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Mechanical Properties of Two Layers Thermal Barrier Coating Deposited on a Plate Made of Cobalt Alloy MAR-M509

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Abstract

The manuscript presents a microstructure and mechanical properties of two layers of thermal barrier coating (TBC) deposited on a plate made of cobalt alloy MAR-M509. Based on measurements of microhardness made with Berkovitz's indenter using Nano Scratch-Tester CSM Instruments, it was stated that elastic (Ee) to total energy (Ec) parameters (M_{IT}=Ee/Ec), γ phase, matrix of alloy MAR-M509 ($M_{IT\gamma}$), metallic interlayer (45%Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y),(M_{ITM}) and ceramic layer (M_{ITZrO2}) there are proportion 0,29:0,22:0,50.

Keywords: Cobalt alloy MAR-M509, Thermal barrier coating (TBC), Microstructure, microhardness, Nano Scratch-Tester

1. Introduction

Thermal barrier coatings (TBC) are applied via plasma spraying technology (HPS-Air Plasma System) and build up usually with two layers: metallic interlayer and external ceramic layer [1-3]. The TBC has an excellent heat resistance and a small thermal conductivity. There are characterized by an erosion and abrasion resistance and resistance to aggressive chemicals [4].

Therefore, the TBC are becoming more commonly used as coatings of jet-propelled parts of aircraft engines (combuster, BOAS-Blade Outer Air Seals, blades of turbine), valves ad parts in chemical reactors.

On the metallic interlayer are usually applied materials with MeCrAlY group, single oxides belong to ceramic materials which are most often used on the external layer in the TBC [4].

In aim of this article is presents a microstructure two layers of TBC, interlayer made of 45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y alloy and a ceramic external layer made of ZrO_2 oxides deposited on the coatings of plate made of MAR-M509 cobalt alloy and its mechanical properties. The mechanical properties the layers of TBC defined by microhardness made with Berkovitz's indenter when Nano Scratch-Tester, CSM Instruments was used.

2. Materials and methodology of testing

The plate coatings made of alloy MAR-M509 of dimension 4x20x90 mm were used for test. The composition of plates was as follow: 0,60% C, 28,8% Cr, 10,0% Ni, 7,12% W, 3,8% Ta, 0,36% Zr, 0,18% Ti, 0,007% B, 0,43% Fe, rest, Co. The surface of coatings was at first sandblasted with Al_2O_3 powder of 200-250 μm grain diameter in and air stream of pressure ca. 0,35 MPa for a few seconds. After single layer of 45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y powder alloy was covered and next triple layers of ZrO_2-8%Y_2O_3 powder oxides in an argon-hydrogen plasma beam.

The testing of microstructure layers in the TBC was conducted with a Berkovitz's indenter and Nano Scratch-Tester, CSM Instruments[1].

3. Results

Microstructure

Figure 1 shows image of cross sections of the plate microstructure made of alloy MAR-M509 with a TBC. A microsections was obtained by mechanical polishing and electrolytic etching in 50% aqueous HNO_3 solution with applied voltage about 9 V.

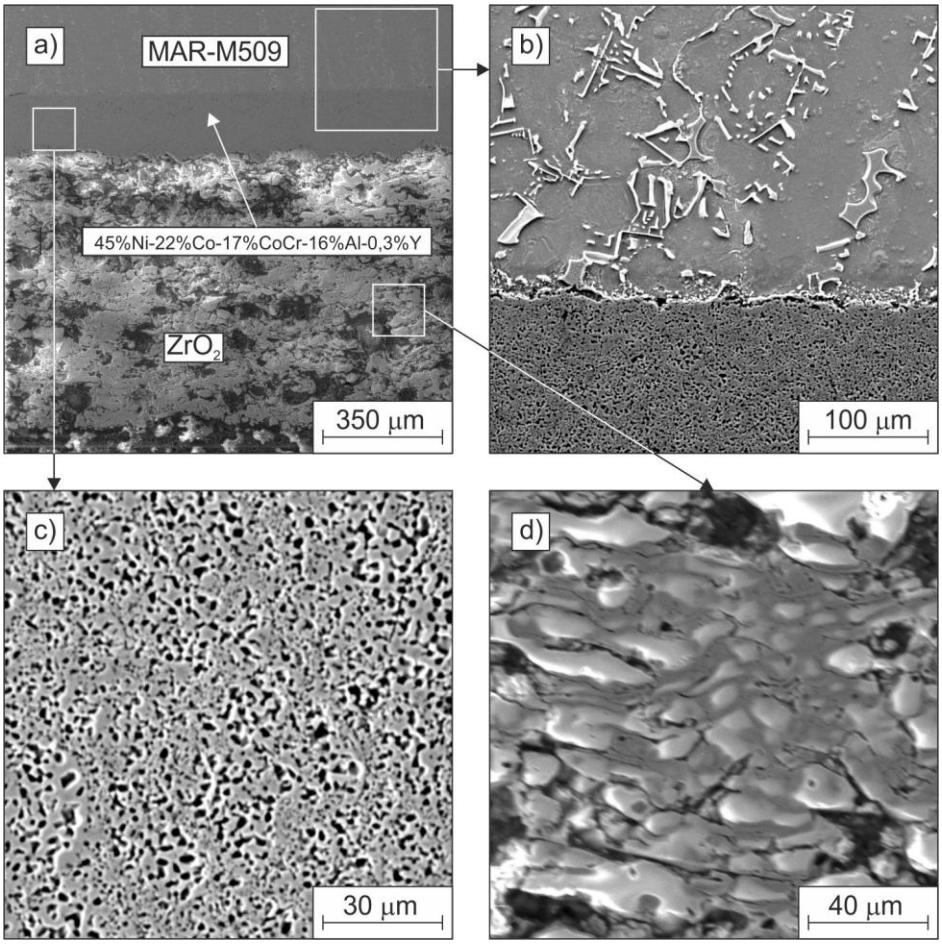

Fig.1. The microstructure at the cross-sections: mould (MAR-M509)) – coating (TBC) (a), MAR-M509-metallic interlayer (b), metallic interlayer (45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y) (c), external ceramic layer (ZrO_2) (d). SEM

[1] The apparatus bought for POPW.01.03.00-18-012 project from the resources of the structural funds in the frame of The Operational Programme Development of Eastern Poland (OP DEP) which is co-financed by European Union from European Regional Development Found, was used in this examination.

Measurements of microharndess

Nano Scratch-Tester, CSM Instruments equipped with a Berkovitz's indenter (a pyramid with equilateral triangle as the base area) is used in measurements of microhardness and to determine other mechanical properties of single grains, thin layer and phase boundaries when loading spreads from 0 to 500 mN [6].

A ratio of elastic strain energy (Ee) to total energy (Ec) during forcing the indenter of the hardness tester, is a very important feature of the tested materials.

Figure 2 shows example courses of changes of energy plastic deformation (Ep) and energy of elastic deformation (Ee) which describe the forcing of Berkovitz's indenter into a γ phase, into the metallic interlayer (45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y) and into the external ceramic layer (ZrO_2) [7].

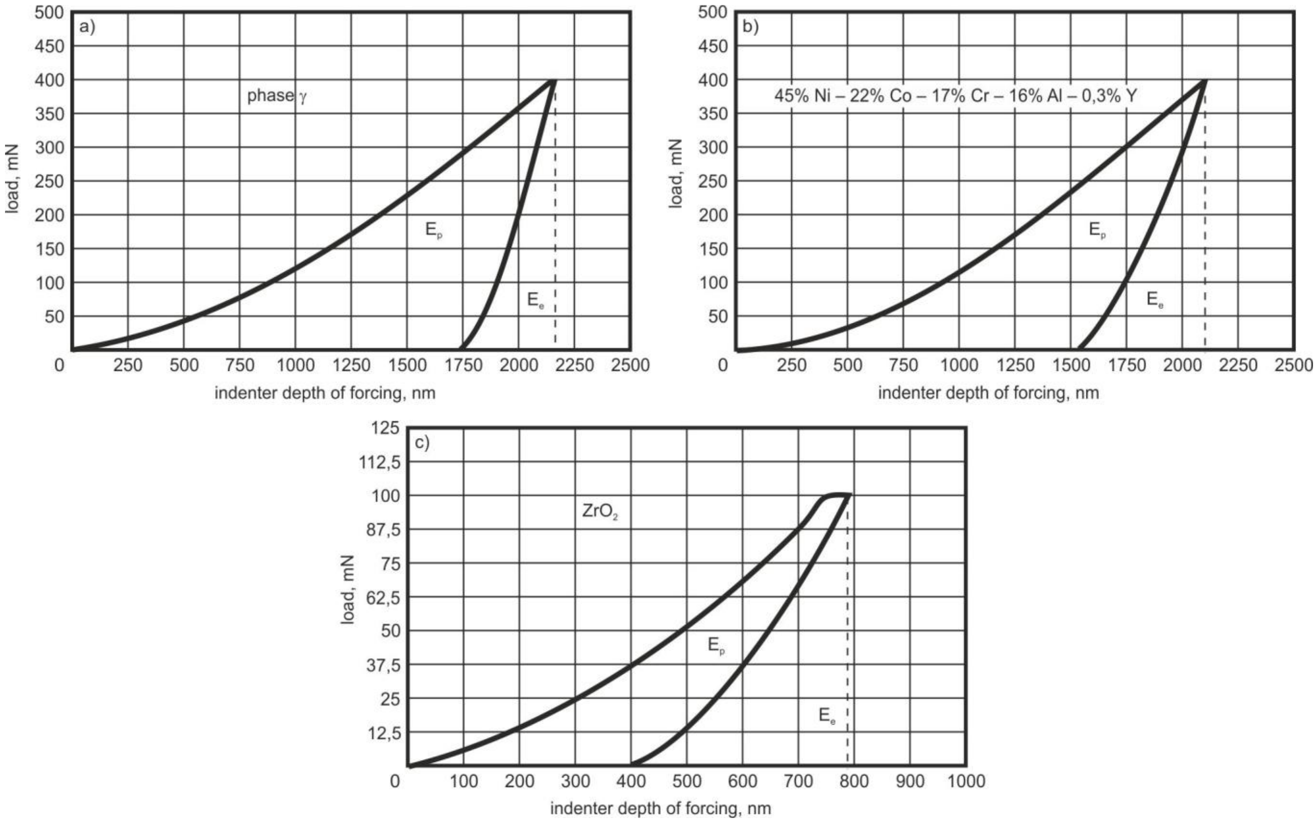

Fig. 2 The influence of loading on depth of forcing in the Berkovitz's indenter and energy change for γ phase (a), metallic interlayer (45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y) (b) and external ceramic layer (ZrO_2) (c)

Table 1 shows values of energy of plastic deformation (Ep), energy of elastic deformation (Ee), total energy (Ec), ratio Ee/Ec, longitudinal modulus of elasticity (Young's modulus E) and microhardness HV0,05 for γ phase, metallic interlayer and external ceramic layer (the average value from five measurements).

Table 1.
The values of energy of plastic deformation (Ep), energy of elastic deformation (Ee), total energy (Ec), ratio Ee/Ec, Young's modulus E and microhardness HV0,05. The average value from five measurements.

phase	Ep[pJ]	Ee[pJ]	Ec[pJ]	M_{IT}=Ee/Ec	E[GPa]	HV0,05
γ	226739±3%	94733±3%	321458±3%	0,29±0,1	122±5	425±5
Metallic interlayer (45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y)	257307±5%	72309±3%	333381±5%	0,22±0,1	103±7	540±8
Ceramic external layer (ZrO_2)	16187±5%	16124±5%	32311±5%	0,50±0,1	125±16	1220±45

4. Summary

The coating of the TBC of ca. 920 μm thickness was obtained as a result of spraying melted fine spherical powder with particle granulation ca. 75±15 μm made of 45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y alloy and ceramic powder made of ZrO_2 – 8%Y_2O_3 with particles irregular granulation ca. 53±15 μm.

Such a coating consists of a two layers fine grain metallic interlayer 45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y of ca. 200 μm thickness and microhardness about 540 HV0,05 and external ceramic layer as a mixture of two phases, regular ZrO_2 (c) and tetragonal ZrO_2 (T) [7]. The microstructure of the metallic interlayer in the TBC is tough, homogeneous and deprived of porosity (total porosity less than 2%) (fig. 1c).

The thin layer of γ phase (it is about 0,015 μm thick), which adheres to the metallic interlayer, is characterized by similar values of microhardness as the metallic interlayer, ca. 520 HV0,05. This is an effect of hardening of γ phase with secondary carbides of $M_{23}C_6$ (fig. 1b).

A gradient of elastic strain energy to total energy (M_{IT}=Ee/Ec) during forcing the Berkovitz's indenter in, is a very good parameter that decribes elastic – plastic properties of materials. The MIT parameter for γ phase (MITγ) equals to 0,29, for the metallic interlayer (MIT_M) 45% Ni – 22% Co – 17% Cr – 16% Al – 0,3% Y to 0,22 and for the external ceramic layer (M_{ITZrO2}) to 0,50.

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