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TECHNOLOGICAL PROPERTIES OF UNDERLAYERS BASED ON NICKEL M-CROLL IN THE FORMATION OF MULTILAYER COATINGS BY THE METHODS OF GAS THERMAL SPRAYING

The article considers the effect on technological characteristics (adhesion strength with the base, values of the stress intensity factor K_1c, number of thermal cycles before failure) depending on the type of thermal spraying and subsequent heat treatment during the formation of multilayer coatings. To deposit underlayers there were used methods of air plasma spraying (APS), in air with argon protective jet (SAPS), vacuum plasma spraying (VPS), high-velocity open-flame spraying (HVOF). From the considered methods of NiCrAlY underlayers deposition for HSC better characteristics of destruction viscosity had those ones sprayed in the air (APS), adhesion strength between the coating and the substrate, heat resistance - vacuum plasma sprayed ones (VPS).

Keywords*: sublayers based on nickel M-croll, formation of multilayer coatings, methods of thermal spraying, properties of the formed coatings*

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ТЕХНОЛОГИЧЕСКИЕ СВОЙСТВА ПОДСЛОЕВ НА ОСНОВЕ НИКЕЛЕВЫХ М-КРОЛЕЙ ПРИ ФОРМИРОВАНИИ МНОГОСЛОЙНЫХ ПОКРЫТИЙ МЕТОДАМИ ГАЗОВОГОТЕРМИЧЕСКОГО НАПЫЛЕНИЯ

В статье рассмотрено влияние на технологические характеристики (прочность сцепления с основанием, значения коэффициента интенсивности напряжений K_1c, количество термоциклов до разрушения) в зависимости от вида термического напыления и последующей термической обработки при формировании многослойных покрытий. Для нанесения подслоев применялись методы воздушно-плазменного напыления (APS), в воздухе с аргоновой защитной струей (SAPS), вакуумно-плазменного напыления (VPS), высокоскоростного напыления (HVOF). Из рассмотренных способов нанесения подслоев NiCrAlY для HSC лучшими характеристиками вязкости обладают способы напыления на воздухе (APS), прочности сцепления между покрытием и подложкой, термостойкости - вакуумно-плазменного напыления (VPS).

Ключевые слова: *подслои на основе никелевых М-кролей, формирование многослойных покрытий, методы газотермического напыления, свойства сформированных покрытий*

1. Introduction

Basic function of an underlayer in heat-shield coatings (HSC) is plastic relaxation of stresses in a coating originating due to uncoordinated volume changes in ceramic and metal materials when heating and cooling of a part. Taking into account that alloys plasticity disastrously reduces due to their high-temperature oxidation and a ceramic layer is permeable for gases, an underlayer material should possess high heat-shield ability. In HSC for aircraft turbine engine parts reduction of under-layer plasticity due to oxidation is the main factor depending on time, which reduces serviceability of a coating. Moreover, formation of an oxide layer on the metal-ceramics boundary, which destruction viscosity is significantly lower, than of PSZ, are an additional (if not the main) source of cracks formation in a coating [1-3]. Thus, the problem of adhesion underlayer formation for HSC is reduced to solution of two basic problems: provision of necessary flexibility of an underlayer within working temperature interval; provision of its heat-resistance. Complex solution of these problems is harder due to a number of circumstances. First, increase of heat-resistance of alloys based on nickel, cobalt and iron by increase of concentration of elements, forming protective films (aluminium, chromium, silicon) are inevitably accompanied with sharp reduction of alloy plasticity. Necessity of strong optimization of chemical and phase alloy composition and also technology of underlayer deposition is obvious. Second, optimization like that has no general solution [4]. Certain materials of a substrate and an outer ceramic layer, typical geometrical sizes of a part and a coating, requirements for service life and reliability of a part make special developments necessary for characteristic groups of parts or a single one [5,6]. In this paper the authors assessed technological possibilities of thermal spraying methods for formation of HSC metal underlayers, which are capable of effective work on piston-type parts of internal combustion engines.

2. Materials and equipment.

For our investigations we were using two types of heat-resistant steels that are used for production of piston-type parts: 40X10C2M (ЭИ-107) steel and 20X25H20C2 (ЭИ-283) steel. As an underlayer material we were using Ni-57% Cr-5% Al-0.5% powder (oxygen concentration - 0.05%). For deposition of an outer ceramic layer we were using ZrO_2-7%Y_2O_3 (ЦИ-7). For deposition of ceramics we were using air plasma deposition (APS). To deposit underlayers there were used methods of air plasma spraying (APS), in air with argon protective jet (SAPS), vacuum plasma spraying (VPS), high-velocity open-flame spraying (HVOF) Processes were carried out with the help of «Plasma-Technic AG» equipment. Argon-hydrogen mixtures were used as plasma-forming gases. During SAPS there were some special nozzles used [3] for better particles distribution in the jet, which suppressed sublimation processes and thermal dissociation of the material under spraying. Structure of the coatings was investigated with the help of optical metallography methods (optical microscopes «Polyvar» (Austria) and «Neophot-20 (Germany)). Thermal cyclization of samples with a coating was carried out according to the following scheme: heating up to 1170 K, holding for 15 minutes, cooling to the room temperature with compressed air. Adhesion strength between a coating and a substrate and stresses intensity coefficient were measured with «Instron» tearing machine with a special device, enabling to get increased precision of the tests.

3. Results and their discussion.

Adhesion strength value between a substrate and an underlayer depends on the types of the underlayer deposition, spraying modes and the following thermal treatment. of the six methods under comparison (APS, SAPS, VPS, HVOF) when spraying on a cold substrate the most high adhesion strength had VPS-deposited coatings (Table 1). Thermal treatment of coatings at 1100 °C for 2 hours in vacuum for all the underlayer deposition methods increases adhesion strength of coatings. Thermal treatment changes underlayers structure and increases uniformity of phases distribution and increase of their thermal stability. At the same time β-phase sizes increase and diffusion of substrate elements into a coating tales place. During APS and SAPS oxide films significantly dissolve in a metal matrix, but lamination of a structure does not disappear in full. It was determined that for all the HSC underlayer types quality of adhesion between metal and ceramics after thermal treatment worsens, value of K_{1c} reduces (Table 2). At the same time K_{1c} parameter reduces among the methods of APS-SAPS-VPS-

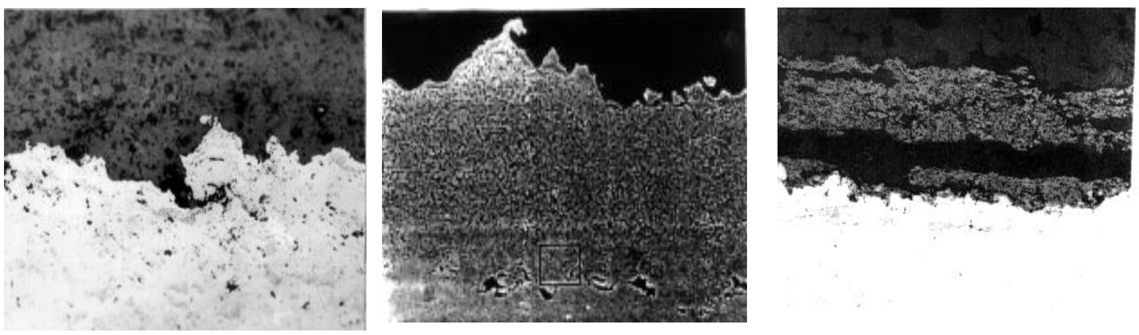
HVOF underlayer spraying. The last fact is connected with reduction of underlayer surface roughness during the change from one method to the other in the way as they were just mentioned.

Table 1. – Adhesion strength of NiCrAlY coatings

Substrate material	Underlayer deposition method	Thermal treatment in vacuum	$\delta_{сц}$, MPa
ЭИ107/ЭИ283	APS	-----	24/28
	APS	1100 °C, 2 hours	72/90
	SAPS	-----	36/42
	SAPS	1100 °C, 2 hours	81/103
	VPS	-----	76/104
	VPS	1100 °C, 2 hours	168/200
	HVOF	-----	61/87
	HVOF	1100 °C, 2 hours	129/156

4. Conclusion

The adhesion strength of the sublayer to the base depends on the method of applying the sublayer, spraying modes and subsequent heat treatment. Of the compared methods (APS, SAPS, VPS, HVOF), when sprayed onto a cold base, VPS coatings had the highest strength. Heat treatment of coatings at 1100K for 2 hours in a vacuum increases the adhesion strength of the sublayer to the base. Heat treatment changes the structure of the sublayers in the direction of improving the uniformity of phase distribution and increasing their thermal stability. In this case, the dimensions of the phase increase somewhat and diffusion of the base elements into the coating occurs. In APS and SAPS coatings, oxide films are largely dissolved in the metal matrix, but the layering of the structure is completely eliminated. It has been established that for all types of HRC sublayers, the quality of metal-ceramic bonding deteriorates as a result of heat treatment, and the K1c value decreases. Moreover, the K1c parameter decreases in a number of APS-SAPS-VPS-HVOF sublayer deposition methods. The latter fact is connected with a decrease in the surface roughness of the sublayer during the transition from method to method in the specified sequence.



a) b) c)

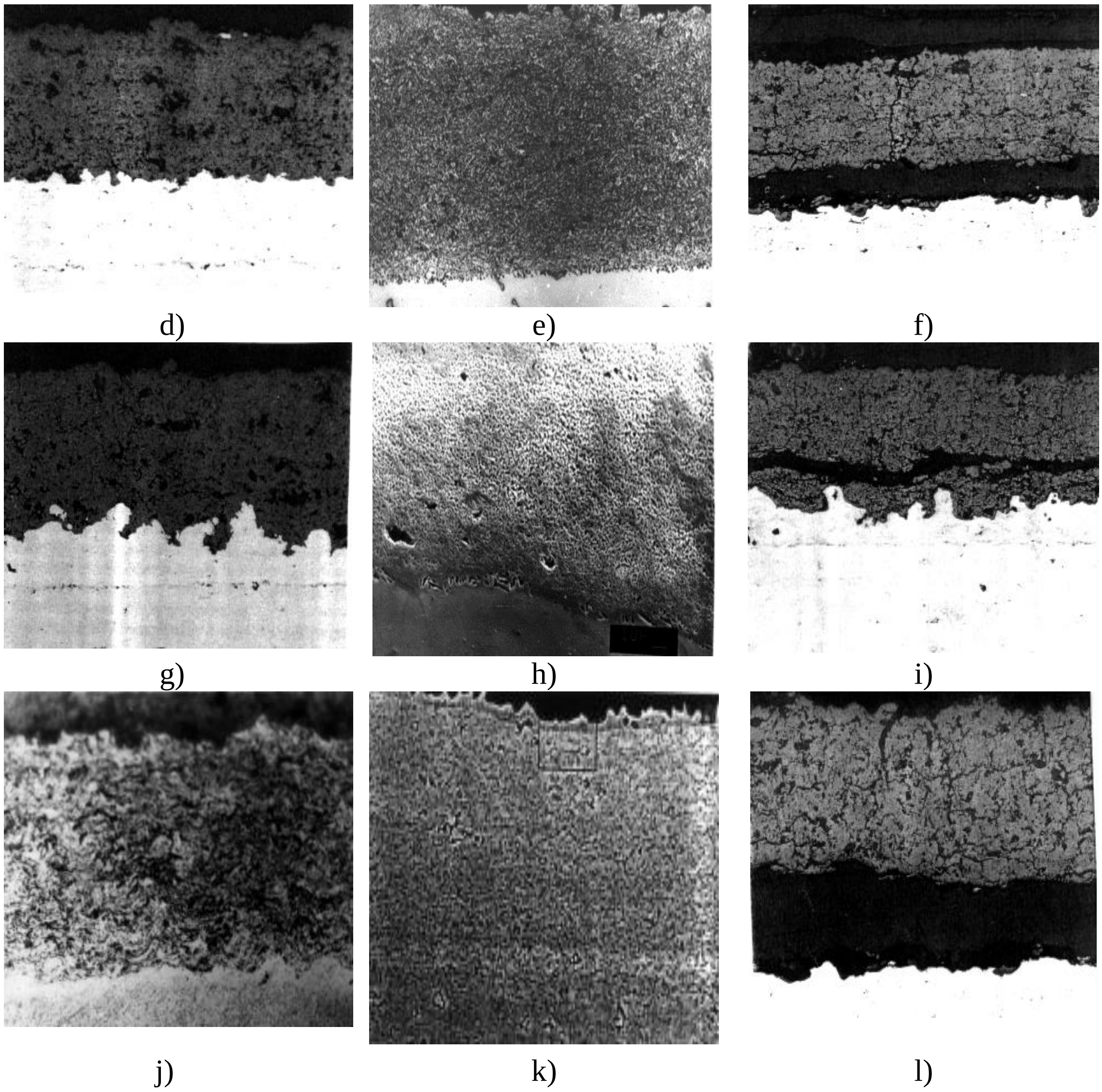


Figure 1. Microstructure of heat-shield coatings of the NiCrAlY-ZrO_2-7%Y_2O_3. 400. a), b), c) - APS; d), e), f) - SAPS; g), h), i) - VPS; j), k), l) - HVOF; a), d), g), j) - coating after deposition; b), e), h), k)- coatings after thermal treatment (1100 °C, 2 hours - vacuum); c), f), i), l) - coatings after thermal cycling (heating up to 1170 K, holding for 15 minutes, cooling down to room temperature with compressed air).

Table 2. – Results of changes of K_{1c} stresses intensity coefficient for HSC-system ZrO_2-7%Y_2O_3-NiCrAlY

Substrate material	Method of underlayer deposition	Thermal treatment in vacuum	K_{1c}, MPa $m^{1/2}$	Number of thermal cycles before the coating destruction
ЭИ107/ЭИ283	APS (Fig.1a)	--- 1100 °C, 2 hours (Fig.1b)	2.7/2.1 1.9/1.2	129/118 162/154 (Fig. 1c)
--	SAPS (Fig.1d)	--- 1100 °C,	2.2/1.8 1.7/1.0	151/142 193/181

		2 hours (Fig.1e)		(Fig.1f)
--	VPS (Fig.1g)	--- 1100 °C, 2 hours (Fig.1h)	1.5/0.8 1.2/0.6	236/220 201/190 (Fig.1i)
--	HVOF (Fig.1j)	--- 1100 °C, 2 hours (Fig.1k)	1.0/0.7 0.8/0.6	290/271 264/250 (Fig.1l)

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