Journal of Achievements in Materials and Manufacturing Engineering

VOLUME 55
ISSUE 2
December
2012

Diffusion AlSi-MeCrAlY coatings obtained on intermetallic γ-TiAl phase

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Received 09.10.2012; published in revised form 01.12.2012

Manufacturing and processing

ABSTRACT

Purpose: The development of new protective coatings for TiAl intermetallics was conducted. The MeCrAlY-AlSi slurry was used with different amount of aluminium-silicon powder in the binder.

Design/methodology/approach: The slurry consisting of aluminium and silicon powder with the addition of MeCrAlY powder were used during the procedure. The inorganic solution made from chromic and phosphoric acid was applied as a binder. The preliminary research of microstructure of obtained coatings was conducted.

Findings: The obtained coating consisting of 3 or 4 zones (depending on chemical composition of the slurry) was obtained during the annealing process (950°C/4h).

Research limitations/implications: The research results revealed the possibility of obtaining coatings with complex phase and chemical composition.

Practical implications: Many problems connected with sedimentation of heavier MeCrAlY powder were observed.

Originality/value: The copletele new technologies was described in article

Keywords: Metallic alloys; Corrosion; Technological design; Thin and Thick Coatings; Surface treatment

Reference to this paper should be given in the following way:

M. Góral, G. Moskal, Diffusion AlSi-MeCrAlY coatings obtained on intermetallic γ-TiAl phase, Journal of Achievements in Materials and Manufacturing Engineering 55/2 (2012) 685-688.

1. Introduction

The alloys based on γ-TiAl intermetallic phase are characterized by low density and higher temperature resistance (in comparison to classical titanium alloys). Those alloys can be applied in automotive industry (valves, turbocharger rotors) as well as aviation industry (blades of high-pressure compressor, blades of low-pressure turbine). The basic limitations concerning application of those materials are high manufacturing costs and low oxidation resistance. As a result of γ-TiAl alloys oxidation, the mulitlayer mixture of aluminium oxide with rutile (not the homogenous aluminium oxide scale) is created. Such a structure of scale causes low oxidation resistance.

One way of increasing the oxidation resistance of TiAl alloys is the process of creating the protective layer on their surface. Different types of protective layers, that protect the γ-TiAl alloy surface against oxidation e.g. aluminide layers based on $TiAl_2$ phases, $TiAl_3$ were developed, included those modified with silicon and chromium and those based on multicomponent MeCrAlY alloy [1].

The most of literature data concerns the aluminide layers based on intermetallic $TiAl_2$, $TiAl_3$ phases. Those layers are obtained using the pack cementation method [2]. Jung proved that alloy additions introduced to the γ-TiAl alloys, diffusing to the formed layer, have a great influence on the morphology of phase composition of the aluminide layers [3]. The positive influence of niobium on the oxidation resistance of aluminide coatings were

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observed. There was also a research on the diffusion chromo-aluminizing conducted [4]. In Japan one developed the concept of combining of chromium plating and pack cementation aluminizing [5]. Different method of modifying the aluminide coatings was proposed by Xiang by using the silicon-aluminizing pack cementation process [6].

Besides the diffusion methods, the aluminide layers can be obtained by aluminium plating, followed by diffusion treatment in vacuum in order to create $TiAl_2$ or $TiAl_3$ phase. The aluminium layer is deposited by thermal spraying or using the physical methods - magnetron atomization or IBAD [7-9].

The tendency to increase the service temperature of the engine during simultaneous mass decrement determines the development of thermal barrier coatings. The research on development of new TBC coatings for TiAl alloys are conducted in Germany. During the early research the deposition process of ceramic layer ($ZrO_2x8Y_2O_3$) was realised through plasma spraying in the conditions of atmospheric pressure (APS) [10]. The bond-coat was obtained during the aluminizing process in the powders and preliminary oxidation - in order to form thin layer of Al_2O_3. Further research were directed to development of new bond-coats and creating the ceramic layer using the physical vapour deposition method involving vaporization with electron beam (EB-PVD) [11]. One way of creating bond-coats for TBC layers was application of so-called “fluorine effect” [12]. The usage of different kind of bond-coat from those applied to nickel superalloys is necessary due to unfavourable influence of diffusive transformation between the substrate and the bond-coat. One of solutions is to apply suitable thin layer forming the diffusion barrier [13]. During the research conducted by Leyens et al., the highest thermal fatigue resistance was observed for TiAlCr bond-coat, obtained with magnetron atomization method [14]. During the further research one proved, that the application of preliminary oxidation enables obtaining the best scaling resistance and falling off the oxide layer [15]. The resent research showed good adhesion of ceramic layer to the CrAlYN [16].

In order to obtain the thermal barrier coatings on the γ-TiAl alloys, it is necessary to conduct further research on new kinds of bond-coats. One of the possibilities is to create bond-coats using the slurry method. Attempts made till now by authors showed a possibility of application of Al-Si slurries usually used to create aluminide coatings on a base of nickel superalloys [17]. The authors presented in this article a research on obtaining aluminide coatings modified with MeCrAlY powder.

2. Experimental

The alloy based on intermetallic 48-2-2 phase (48 at.% Al, 2 at% Cr - 2 at% Nb, Ti-bal.) manufactured by ALD company was the base material. Samples were cut out of ingots using the electro spark method. The slurries were made by application of minced NiCoCrAlY powder used for plasma spray by Sulzer-Metco company and commercial Al-Si slurry. The mass of Si powder was 11% of aluminium powder in the slurry The inorganic binder of the slurry contained i.a. phosphorous and chromium acid. The MeCr-Al Si powder was used in the 1:2 and 3:4 ratio. The liquid fraction was approx. 50% of total mass of the slurry.

Samples were submitted to sand blasting, washing and degreasing before the coating deposition. The coating was applied by two time 30 second immersion. The sedimentation process of heavier MeCrAlY powder were observed during the application process. Next samples were dried in the temperature of 80ºC in the vacuum drier. The diffusion treatment was conducted in the argon atmosphere during 4 hour process, in the temperature of 950ºC - analogous to those used for Al-Si slurry. Samples were submitted to shot peening and washing after the annealing process.

The microstructure analysis was conducted with a use of scanning microscope (Hitachi S-4200) with attachment for chemical composition microanalysis (Thermo).

3. Results and discussion

The coatings made in the process of diffusion treatment were characterized by thickness of approx. 50 micrometers. Four characteristic zones (Fig. 1a) in the structure of the coating made from slurry with MeCrAlY-AlSi ratio of 1:2 could be observed. The outer zone was characterized by high concentration level of chemical elements creating MeCrAlY-Co and Ni powder (pt. 5 on Fig. 1a, Table 1). The aluminium content in this area was 51% at. and approx. 22% at for titanium. The silicon content was of 8% at. Below (area 4), the aluminium concentration was higher and was approx. 63% at. and for titanium - approx. 22% at. The lower silicon, cobalt and nickel concentration - not exceeding 5% at was observed in this area. This zone was characterized by the presence of large amount of precipitates with higher aluminium content (71 at %, pt. 19 on Fig. 1b). It can indicate the possibility of creation of $TiAl_3$ phase. A content of silicon (approx. 3% at), nickel and cobalt were observed also in these points. In the lower area (area no. 3 and pt. 8 on Fig. 1 a,b) the aluminium concentration was approx. 64 at. % and titanium concentration was approx. 34 at.%. Below this zone, in the area no. 2, the aluminium content was approx 50% at. and titanium content was approx. 46 at.%. Microanalysis in this place (pt. 7, Fig. 1b) showed the aluminium content of approx. 64 at. %. In the first area (Fig. 1a) the chemical composition was analogous to the substrate material.

The coating obtained from the slurry containing larger amount of MeCrAlY powder had different structure. No coherent precipitate, which were present in the external part of coating obtained from slurry, that contained lesser amount of MeCrAlY powder (1:2) was observed in the outer zone. The silicon content in the outer zone obtained by local analysis (pt. 9 on Fig. 2b) as well as in the zone no. 4 (on Fig. 2a, Table 2) was approx. 13 at. %. The aluminium concentration in this zone was approx. 43 at. % and titanium content was 16-17 at.%. A high cobalt content of 15 at. % as well as nickel and phosphorus content were observed in the outer zone. Below, in the zone no. 3. marked on the Fig. 2a one observed many columnar precipitates. Mean value of aluminium in this zone was 56 at. % and for the titanium it was approx. 30 at.%. The local analysis of chemical composition proved the existence of precipitates (pt. 7 on Fig. 2b) containing 31 at. % of silicon and 50 at. % of titanium, which may prove the presence of the titanium silicide. The base containing over 65 at. % of aluminium and approx. 26 at. % of titanium, doesn't contain silicon, which can be a proof of existence of $TiAl_2$ or $TiAl_3$ phase in this zone. Below, in zone no. 2 (marked on Fig. 2a), the aluminium concentration was over 63 at. % and for titanium was approx. 34 at. % and the small amount of silicon indicates on formation of the $TiAl_2$ phase. The chemical composition in the zone no. 1 below (Fig. 2a) was analogical to base material - 48-2-2-type alloy.

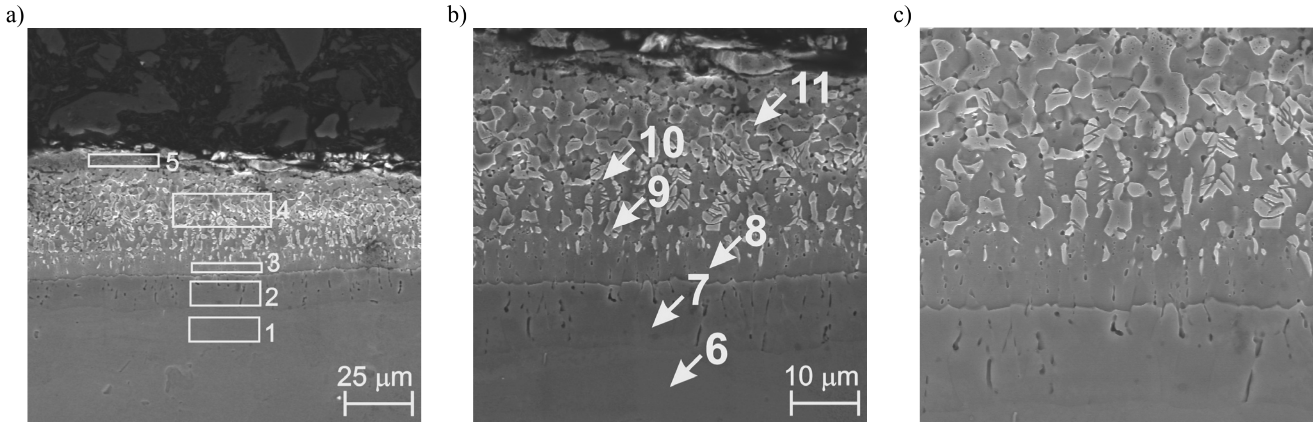

Fig. 1. The microstructure of the aluminide coating obtained from Al-Si, MeCrAlY slurry with mass ratio 2:1, after four hours diffusion treatment, in the temperature of 950°C and argon atmosphere, with marked points of chemical composition analysis

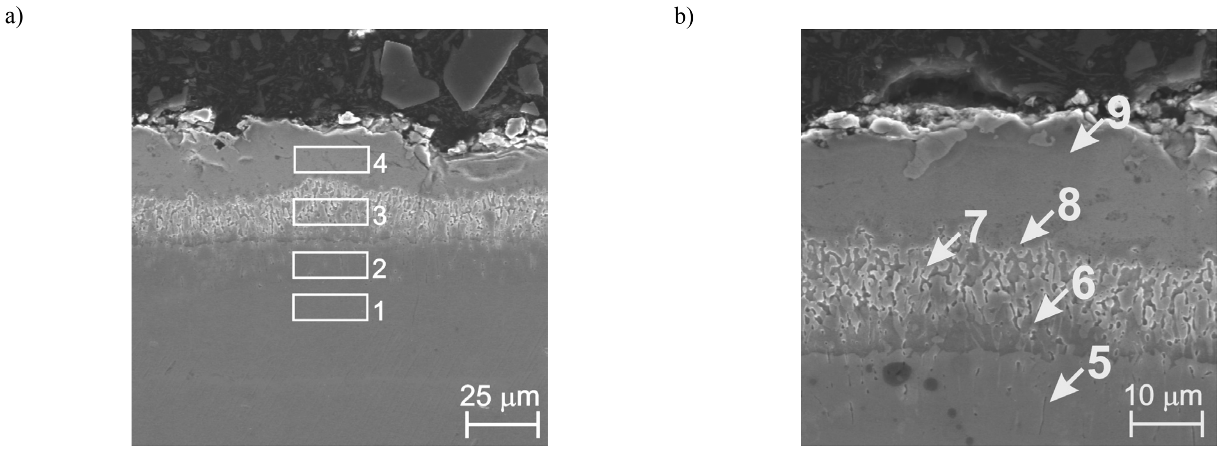

Fig. 2. Microstructure of aluminide coating obtained from Al.-Si and MeCrAlY slurry with weight ratio 4:3, after 4 hour diffusion treatment in the temperature of 950°C and argon atmosphere, with marked places of chemical composition analysis

4. Summary

Attempts made to create coatings from slurries containing aluminium, silicon powders and MeCrAlY alloys confirmed that there is a possibility of obtaining diffusion coatings. Coatings with different chemical composition, depending on composition of used slurry were created. Using smaller amount of MeCrAlY powder caused formation of coating consisting of 2 characteristic areas. The outer zone was probably $TiAl_3$ phase or $TiAl_3$ phase containing also MeCrAlY - Ni and Co alloy components (area no. 5 on Fig. 1a). Below many precipitates with high content of Al, probably precipitates of $TiAl_3$ and $TiAl_2$ phase containing nickel and silicon (area no. 4 on Fig. 1a) were observed. The third zone was formed by grain of $TiAl_2$ phase (area no. 2 on Fig. 1a). Using the larger amount of MeCrAlY powder in a Al-Si ratio of 3:4 had strong influence on the structure of obtained coating. The outer zone consisted of aluminium, titanium, cobalt, silicon, chromium and nickel. It is necessary to conduct thorough analysis of phase composition in that zone. The middle zone, marked as „3" on Fig. 2a, had structure typical for coating obtained from Al-Si slurry. It consisted of Ti_5Si_3 titanium silicide precipitate based on $TiAl_3$ phase. The inner zone of the coating (zone no. 3 on Fig. 2) consisted of $TiAl_2$ phase, below which the chemical composition corresponds the base material.

Research proved that there is a problem with sedimentation of MeCrAlY powder during coating process. It indicates the necessity of using different method of obtaining the coatings and of changing the chemical composition of powder. It was showed, that application of MeCrAlY bond-coat doesn't ensure suitable oxidation resistance of γ-TiAl alloys with a use of thermal barrier coatings [10]. Further research should be directed to development of optimal chemical composition of the coating and application of different manufacturing method.

Table 1.
The results of EPMA analysis in areas marked on Fig. 1

	Chemical composition (at. %)						
	Al	Si	Ti	Cr	Co	Ni	Nb
1	46.39	-	49.04	1.97	-	-	2.60
2	50.03	-	46.24	1.63	-	-	2.10
3	63.74	-	33.99	0.86	-	-	1.40
4	61.93	4.04	22.62	2.13	3.11	4.95	1.23
5	51.47	8.08	21.50	2.60	8.04	7.24	1.07
6	48.34	-	47.69	1.66	-	-	2.32
7	64.50	-	33.14	0.92	-	-	1.45
8	63.89	0.29	33.43	0.70	-	-	1.69
9	71.38	0.99	23.89	0.81	-	-	2.93
10	59.59	3.12	28.90	4.02	1.33	3.05	-
11	64.88	3.49	24.99	1.66	1.66	1.62	1.71

Table 2.
The results of EPMA analysis in areas marked on Fig. 2

	Chemical composition (at. %)							
	Al	Si	P	Ti	Cr	Co	Ni	Nb
1	49.83	-	-	46.11	1.70	-	-	2.36
2	62.76	1.00	-	34.17	0.65	-	-	1.42
3	56.28	7.19	-	30.63	1.67	1.15	1.47	1.61
4	42.54	12.52	2.08	17.50	2.55	15.31	6.88	0.63
5	58.10	-	-	38.20	1.38	-	-	2.32
6	65.55	-	-	25.63	2.22	1.17	4.21	1.21
7	5.79	31.67	-	49.37	8.86	1.35	0.95	2.00
8	25.71	21.68	-	34.04	6.27	5.25	5.47	1.58
9	42.97	12.91	1.54	16.60	3.59	15.03	7.36	-

Acknowledgements

The research was supported by Ministry of Science and Higher Education under Iuventus Plus program.

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