the cheapest available methods of manufacture of aluminide coatings. The suspension can be easily modified and may be stored for a long time. The technological process of coating is sufficiently simple gives the possibility to deposit on the elements of large size and any geometry. A problem of coating the area of cooling internal passages of turbine blades is one of crucial flaws of this method. Mechanism of the formation of the aluminide coating with method "out of pack" is analogous like in the method "pack cementation" [1-3,6]. In the process elements to coat are placed above the layer of powder. Layer of mixture of powders in which mainly  $Al_2O_3$  and the small amount of aluminium are and ammonium chloride ( $NH_4Cl$ ) is close the covered element. The separation of powder from the coated element and the transport of substrates in the gaseous form enables deposition of layers in places where access is difficult for powder such as cooling channels. In the method "out of pack"  $AlX_n$  halides (where x may be Cl, F, B) are formed in the reaction which takes place at 700°C when the chlorine forming from the dissociation of the ammonium chloride and reacts with aluminium. This reaction already starts in 300°C, when forms  $AlX_3$ , which further at a higher temperature is becoming saturated with aluminium. Created products at 850°C are already in the gas phase [3]:



The  $AlX_3$  compound is called „activator”. At the temperature 900-1150°C halides in the gaseous phase are reacting with substrate according to the reaction:



where :  $1/3 < n < 3$

Activator is one of reaction products, is penetrating into the source of aluminium and is supporting the process according to the scheme [3]:



All reactions are in the equilibrium and are leading for creating the intermetallic phase  $Ni_xAl$  [6].

In the CVD method exactly the same chemical reactions are occurring like in the method "out of pack" [1,7]. The difference results from the fact, that reaction:  $Al + AlX_3 \rightarrow AlX_n$  is occurring in the special generator (external) where from products are transported in the gaseous phase to the retort in which coated elements are. The CVD method gives the possibility of control of the  $AlX_n$  concentration and the temperatures of the processes and through this control of aluminizing process [1]. As shown by the studies conducted by Sun et al. [7] increasing the temperature of aluminizing causes faster formation of layer. The change of temperature of halide has an also significant influence on the growth of the layer. If the temperature of the halide and the process of deposition of layer is higher, then a rate of the increase in mass of the sample is higher. This method is only assuring possibility of controlling growing layer thanks to the fact that the reaction is being conducted in the separate generator. Applying hydrogen as the carrier of gasses causes the forced flow of gasses improving properties of deposition of coating in thin canals of the blades.

## 2. Experimental and methodology

For examinations cast polycrystalline rods of the alloy of Rene80 nickel were used. Rods had dimensions  $120 \times \varnothing 15$  mm. Rods were cutted to round samples about the height of 4 mm and the  $\varnothing 15$  mm in diameter. Samples next were being grinded using Struers abrasive papers finishing on number 1000, next were washed in the ultrasonic cleaner. Samples were divided into three lots. Aluminide layers on the substrate of the René 80 superalloy have been carried out the different methods of:

- VPA - "out of pack" method;
- "Slurry" method;
- CVD aluminizing in Research and Development Laboratory for Aerospace Materials at the Rzeszow University of Technology.

The process of the VPA were carried out at a temperature of  $1000^\circ C$  for 4 h, in the atmosphere of Ar. Pellets Cr-Al of equal content of the constituents was used. In the method "slurry" suspension Al-Si about the content of the 11 mass % of Si was applied. Samples were immersed in suspension twice and then they were dried. The process of annealing was realized at temperature of  $950^\circ C$  for 2 h, in an atmosphere of hydrogen. The process of CVD were carried out using BPXPRO325S apparatus of The IonBond Company (Fig. 1), at  $1000^\circ C$  for 4 h.

### 2.1. High temperature cyclic oxidation tests

The tests of resistance to high temperature oxidation corrosion were realized using the furnace Carbolite CWF 1300. The samples before the test were measured and weighed. Next, isothermal oxidation test at temperature  $1100^\circ C$  in a chamber furnace, in the air atmosphere were being conducted. Samples were taken out of the oven every 23 h, chilled to the room temperature and weighed using the precise analytical balance with the accuracy 0.0001 gram.

The oxidation test was led to the moment of achieving by the sample mass smaller than initial. Oxidised samples were being

cleaned precisely and they were plating a thin layer of nickel using electroless nickel plating method. Metallographic specimens were carried out applying the standard method: samples were cutted along the diameter, samples were mounted, then microsections were being grinded using abrasive papers, samples were being washed, and then were polished mechanically using diamond suspensions finishing on  $1 \mu m$ . Samples weren't being etched. The microstructure investigations of all kinds of the coatings (after processes of coating with diffusion layers and after processes of isothermal oxidation) were conducted by the use of light microscope (Nikon Epiphot 300) and a scanning electron microscope (Hitachi S-3400N) which was equipped with Thermo EDS attachment for analysis of the chemical composition. The thickness of the aluminide layers was measured with microscopic methods with using the software NIS-Elements 2.30.



Fig. 1. IonBond BPXPRO325S apparatus for CVD aluminizing

## 3. Results

The Microstructure of obtained coating by VPA method consisted of two zones (Fig. 2), outer about an average thickness ca.  $46 \mu m$  (Table 4) and much thinner internal for thicknesses ca.  $9 \mu m$  - total layer thickness was ca.  $55 \mu m$ .

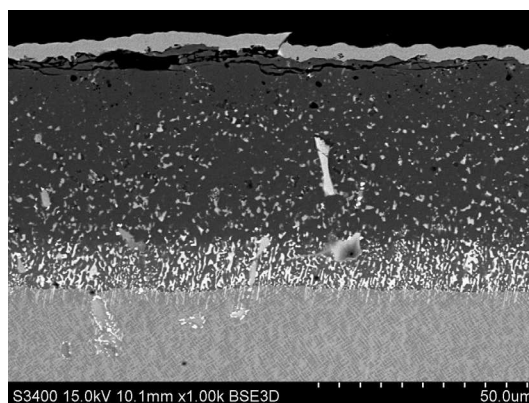


Fig. 2. The cross-section (SEM) of the microstructure coated by VPA method

Table 1.  
The chemical composition of the coating produced by VPA method (as showed in Figure 3)

Area of analysis	Elements content [% at.]										
	O	Al	Si	S	Ti	Cr	Co	Ni	Zr	Mo	W
1	-	-	-	-	-	-	-	89.26	10.74	-	-
2	6.11	49.58	0.55	-	1.50	4.13	4.31	33.82	-	-	-
3	7.13	46.93	-	-	1.48	5.58	4.93	33.06	-	-	0.89
4	-	19.06	-	-	12.65	21.92	7.13	33.33	-	2.40	3.52
5	-	6.37	-	1.39	5.53	15.96	9.14	59.74	-	-	1.86
6	-	39.70	-	-	18.33	2.58	4.06	29.69	-	2.02	3.63
7	-	20.09	-	-	8.65	28.97	5.45	31.14	-	2.66	3.05

Table 2.  
The chemical composition of the coating produced by "slurry" method (as showed in Figure 5 a-b)

Area of analysis	Elements content [% at.]							
	Al	Si	Ti	Cr	Co	Ni	Mo	W
1	6.04	44.13	4.79	34.13	-	1.43	5.32	4.16
2	40.89	13.47	1.26	3.86	5.08	34.60	0.50	0.33
3	42.30	10.32	1.10	3.29	5.39	36.33	0.55	0.73
4	28.96	11.13	1.17	28.53	3.06	23.24	1.89	2.01
5	47.22	0.25	0.72	2.76	4.84	43.48	0.43	0.30
6	20.82	-	11.10	27.76	6.64	26.72	3.27	3.70
7	11.31	-	10.83	6.69	6.27	62.30	1.24	1.36

Table 3.  
The chemical composition of the coating produced by CVD method (as showed in Figure 7)

Area of analysis	Elements content [% at.]						
	Al	Ti	Cr	Fe	Co	Ni	W
1	44.99	-	2.15	0.93	5.27	46.65	-
2	38.17	1.50	4.21	1.02	6.85	48.25	-
3	41.57	0.83	3.40	1.00	5.63	47.56	-
4	26.56	2.47	12.94	0.99	8.35	42.09	6.60
5	11.03	2.52	11.32	-	9.49	62.34	3.31

The examinations of the microstructure using of SEM and EDS method demonstrated considerable diversifying the content of aluminium on the cross-section of layers from ca. 49% at. in area close the surface of the sample to ca. 19% at. in the inner zone - in the vicinity of substrate (Table 1 and Fig. 2). However the inner zone is more abounding into titanium, chromium and tungsten. On the cross-section of the entire layer regular distribution of nickel was stated - ca. 33% at. (Table 1) with the highest chromium content - ca. 22% at. (Table 1) in inner zone is characterized.

In the microstructure of obtained layer with method "slurry" can be distinguished three different zones: the outer, inner and internal (Figs. 4, 5a,b). EDS point analysis method of the chemical composition of "slurry" coating showed in the outer

zone about an average thickness ca. 7  $\mu\text{m}$  (Fig. 5, Table 2) high silicon content - 44.13 % at. and of chromium - 34.13 % at. (Fig. 5, Table 2). In the middle zone about an average thickness ca. 59  $\mu\text{m}$  (Fig. 4) appearing of precipitates about the increased silicon content was stated (Fig. 5, Table 2). The content of aluminium is included in a range from 40.89 % at. to 47.22 % at. (Table 2). The content of the different elements in the inner-middle zone, in the area near the diffusion zone (point 5 - Figure 5b) amounted: approx. 47% at. aluminium and 43% at. nickel, and ca. 5% at. cobalt and 3% of chromium (Table 2). In the inner zone (diffusion) a presence of silicon wasn't stated. This zone contained chromium mainly - 20% at. and nickel - 27% at. (point 6 - Fig. 5b, Table 2).



Table 4.  
Measurement of the VPA coating (Fig. 3)

No.	Thickness of the coating [ $\mu\text{m}$ ]	
	Outer zone	Total thickness
1.	46.17	56.10
2.	46.92	54.44
3.	46.02	53.39
4.	46.77	58.89
5.	44.37	54.74
Average:	45.87	55.51
Min.	44.37	53.39
Max.	46.92	58.89
Standard deviation	1.796	2.82

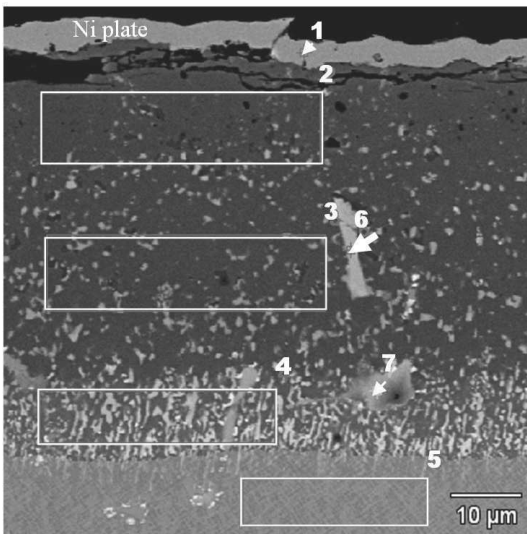


Fig. 3. The microstructure of the coating obtained by VPA method (SEM-BSE) with marked places of spot analysis of the chemical composition (Table 1)

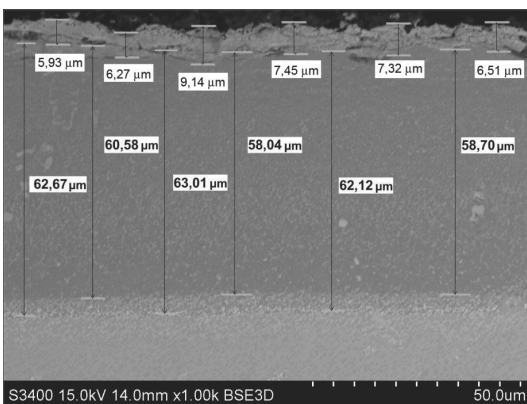


Fig. 4. The microstructure of the coating obtained by the „slurry” method

In area in the vicinity of layer and material of base the concentration of aluminium decreased to 11.31% at., however of nickel increased to 62.30% at. (Table 2 and Fig. 5.). The concentration of titanium in this zone amounted to approximately 10% at., and 6% at. of chromium and cobalt also around 6% at. Coating produced on the base of nickel Rene 80 superalloy by use of „slurry” method is characterized by considerable developing of the surface of outer layer and the discontinuity (Figs. 4-5a.).

On the basis of the results of the measurement of thickness of zones of coating carried out with method "slurry" (Table 5) it is possible to state that the total coating thickness amounts on average to 69.7  $\mu\text{m}$ , however of inner zone ca. 3.5  $\mu\text{m}$ .

Table 5.  
Measurement of the “slurry” coating

No.	Thickness of the coating [ $\mu\text{m}$ ]		
	Outer zone	Middle zone	Middle & inner zone
1.	5.93	60.58	62.67
2.	6.27	58.04	63.01
3.	9.14	58.70	62.12
4.	7.45	-	-
5.	7.32	-	-
6.	6.51	-	-
Average:	7.1	59.11	62.6
Min.	5.93	58.04	62.12
Max.	9.14	60.58	63.01
Standard deviation	1.66	1.82	0.446

In the microstructure of coating obtained by CVD method an outer and inner zone is visible (Fig. 6.). The coating thickness amounted to approximately 15  $\mu\text{m}$ , while thickness of zones outer and internal appropriately ok. 7.5 and 7  $\mu\text{m}$  (Table 6).

Table 6.  
Measurement of the CVD coating

No.	Thickness of the coating [ $\mu\text{m}$ ]	
	Outer (additive) zone	Total thickness
1.	7.44	15.33
2.	8.59	13.87
3.	6.82	14.49
4.	9.05	14.95
5.	6.52	16.02
6.		14.1
Average:	7.68	14.79
Min.	6.52	13.87
Max.	9.05	16.02
Standard deviation	1.27	1.19

Analysis of the chemical composition in chosen areas of aluminate layer obtained by CVD method (Fig. 7) showed that the content of aluminium in the outer zone was averaging 41.58% at.,

internal 26.56% at. however in substrate (in the vicinity of layer) ca. 11% at. (Table 3). The concentration of nickel in the outer zone averaged 47.48% at., however in internal the concentration was smaller - 42.09% at. (Table 3). The highest chromium content was being observed in internal layer - 12.94% at.. In this area appearing of tungsten was also stated - 6.60% at. (Table 3).

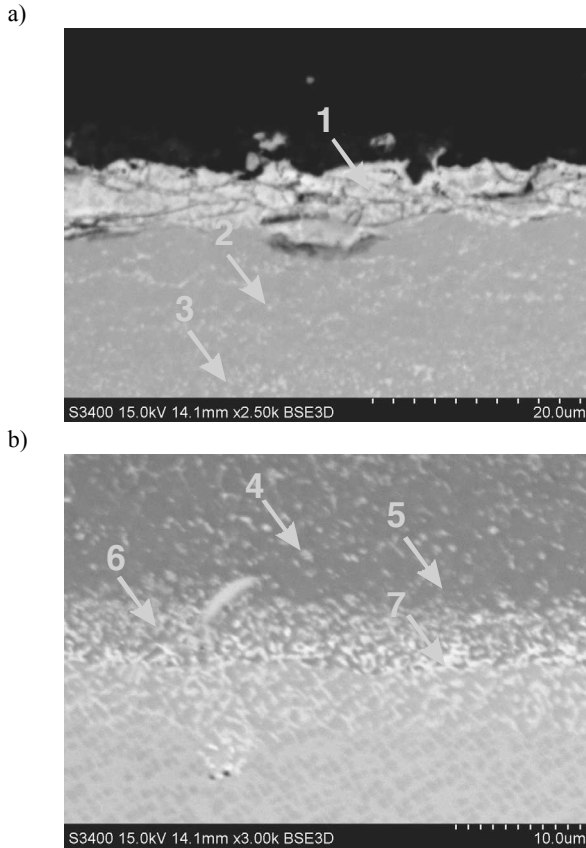


Fig. 5. The microstructure of obtained coating with method "slurry" (SEM) with marked places of point analysis of the chemical composition (Table 2)

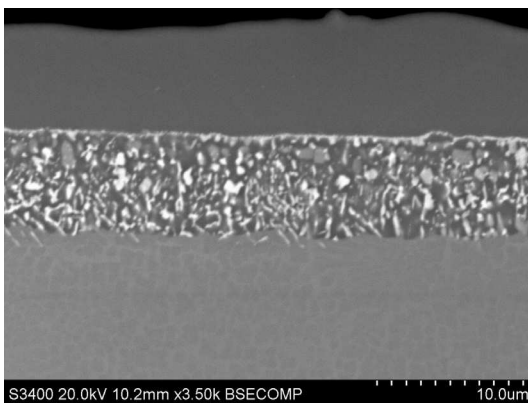


Fig. 6. The microstructure of coating produced by CVD method (SEM)

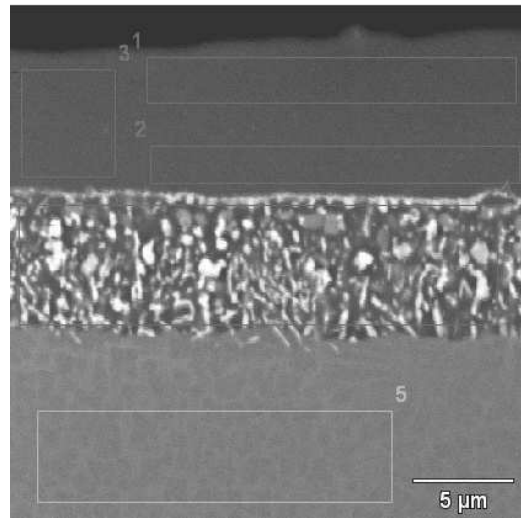


Fig. 7. The microstructure of coating obtained by CVD method (SEM) with marked places of point analysis of the chemical composition (Table 3)

### 3.1. High temperature cyclic oxidation tests

As a result of the carried examinations resistances to high temperature oxidation of René 80 superalloy without protective coating were stated that the maximum increase of mass of the sample is already appearing between 1st and 2nd with cycle (Fig. 8.). The sample achieved the initial value of mass between 3rd and 4th with cycle. The sample achieved the initial value of mass between 3 and 4 with cycle. The complex and long-term plan of examinations made it impossible to conduct cyclical oxidizing René 80 alloy with layer carried out by VPA method (examinations last). Based on achieved results (Fig. 9) it was determined, that the maximum increase of mass of the sample was taking place later than in case of alloy without layer - after 5th of the cycle. It is possible to suppose reaching initial mass will take place after 15th cycle.

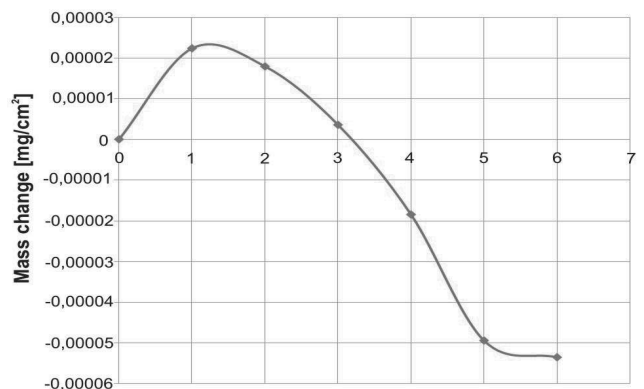


Fig. 8. Change of mass of the sample in the function of the number of cycles in the oxidation test of René 80 superalloy without protective coating

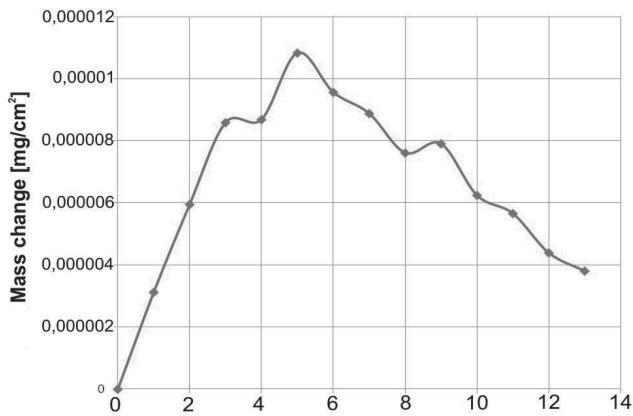


Fig. 9. Change of mass of the sample in the function of the number of cycles in the oxidation test of René 80 superalloy coated by VPA process

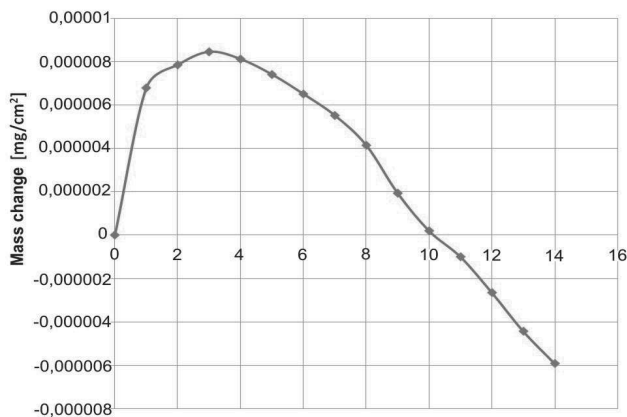


Fig. 10. Change of mass of the sample in the function of the number of cycles in the oxidation test of René 80 superalloy coated by "slurry" method

On the basis of the cyclical oxidation tests carried out on samples with layers of "slurry" type may be noted that the

Table 7.

The chemical composition of the microstructure (as was showed in Figure 12b - without protective coating) in chosen areas

Area of analysis	Elements content [% at.]							
	O	Al	Ti	Cr	Co	Ni	Zr	W
1	64.73	-	-	0.65	2.46	16.86	-	15.30
2	60.55	36.27	-	-	-	3.17	-	-
3	39.53	16.73	0.95	2.44	4.24	32.13	-	3.98
4	54.73	19.61	0.55	2.17	2.00	19.28	0.77	0.88
5	27.89	18.59	1.67	6.97	6.45	35.32	-	3.10
6	11.52	4.06	1.70	10.55	9.74	58.01	-	4.42
7	10.61	4.17	1.88	9.86	10.26	59.88	-	3.34
8	-	-	-	-	-	100.00	-	-

maximum increase of the sample was after a 3rd of the cycle. The initial mass has been reached after 10th cycle (Fig. 10). The highest hot-corrosion resistance of tested samples of superalloy René 80 was achieved in the result for applying CVD aluminate layers. The Maximum increase of mass of the sample was being observed after 28th of cycle (Fig. 11). However the return to initial mass was noted after 48th of cycle.

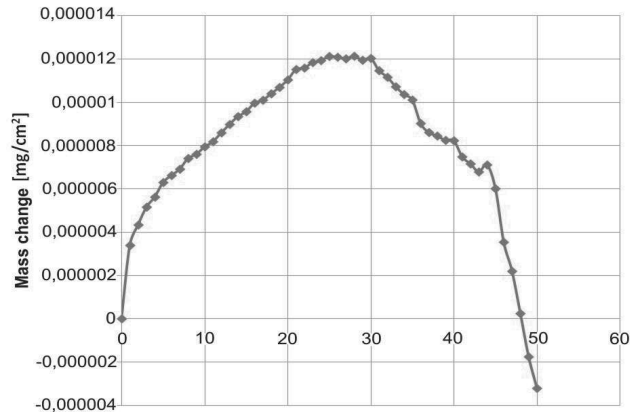


Fig. 11. Change of mass of the sample in the function of the number of cycles in the oxidation test of René 80 superalloy coated by CVD process

### 3.2. The microstructure of coatings after tests of cyclic oxidation

Microscopic examinations after the tests of cyclic oxidation showed the significant rate of the degradation of the surface of superalloy René 80 which was coated with no protective coating (Fig. 12a). Analysis results of the chemical composition (Table 7) are showing at the large oxygen content in the outer zone (Table 7) (forming oxides) and diversifying the content of individual elements on the cross-section of the surface layer of alloy (diffusion processes).

Table 8.

The chemical composition of the microstructure (as was showed in Figure 13b - with "slurry" coating) in chosen areas

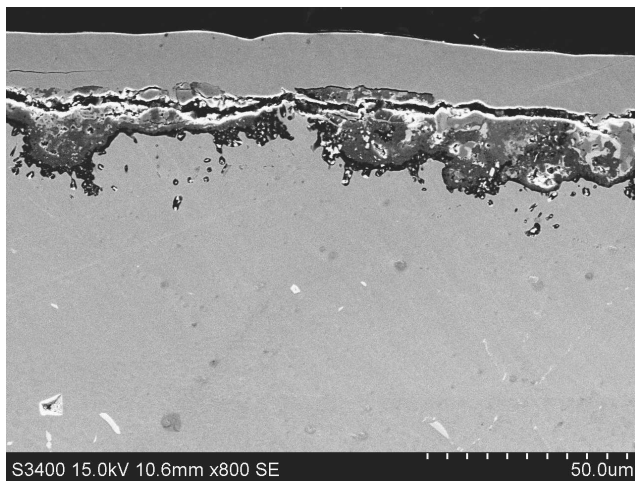
Area of analysis	Elements content [% at.]							
	O	Al	Si	Ti	Cr	Co	Ni	W
1	57.70	17.25	10.08	3.67	8.65	-	2.64	-
2	11.78	13.37	7.60	1.99	7.22	7.28	50.77	-
3	-	14.59	7.25	3.59	3.90	5.94	64.72	-
4	10.30	8.18	7.90	1.46	10.56	9.85	51.75	-
5	12.37	7.79	-	1.33	13.61	9.71	51.39	3.80
6	9.48	8.78	9.10	2.18	9.19	8.94	52.34	-
7	10.69	9.71	-	2.01	9.61	8.65	54.35	4.98
8	12.30	9.62	-	2.06	9.95	9.45	52.08	4.54
9	9.71	9.10	-	2.33	9.40	9.19	54.72	5.56
10	3.15	-	-	-	-	-	96.85	-

Table 9.

The chemical composition of the microstructure (was showed in Figure 13b - with CVD coating) in chosen areas

Area of analysis	Elements content [% at.]							
	O	Al	Ti	Cr	Fe	Co	Ni	W
1	59.76	29.47	-	0.48	0.40	2.07	7.82	-
2	58.51	41.28	-	-	-	-	0.21	-
3	39.76	30.28	0.66	4.26	-	3.50	19.06	2.47
4	59.10	39.58	-	0.31	-	-	1.02	-
5	36.55	25.56	0.66	5.77	-	4.84	24.34	2.29
6	-	8.35	2.13	13.61	-	10.90	58.95	6.06
7	12.10	7.07	1.78	11.22	-	9.82	52.44	5.58

a)



b)

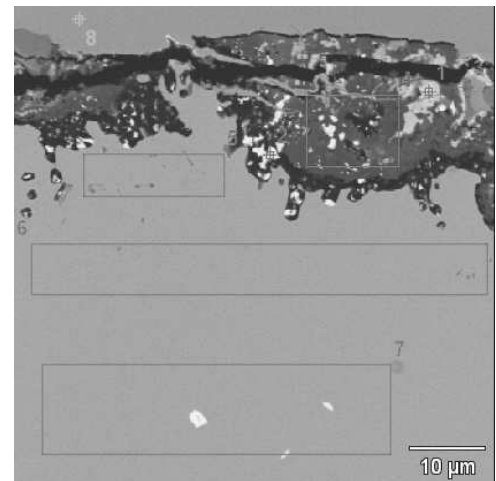


Fig. 12. The microstructure (cross-section) of the surface of superalloy René 80 without protective coating after the test of cyclic oxidation at 1100°C (SEM) (a), areas of carrying out of analysis of the chemical composition (b)

Coating of the "slurry" type on the base René 80 is characterized by large development of surface (Fig. 13a). The results of the chemical composition analysis (Table 8) shall indicate on a much smaller the content of oxygen in the surface layer of alloy than in the case where there was no protective coating.

The surface of alloy René 80 coated with CVD layer is characterized by a low of the development (Fig. 14a). Analysis results of the chemical composition are showing the diffusion of oxygen deep into of material for the depth ca. 30 µm (area 5 on Fig. 14b, Table 9).



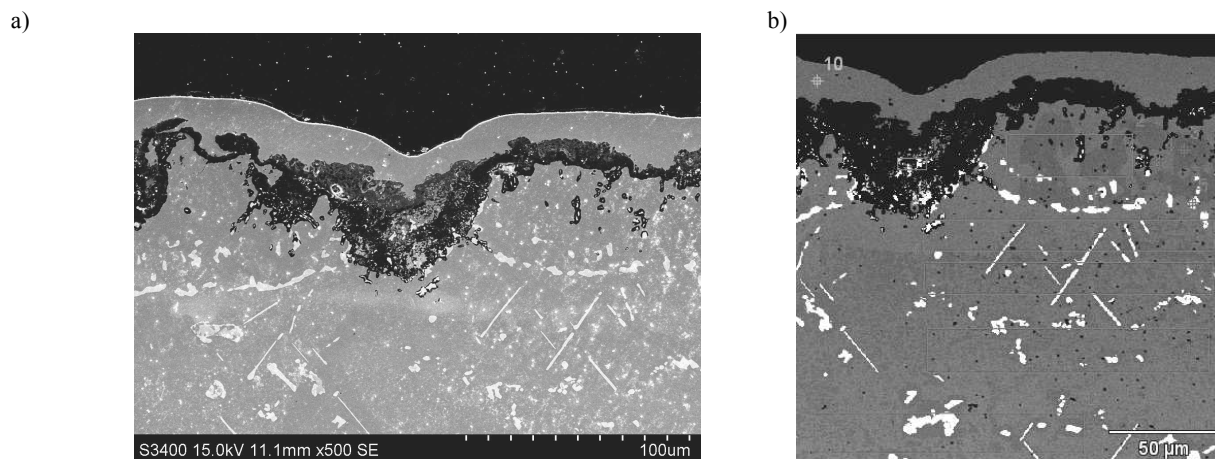


Fig. 13. The microstructure (cross-section) of the surface of superalloy René 80 coated with protective coating of the “slurry” type after the test of cyclic oxidation at 1100°C (SEM) (a), areas of carrying out of analysis of the chemical composition (b)

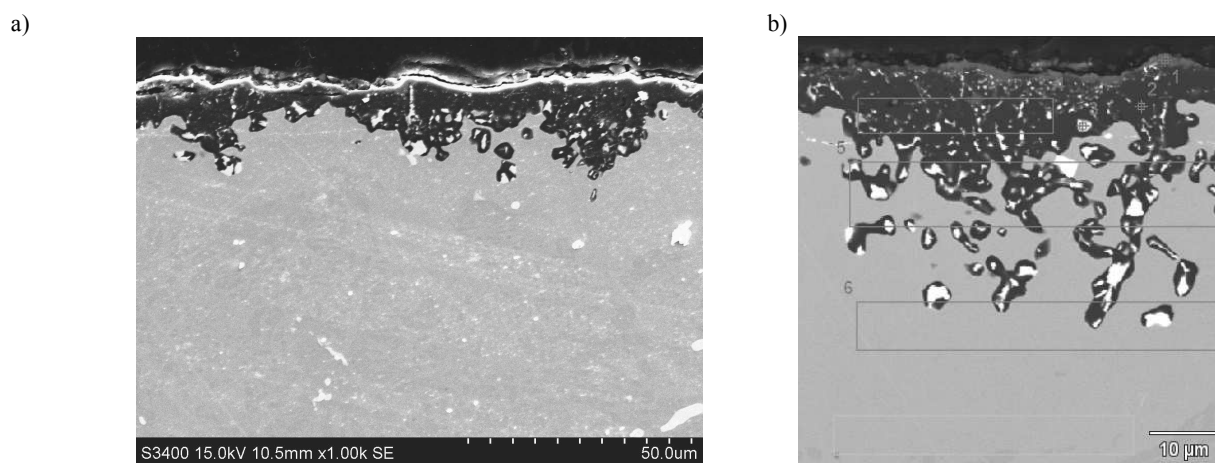


Fig. 14. The microstructure (cross-section) of the surface of superalloy René 80 coated with CVD protective aluminide layer after the test of cyclic oxidation at 1100°C (SEM) (a), areas of carrying out of analysis of the chemical composition

## 4. Conclusions

On the basis of microscopic examinations of cross-sections of obtained coatings it is possible to state that they consist of two zones - outer and internal - VPA and CVD or three - containing the middle zone additionally - process “slurry” (Figs. 15, 16 and 17). The results of measurements show the thickness of the coatings that the thinnest layer is being get after applying the CVD method, however the thickest applying the layer of the type “slurry”. The VPA method is leading for creating the thick outer zone which is amounting to ca. 80% of the total layer thickness. In case of produced layer with CVD method thicknesses of zones (internal and outer) are similar. In the layer of the type “slurry” a internal zone is dominating (Fig. 15). The research of the hot-corrosion resistance demonstrated the high-temperature method of cyclic oxidation on the surface of superalloy René 80 causes deficiency in protective coating the maximal increase in mass associated with the formation of products of oxidation (Fig. 16)

and the shortest time of achieving the initial value of mass of the sample (Fig. 17) - the fundamental criterion of the oxidation resistance. The maximal increase of the mass of samples with obtained coating was being observed in case of the CVD method, and smallest after the application of the “slurry” method (Fig. 16). The largest number of oxidation cycles to achieve the initial mass was for the CVD coatings stated - 48, less for the VPA coatings - 15 (estimated value) and least for the „slurry” coatings - 10 (Fig. 17). It was found that higher growth in the oxidation process is directly correlated with great resistance to the effect of this phenomenon, what how it is possible to suppose results from “purity” of additive CVD  $\beta$  - NiAl layer as well as the easiness of the formation of the tight and protective of thin  $\text{Al}_2\text{O}_3$  layer (large number of cycles) (Figs. 16, 17). The aluminide coating obtained by CVD method demonstrated the greatest oxidation resistance, thinnest from received. In this case it is possible to suppose, that good oxidation resistance results from the coating structure and its purity than its thickness.

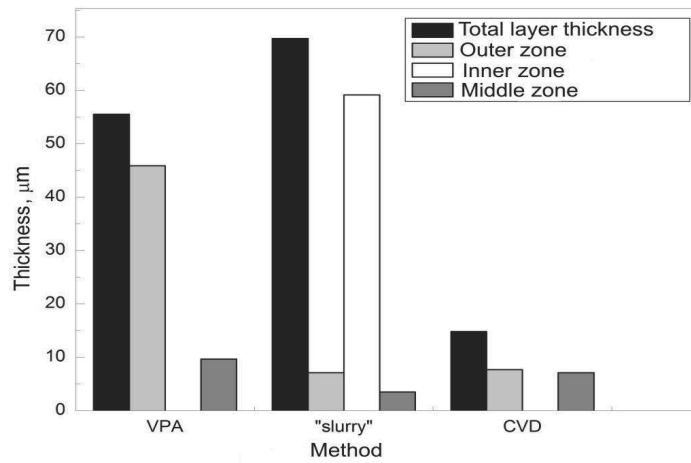


Fig. 15. The thickness of aluminide coatings deposited by different methods on Rene 80 superalloy

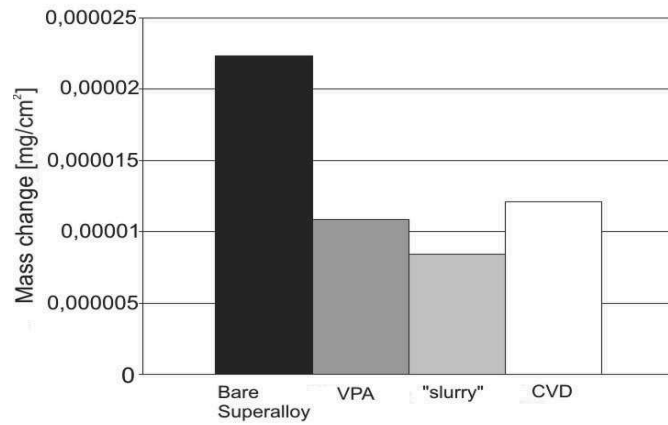


Fig. 16. The maximum mass change of the samples in the tests of cyclical oxidation

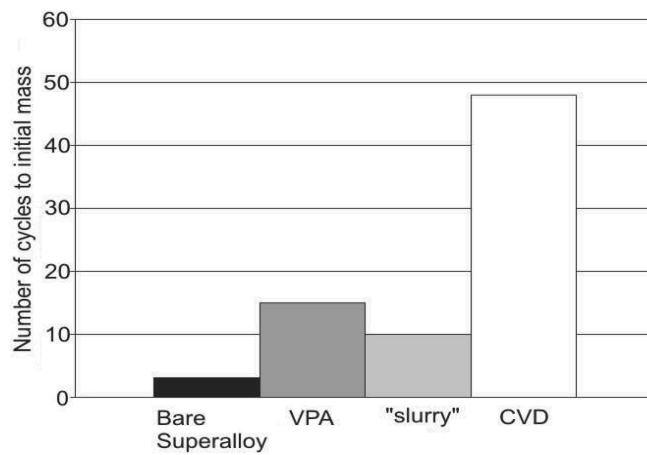


Fig. 17. Number of cycles of oxidizing samples to achieve initial mass (in case of VPA - examinations didn't end - an appraised value was accepted)

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