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Influence of Spaying Parameters on the Property of Detonation Coatings Based on Ta

This paper investigates the influence of sputtering parameters on the properties of tantalum-based detonation coatings. One of the key parameters in sputtering is the volume of barrel filling, which affects the properties of the resulting coatings. Tantalum coatings were produced at various levels of barrel filling with explosive gas, specifically at 50–70% fill levels. The results demonstrated that the roughness of the coatings decreases as the barrel fill volume increases, leading to coatings with a more homogeneous structure. Additionally, the tests revealed that coatings produced at 60% fill exhibited superior corrosion resistance compared to the other samples. Based on these findings, the optimal barrel fill level for explosive gas was determined.

Keywords: detonation spraying, hardness, tantalum, corrosion, structure, coating, tribology

Introduction

Modern industries such as power generation, aviation, aerospace and medical technology are faced with the need to protect equipment from severe wear and corrosion. Various methods of spraying protective coatings are used to increase the durability of equipment and prevent its premature destruction [1–4].

Tantalum-based coatings have unique properties that allow them to withstand very high temperatures without losing their mechanical properties [5]. This makes it particularly valuable in industries such as aerospace, energy and chemicals, where materials are often subjected to extreme temperature conditions. For example, in the aerospace industry, tantalum is used in the production of parts for rockets and airplanes, where high strength and resistance to heat are required [6–8]. In addition, tantalum is characterized by high corrosion resistance, which allows it to retain its properties even in aggressive chemical environments. Tantalum-based coatings also demonstrate exceptional resistance to thermal cycling, which allows them to retain their characteristics even under abrupt temperature changes. Various sputtering methods are used to produce tantalum (Ta) coatings. The most efficient and advanced method is powder detonation sputtering, which has a number of important advantages over other sputtering technologies such as plasma or arc sputtering [9–11]. The main advantage of the detonation method is the very low porosity of the coating, which ensures high corrosion resistance even in the most aggressive environments. In addition, due to the high speed and energy of the process, detonation spraying produces coatings with high adhesion to the base material, which allows them to retain their properties even under intense mechanical and thermal stresses [12]. Unlike plasma spraying, which is often characterized by high porosity and requires sophisticated equipment for process control, detonation spraying produces coatings with a dense structure and fewer internal defects. This makes it the preferred choice for protecting highly loaded parts such as turbine blades and power heat exchangers. Also in aviation and aerospace, this method can protect critical structural components from the damaging effects of extreme temperatures and pressures, making it indispensable for these industries [13].

The parameters of detonation sputtering (DS) significantly affect the properties of the resulting tantalum coating [14]. One of the important parameters of sputtering is the filling of the barrel with gas mixture. In this connection, the aim of this work is to study tantalum coatings obtained at different degrees of barrel filling.

Materials, equipment and methods of experiments

Heat-resistant low-alloy steel 12Kh1MF (equivalent to 14MoB63) was chosen as the substrate. The specimens were ground to obtain an even and smooth surface. After grinding, the specimens were sandblasted. Ta spherical shaped powder with size 15–45 µm was used for sputtering (Fig. 1). Detonation atomization was carried out using a CCDS2000 unit. The modes were alternated depending on the barrel filling volume (Table). The barrel is filled with gases through a high-precision gas distribution system controlled by a computer. The process begins by filling the barrel with carrier gas.

Table

Spray mode of detonation spraying

Sample	Fuel / oxide ratio littler	Stem fill volume, %	Spray distance, mm	Number of shots
1	1.026	50	150	15
2	1.026	60	150	15
3	1.026	70	150	15

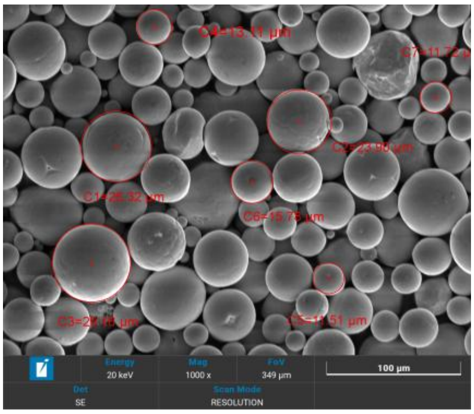

Figure 1. Image of Ta powder

A Tescan Vega 4 scanning electron microscope was used to analyze the powder morphology and coating structure.

Microhardness measurement was carried out on a METALAB 502 device in accordance with GOST 9450-76. Also tribological tests were carried out on tribometer TRB3 on the basis of standard method (international standards ASTM G99), based on the scheme “ball disk” (Fig. 2). Sample rotation speed — 3 cm/s, load 10 N, a steel ball 100Cr6 with a diameter of 6 mm was used as a counterweight.

Corrosion resistance was studied on a CS300-galvanostat potentiostat. It was tested at room temperature (25 °C) in a 3.5 % NaCl solution over an area of 1 cm^2. A three-electrode cell system was used in the experiment, in which a silver chloride electrode served as a comparison electrode and a platinum electrode served as an auxiliary electrode. Before each polarization experiment, the sample was exposed to the electrolyte by immersion in water for 60 min until a stable open circuit potential (PRC) state was found. The corrosion potential and current density were obtained from the polarization curves by Tafel extrapolation for the four samples.The potential was scanned from −0.1 to 0.1 in relative to OCP, and the scan rate was 0.5 mV/s. The tests were repeated three times for each sample, and the results were analyzed using CS Studio 6.

Results and discussion

Figure 2 shows the results of the coating surface roughness measurement. The measurement results showed that all coatings are characterized by moderate roughness. At 50 % of barrel filling the coating has the highest roughness (Ra = 4.26 μm) this is probably due to the fact that the reduction of particle energy leads to the formation of protrusions and defects on the coating. When the barrel is filled to 60 % the roughness decreases compared to 50 %, indicating a more uniform distribution of material. The lowest value of roughness among all samples has a coating obtained at 70 % filling of the barrel, because the decrease in particle energy leads to complete melting of particles, which reduces the roughness.

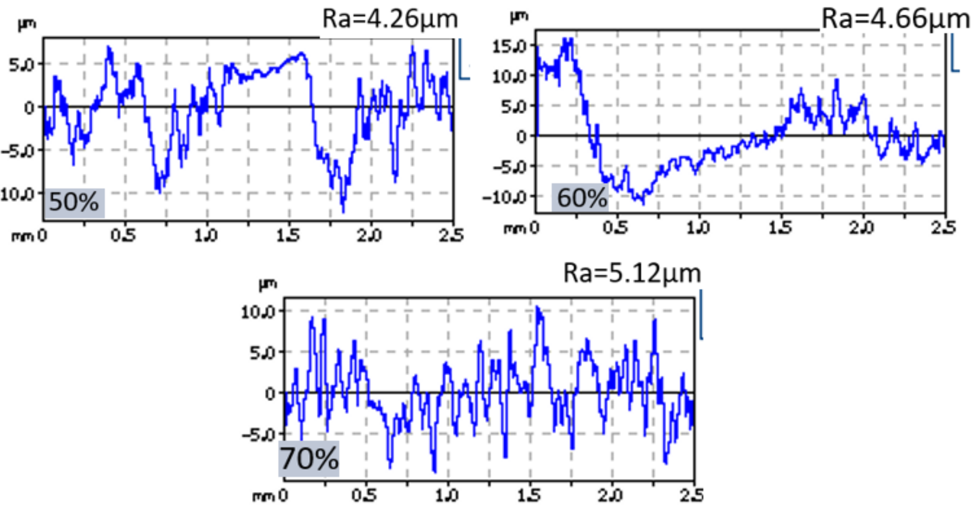

Figure 2. Results of roughness measurement

The corrosion resistance of tantalum-based coatings obtained with different barrel fillings was evaluated by testing with an open area of 1 cm^2 at room temperature (25 °C) in 3.5 wt% NaCl solution. The potentiodynamic polarization curves of the three types of coatings applied by detonation sputtering are shown in Figure 3. To obtain the electrochemical parameters, the Tafel area of both cathodic and anodic branches was extrapolated, and the point of intersection of these two lines was used to determine the corrosion current density (I_{corr}) and corrosion potential (E_{corr}).

The presented Tafel diagram (Fig. 2) shows the polarization dependences for coatings obtained at different degrees of filling of the detonation sputtering barrel: 50 %, 60 % and 70 %. In the region of positive potential displacements (relative to the corrosion potential) there is an increase in the current density, which is associated with the anodic dissolution of the coating material. The slope of the anodic branch varies with the degree of filling, indicating different rates of anodic processes. The corrosion potential shifts to a more negative side with increasing trunk filling degree: For 60 %: a more noble potential (E_{corr}) indicates better corrosion resistance.

For 50 % and 70 %: the potentials shift towards active values, indicating a decrease in the corrosion resistance of the coating.

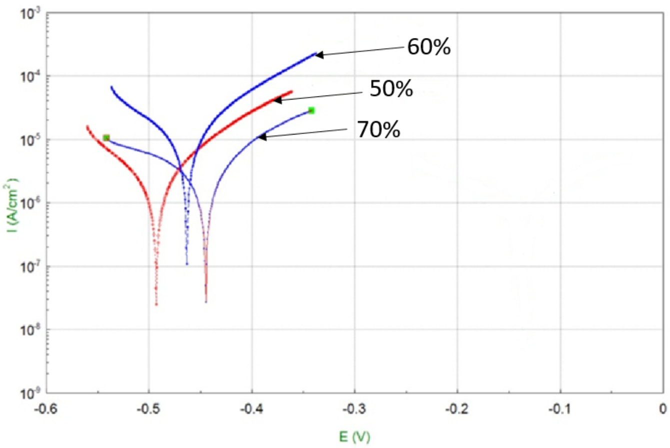

Figure 3. Corrosion test results

Figure 4 shows the cross-sectional morphology of the coatings obtained with varying barrel fill. The results of the study show that all coatings have a characteristic structure for detonation coatings. All coatings are tightly adhered to the substrate without any cracks and failures and no signs of delamination were observed. When filling the barrel, the coating has visible inhomogeneity, which may be due to insufficient particle energy during sputtering. And when the barrel is filled, the coating shows a more even surface and significantly lower porosity compared to 50 % and 70 %.When the barrel is filled to 70 %, the top layer again becomes less even, cracks and defects are observed, probably related to excessive particle energy.

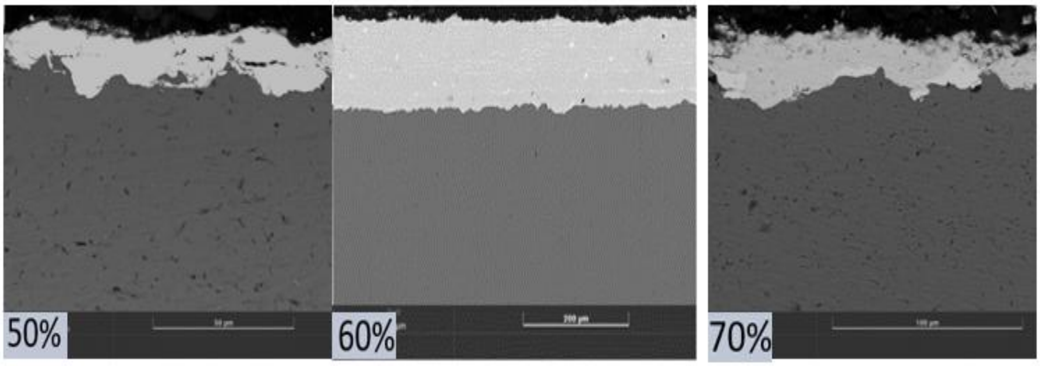

Figure 4. SEM images of cross-sectional morphology of tantalum coatings obtained with varying barrel fill

Figure 5 shows the dependence of coating hardness on the degree of barrel filling. Coatings obtained at 70 % of filling have low hardness compared to the rest of the samples. This is probably due to the formation of cracks or internal stresses due to excessive particle energy, which worsens the mechanical properties. At 60 % barrel filling the coating gives the best result in terms of coating hardness, which confirms the most favorable conditions for the formation of dense and defects of minimal structure.

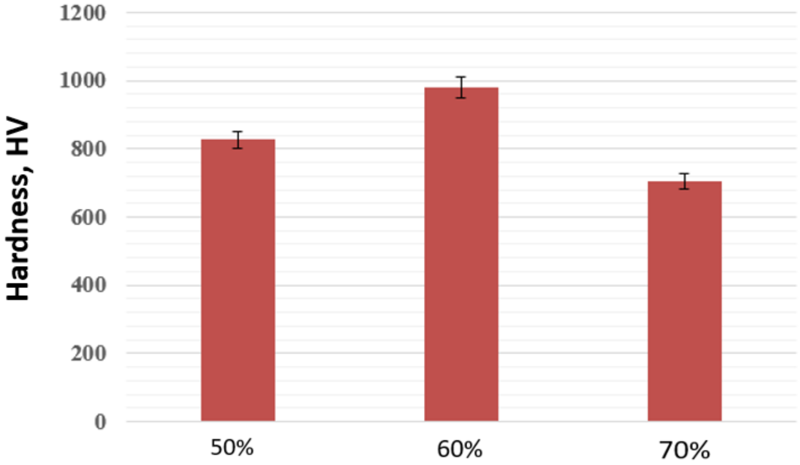

Figure 5. Graph of coating hardness distribution

The tribological study was carried out using the ball-disk method. Figure 6 shows a graph showing the results of the study of the wear volume and wear coefficient of the coating obtained at different fillings of the barrel. The results of the study showed that at 50 % fill rate the wear volume and wear coefficient are relatively low. This may be due to insufficient particle energy during sputtering, which leads to the formation of defects in which reduces the wear resistance of coatings. With the increase in filling percentage, we observe an increase in wear volume and wear coefficient, which may be due to the improvement in coating properties such as adhesion and coating density. Perhaps the coating at 60 % fill rate becomes denser and more resistant to stress, which improves its wear resistance. At 70 % fill rate, the highest volume and wear coefficient is observed which is probably due to excess particle energy.

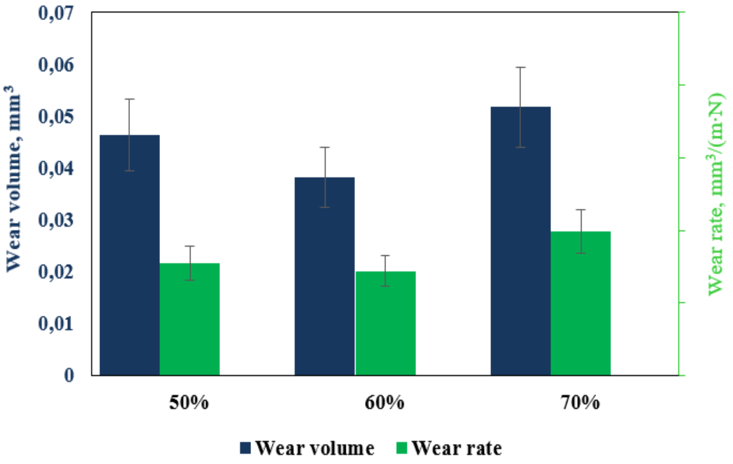

Figure 6. Graph of wear volume dependence on the degree of barrel filling

Conclusion

According to the evaluation and analysis of all the results obtained, the following main conclusions can be drawn on the present research work:

It was found that an increase in the volume of barrel filling leads to a decrease in the surface roughness value.

It has been established that at various degrees of barrel filling at detonation spraying coatings provide an increase in strength properties and hardness of the matrix without significant degradation of the surface.

The highest wear volume and wear rate are observed at a 70% fill rate, which may be attributed to the increased density of the coating, making it less elastic and more susceptible to microcracks and mechanical damage.

The results of coating hardness tests showed at optimum spraying mode the hardness increases from 742 HV to 986 HV

It has been established that detonation coating technologies provide, under optimal modes, the formation of wear-resistant and corrosion-resistant tantalum-based coatings.

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Тозаңдандыру параметрлерінің Та негізіндегі детонациялық жабындардың қасиеттеріне әсері

Мақалада тозаңдандыру параметрлерінің тантал негізіндегі детонациялық жабындардың қасиеттеріне әсері қарастырылған. Алынған бүріккіш жабындардың қасиеттеріне әсер ететін маңызды параметрлердің бірі — оқпанды жарылғыш газбен толтыру көлемі. Тантал жабындары оқпанды толтырудың әртүрлі деңгейлерінде алынды (50-70 %). Нәтижелер оқпанды толтыру көлемі ұлғайған сайын жабындардың кедір-бұдырлығы төмендейтінін және құрылымы біркелкі болатынын көрсетті. Сынақ нәтижелері 60% толтыру кезінде жабынның басқа үлгілермен салыстырғанда коррозияға төзімділігі жоғары екенін айқындады. Зерттеу нәтижелері бойынша оқпанды жарылғыш газбен толтырудың оңтайлы режимі анықталды.

Кілт сөздер: қатайту, детонациялық бүрку, каттылық, тантал, коррозия, құрылым, жабын, трибология

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Влияние параметров напыления на свойства детонационных покрытий на основе Та

В статье рассмотрено влияние параметров напыления на свойства детонационных покрытий на основе тантала. Одним из важных параметров, влияющим на свойства получаемых покрытий напыления, является объём заполнения ствола взрывчатым газом. Были получены покрытия из тантала при разных степенях заполнения ствола (50–70 %). Результаты показали, что при увеличении объёма заполнения ствола шероховатость покрытий уменьшается, а структура становится более однородной. Результаты исследований показали, что при 60 % заполнения покрытие имеет высокую коррозионную стойкость по сравнению с другими образцами. По результатам исследования был определён оптимальный режим заполнения ствола взрывчатым газом.

Ключевые слова: упрочнение, детонационное напыление, твердость, тантал, коррозия, структура, покрытие, трибология

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