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The results of water droplet erosion tests of ion-plasma coatings formed on titanium Ti-6Al-4V alloy samples manufactured by using 3D-printing and traditional technological process

To cite this article: Alexey F Mednikov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **537** 022066

The results of water droplet erosion tests of ion-plasma coatings formed on titanium Ti-6Al-4V alloy samples manufactured by using 3D-printing and traditional technological process

Alexey F Mednikov, Alexander B Tkhabisimov, Olga S Zilova, Andrey A Burmistrov and Sergey V Sidorov

National Research University «Moscow Power Engineering Institute», 14, Krasnokazarmennaya st., Moscow, 111250, Russian Federation

E-mail: MednikovAlF@mpei.ru

Abstract. The paper presents the results of erosion tests and metallographic studies of titanium alloy samples manufactured by using 3D printing and traditional technological methods without coatings and with various types of ion-plasma coatings. As a result of the tests, the kinetic curves of erosion wear of the studied alloys and coatings were obtained, showing that the best type among those considered is a DLC (Diamond Like Carbon) coating, which increases the relative erosion resistance of uncoated samples in incubation period duration of the water droplet erosion process by not less than in 1.8 times.

1. Introduction

Optimization of production technology through 3D printing allows the creation of integrated products in one cycle and increases the efficiency of managing their physico-mechanical properties. In addition, the using of additive technologies significantly improves the maintainability of the installation [1], which needs replacement of the worn part.

There are other factors associated not only with the operation, but also with the production of "printed" products. The cost of the equipment required for the additive production of titanium components is cheaper than production using subtractive methods. In addition, the production cycle itself is shortened. For example, Concept Laser indicates a reduction in elapsed time by 75% or more. Production of aircraft parts due to mechanical processing yields about 95% of waste by weight, while laser melting using Laser Cusing technology reduces the proportion of waste to 5%. Last but not least, any design errors can be noticed and corrected in the early stages of production, and the design adjustment does not require expensive reconfiguration of production lines - just change the digital model [1].

At the same time, there are certain limits of strength, limiting the endurance of "printed" parts in terms of mechanical fatigue. However, methods such as microwave processing, using protective multilayer coatings, etc., can improve their characteristics. If we talk about the details of a more or less standard version, then 3D printing, as a rule, cannot compete with casting economically when it comes to mass production. On the other hand, aircraft manufacturers, for example, can afford to create more expensive parts, provided that it is well reflected in the performance of the aircraft, including efficiency. In the course of prototyping and testing, 3D printing has no equal. So, when creating the Airbus A350 XWB, Concept Laser manufactured several thousand brackets in small batches for testing. In addition, 3D printing opens up the possibility of producing the necessary spare parts anywhere in the world on demand, which makes it unnecessary to manufacture and store large volumes of spare parts “just in case” [2].

An additional factor hindering the development of the power engineering industry is the lack of regulatory documents and standards that would regulate the use of parts obtained by additive technologies in the design of an aircraft engine or a power turbine installation. Making the transition to partial or full production of elements of equipment by using 3D printing technology, including subsequently strengthened and, as a result, possessing new properties [3] compared to traditional methods, is impossible without conducting regulated studies of the wear resistance of “printed” materials, including resistance to droplet impact when solving the problem of erosion wear of the blades of the last stages of powerful steam turbines.

2. Researches

Experimental studies of titanium alloy samples with different types of coatings were carried out with the use of research and development equipment of Unique Research Installation "Hydro-impact rig" Erosion-M" of National Research University “Moscow Power Engineering Institute” (NRU "MPEI") at the rate of 300 m/s of sample collision with drops of liquid with a diameter d_d = 800 microns. Sample testing time varied. To build the curve of erosion wear, at least ten different exposure times were selected. To carry out a comparative analysis of the erosion tests results, the mass loss dependences of the sample Δm, (g) on the exposure time on the stand t, (min) were constructed.

For samples with coatings formed on two different types of substrates (made by using 3D printing and the traditional technological method), measurements of thickness, microhardness and coating composition were carried out. The microhardness was measured on a DuraScan 20 hardness tester at various points on the surface with a load of 0.05 kgf (0.49 N). The elemental composition of the coatings was determined on a GD Profiler 2 optical emission spectrometer of the glow discharge, as well as using an X-Max 50 X-ray energy dispersive X-ray spectrometer mounted on a MIRA 3 LMU microscope.

Using a scanning electron microscope MIRA 3 LMU on transverse thin sections, the thickness of the coatings was determined. Images of thin sections were obtained in the mode of back-reflected electrons (BRE), giving a contrast atomic number.

3. Results and discussion

Two types of titanium Ti-6Al-4V alloy samples were made for research using 3D printing and traditional technological method.

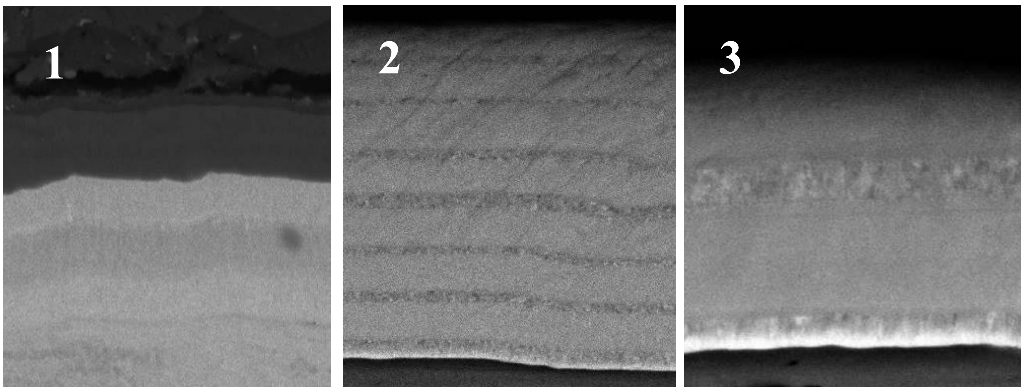
Ion-plasma DLC coatings (with an intermediate layer of TiC titanium carbide) and Cr-CrC of various thickness were formed on the manufactured samples by using the Gefest HiPIMS installation.

The thickness of the formed coatings with the upper layer of DLC is from 3.4 ÷ 3.6 to 10.3 ÷ 11.7 μm, samples of Cr-CrC coatings have a thickness of from 2.6 ÷ 3.1 to 6.7 ÷ 8.7 μm. Cr-CrC layers have a grain-column structure (figure 1).

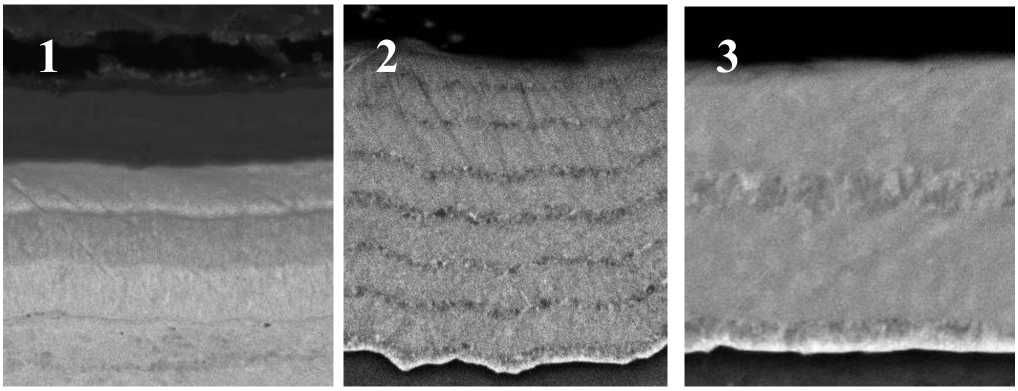
The DLC layer in the considered coatings contains on average from 67 to 73% carbon, from 16 to 23% oxygen, from 1 to 6% nitrogen, from 3.5 to 16% titanium. The sublayers formed in these coatings contain from 5 to 18% carbon in the titanium-based layers and about 2% in the chromium-based layers. In Cr-CrC coatings, the carbon content averages from 1.5 to 6%, from 1 to 6.5% of titanium is available (figure 1).

The microhardness of Ti-6Al-4V samples without coating is approximately the same, it is on average, 410 and 420 HV 0.05, respectively. For coatings with a top DLC layer, the microhardness is in the range of 780 ÷ 1060 HV0.05, for Cr-CrC coatings - 1090 ÷ 1620 HV 0.05. The results of measuring the thickness, microhardness and composition of the coatings are presented in table 1.

IOP Conf. Series: Materials Science and Engineering **537** (2019) 022066 doi:10.1088/1757-899X/537/2/022066



a)



b)

Figure 1. View of the cross section of DLC (1) and Cr-CrCcoatings (different thickness; 2, 3) on Ti-6Al-4V substrates (a - 3D printing; b - traditional technological method).

Table 1. Measurement results of microhardness, thickness and composition of coatings.

N	Sample description	Coating composition	Coating thickness δ, µm	Microhardness HV 0,05
1	*Ti*-6*Al*-4*V* (3D) without coating	-	-	370±40
2	*Ti*-6*Al*-4*V* (3D) with *DLC* coating	*DLC* layer (upper): 73 wt. % C, 17 wt. % O, 6 wt. % N, 4 wt. % Ti. TiC layer: 87 wt. % Ti, 10 wt. % C, 3 wt. % N.	3,5±0,2	780±90
3	*Ti*-6*Al*-4*V* (3D) with *Cr*-*CrC*-*1* coating	96 wt. % Cr, 1.5 wt. % C, 2.5 wt. % Ti	6,7±0,3	1090±60
4	*Ti*-6*Al*-4*V* (3D) with *Cr*-*CrC*-*2* coating	87 wt. % *Cr*, 6 wt. % *C*, 6,5 wt. % *Ti*, 0,5 wt. % *O*	2,6±0,2	750±80
5	*Ti*-6*Al*-4*V* without coating	-	-	420±50
6	*Ti*-6*Al*-4*V* with *DLC* coating	*DLC* layer (upper): 72 wt. % *C*, 19 wt. % *O*, 5,5 wt. % *N*, 3,5 wt. % *Ti*. *TiC* layer: 87 wt. % *Ti*, 10 wt. % *C*, 3 wt. % *N*.	3,6±0,2	920±70

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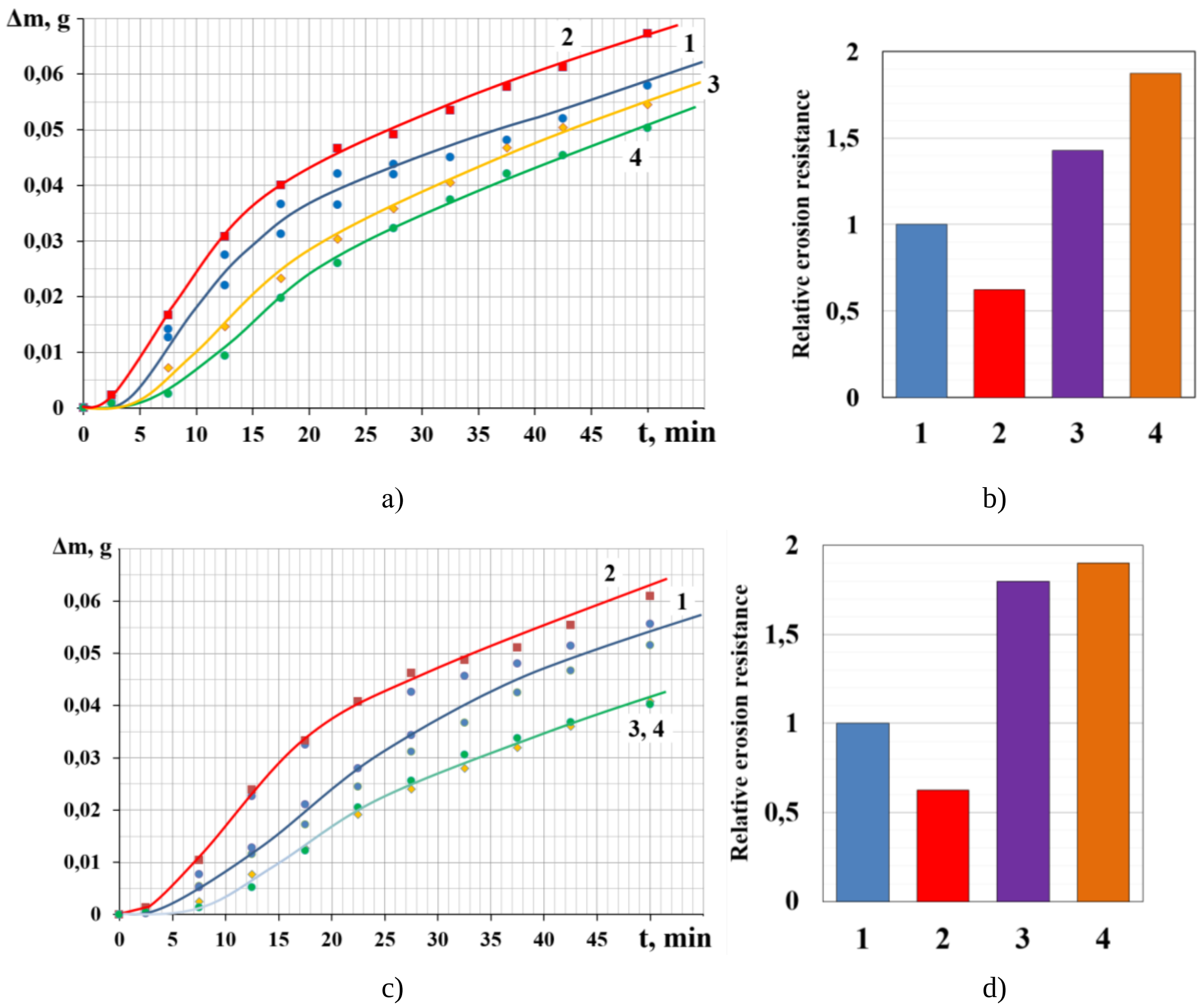
N	Sample description	Coating composition	Coating thickness δ, μm	Microhardness HV 0,05
7	*Ti*-6*Al*-4*V* with *Cr-CrC-1* coating	97 wt. % *Cr*, 1,8 wt. % *C*, 1,2 wt. % *Ti*	6,8±0,3	1340±70
8	*Ti*-6*Al*-4*V* with *Cr-CrC-2* coating	90 wt. % *Cr*, 4,5 wt. % *C*, 5 wt. % *Ti*, 0,5 wt. % *O*	3,1±0,2	930±60

The results of experimental studies of the water droplet erosion resistance of titanium samples obtained by the method of 3D printing and the traditional technological method, with various types of protective coatings (figure 2), made it possible to identify the coating most resistant to pulsed exposure to liquid particles. The best for both types of samples according to the results of the tests carried out is a coating based on DLC, which showed an increase in resistance to water droplet impact in the duration of the incubation period of at least in 1.8 times.



1 – titanium (without coating); 2, 3 –titanium+Cr-CrC (various thickness); 4 – titanuim+DLC

Figure 2. The results of erosion testing of titanium Ti-6Al-4V samples obtained by 3D printing (a, b) and traditional technological method (c, d) without and with protective coatings (a, c - wear curves; b, d - histograms of relative erosion resistance).

4. Conclusions

On samples of titanium alloy Ti-6Al-4V, manufactured by using 3D printing and traditional technological methods, several types of protective nanocomposite coatings were formed.

It has been established that at a collision speed of 300 m/s and a droplet diameter of 800 μm, the DLC coating formed on samples of titanium alloy made using 3D printing, increases water droplet erosion resistance of samples without coating by at least in 1.6 times at the stage of the incubation period.

It has been established that at a collision speed of 300 m/s and a droplet diameter of 800 μm the Cr-CrC-1 coating (about 7 μm thickness) and DLC coating, formed on samples of titanium alloy made by the traditional technological method, showed similar results - increase of water droplet erosion resistance at the stage of the incubation period by not less than 1.8 times.

Acknowledgements

The study results have been achieved thanks to financial support of the Russian Science Foundation pursuant to the Agreement No. 17-79-10462 of 01.08.2017.

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