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MODELING OF THE SUBSTRATE COOLING SYSTEM IN THE INSTALLATION FOR THE DEPOSITION OF COATINGS BY THE GAS PLASMA METHOD

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The efficiency of diamond coating synthesis depends on both the parameters of the plasma flow and the uniform temperature distribution on the surface of the substrate on which the coating is synthesized. Mathematical modeling of the substrate cooling system in the installation for the deposition of coatings by the gas plasma method was carried out in order to find optimal parameters at which high density and radial uniformity of energy and chemically active particle flows are simultaneously achieved on the substrate in the process of synthesis of diamond coatings. The task was solved by direct search methods using the FlowSimulation module of the SolidWorks package.

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INTRODUCTION

Plasma coating refers to advanced technologies that allow to increase the reliability and durability of machine parts and tools with high efficiency. The main purpose of these technologies is to ensure high wear and corrosion resistance of the surfaces of parts, restoration of the dimensions of worn surfaces of parts due to the application of coatings on them

The advantages of plasma coating include the possibility of the widest variety of materials, the minimum possible heating of the substrate, a small zone of thermal influence, the possibility of coating in all positions.

This technology allows you to apply multi-component coatings made of various materials and diamond-like structures, designed to protect the working surfaces of parts, tools and equipment from wear, erosion, the influence of the external environment, increase heat resistance, etc.

One of the most promising are diamond coatings, which are characterized by strength, hardness, high modulus of elasticity, low coefficient of linear thermal expansion, high thermal conductivity, good tribological properties, as well as erosion, thermal and chemical resistance. These properties allow them to be used in various industries, in particular, to increase the reliability and durability of machine parts and tools.

The efficiency of the synthesis of the diamond coating is determined by the parameters of the plasma flow and the thermal regime of the substrate where the coating is deposited (Fig. 1).

The optimal conditions are the temperature of the surface of the substrate in the range of 800…900°C, while the uniformity of the thickness of the coating depends on the uniformity of the temperature distribution over the surface of the substrate. With a given thermal power of the plasma flow, the optimal thermal regime of the substrate can be ensured by selecting the parameters of the cooling system.

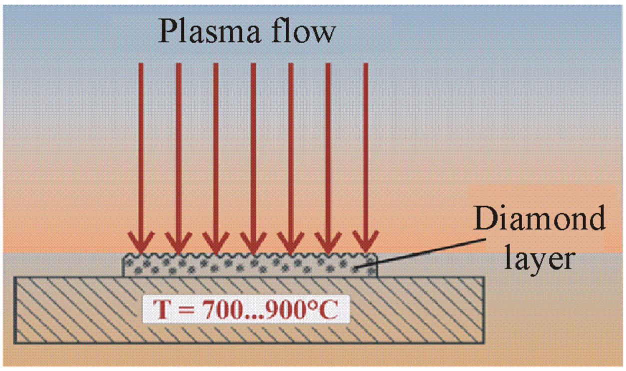

Fig. 1. Scheme of the deposition process of diamond coatings

The aim of the work: search for optimal parameters of the cooling system of the substrate of the gas plasma deposition of diamond coatings, which ensure a uniform temperature distribution of the surface of the substrate in a given range and the efficiency of the synthesis of the diamond coating.

1. OPTIMIZATION OF THE COOLING SYSTEM OF THE SUBSTRATE

The geometric model of the cooling system for being optimized is shown at Fig. 2 [1, 6].

The substrate, a molybdenum disk with a diameter of 40 mm, is attached to the end of the cooling collector in the form of a hollow cylinder with a diameter of 40 mm. The water cooling cavity has the shape of a cylinder with a diameter of 20 mm, ending with a spherical top. The coolant (water) is fed into the cavity through a tube measuring 6×0.5 mm; made of stainless steel. The ambient temperature is 20°C, the integral thermal power of the plasma flow is 5000 W.

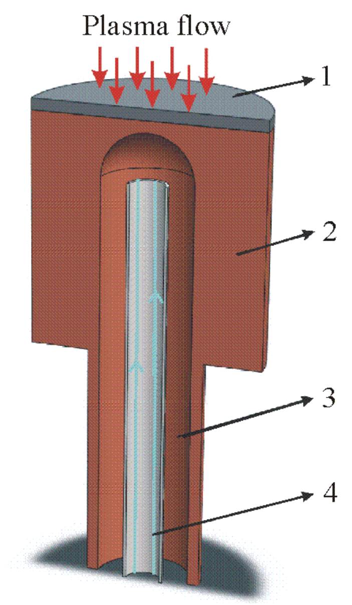

Fig. 2. Geometrical model of the substrate cooling unit: 1 – molybdenum substrate (disk with a diameter of 40 mm); 2 – cooling collector; 3 – coolant supply tube (stainless steel 6×0.5 mm); 4 – coolant (water)

The optimization task was solved as a mathematical programming task – finding the extremum of the objective function by varying the controlled parameters within the permissible range

$$\underset{x \in D_x}{extr} F(X),\ D_x = \{X / _{\varphi(x)>0,\ \psi(x)=0}\},$$

where $F(X)$ – goal function (temperature distribution over the surface of the molybdenum substrate along the radius); X is a vector of controlled parameters (the thickness of the molybdenum substrate is 1 and 0.1 mm; the material of the cooling collector is copper, zinc, steel; the water flow rate in the cooling collector is 1, 0.5, 0.08, 0.012 l/s; gap (from the top of the sphere of the water cooling cavity to the substrate) – 2 mm, 0.2 mm; $\varphi(x)$; $\psi(x)$ – restriction functions (temperature range ~ 800…900°C); D_x – admissible area in the space of controlled parameters; the heat flux density distribution over the surface of the substrate is uniform or Gaussian.

The task was solved by direct search methods using the FlowSimulation module of the SolidWorks license package.

2. MODELING RESULTS

When studying the influence of the collector material on the goal function, calculations were made for stainless steel and copper. In Figs. 3 and 4 it is shown the temperature distribution over the surface of the substrate for the case of a stainless steel cooling collector and two options for the distribution of the thermal power density of the plasma flow: uniform or Gaussian.

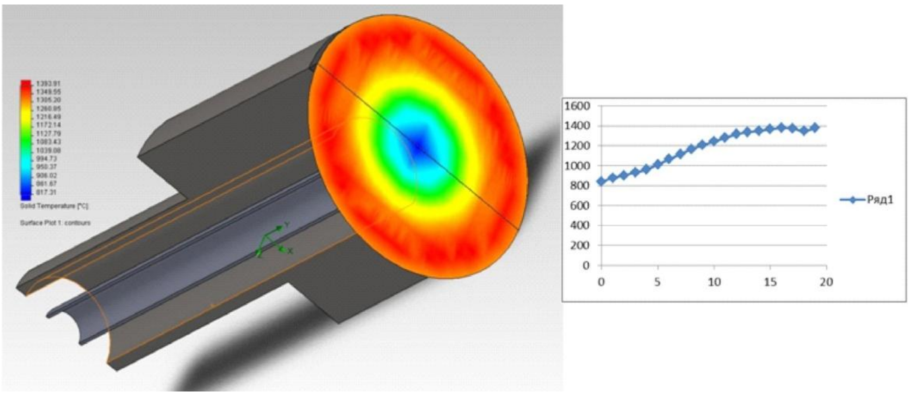

Fig. 3. The material of the collector is steel. Heat distribution is uniform. Water consumption – 1 l/s

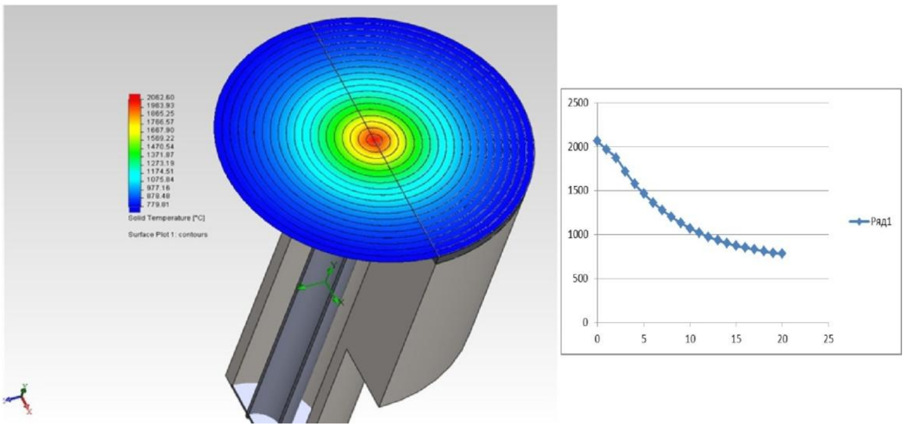

Fig. 4. The material of the collector is steel. Gaussian distribution of heat. Water consumption – 1 l/s. The gap is 0.2 mm

In both variants, the temperature distribution over the substrate is nonuniform, and for a Gaussian flow $\Delta T/T=1.1$, and the maximum temperature falls on the center of the substrate, and for a uniform flow $\Delta T/T=0.5$, and the temperature reaches its highest value at the periphery. The same regularity is observed in the case of a copper collector: the temperature distribution is more uniform for a uniform plasma flow.

The effect of the flow rate of the cooling liquid on the target function can be seen in Figs. 5 and 6, it can be seen that reducing the flow rate from 0.5 l/s to 0.08 l/s slightly improves the uniformity of the temperature distribution over the surface of the substrate, but at the same time, the maximum temperature value deviates more from the optimal range.

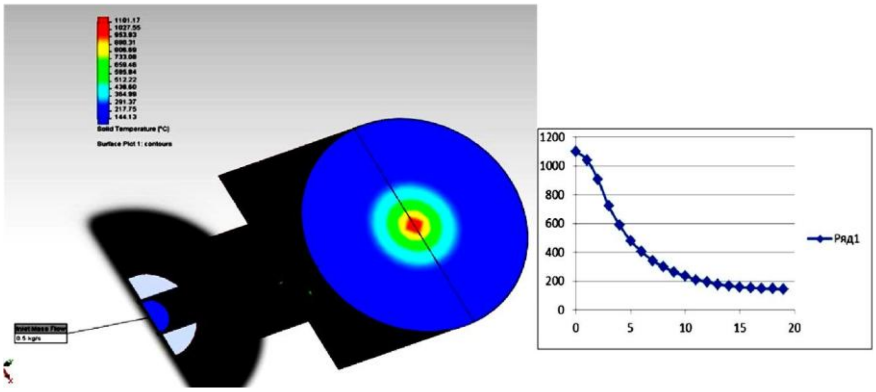

Fig. 5. Collector material copper Gaussian heat distribution. Water consumption – 0.5 l/s. ΔT/T=1.5

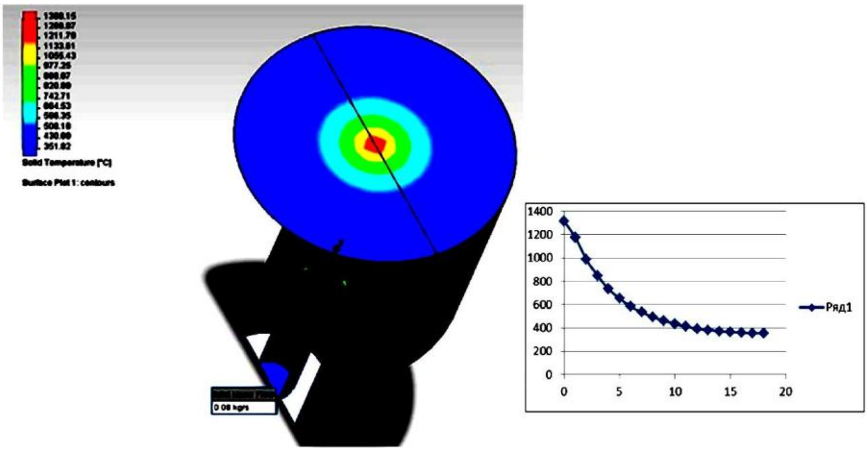

Fig. 6. The material of the collector is copper. Gaussian distribution of heat. Water consumption – 0.08 l/s. ΔT/T=1.1

Removing the water-cooling cavity from the substrate (increasing the gap) makes it possible to reduce the unevenness of the temperature distribution by reducing its maximum, but both the maximum and minimum values remain far outside the optimal range (compare Figs. 5 and 7).

The analysis of the results shows that the distribution of the thermal power density of the plasma flow has the greatest influence on the objective function. With a uniform flow, it is possible to achieve that the temperature of all points of the surface of the substrate falls into the optimal range, while there remains some inhomogeneity of the temperature distribution along the radius ($\Delta T/T=0.06$), which is much smaller than in all the options considered (Fig. 8).

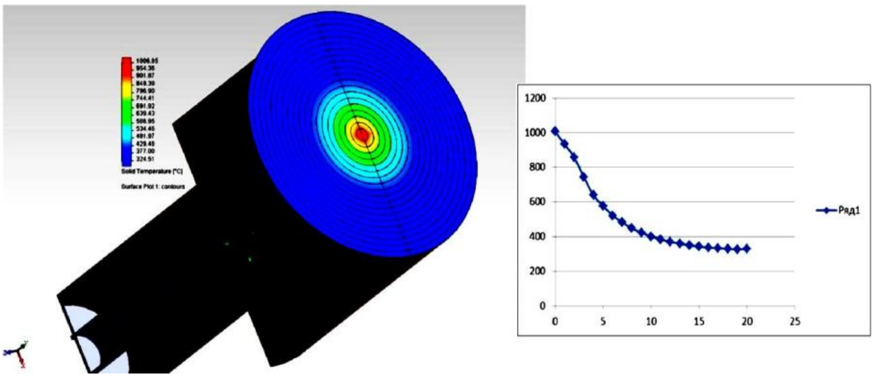

Fig. 7. The material of the collector is copper, the gap is 2 mm. Gaussian distribution of heat. The thickness of molybdenum is 0.1 mm. Water consumption – 0.5 l/s. ΔT/T=1.1

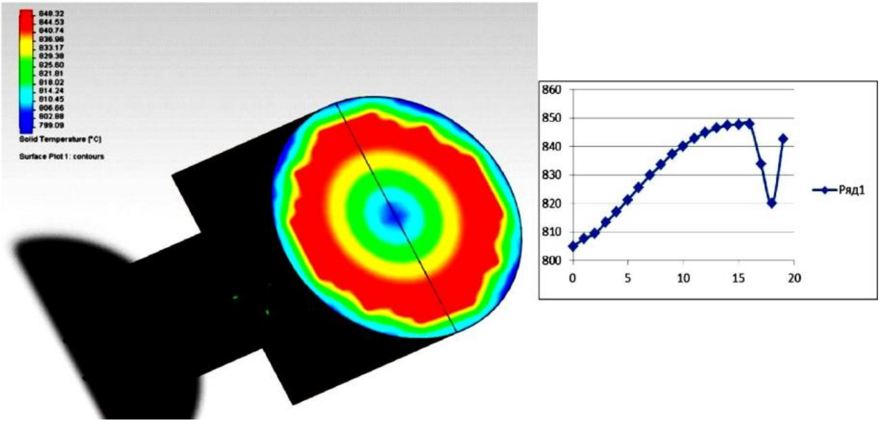

Fig. 8. The collector material is copper. The heat flux power density is uniform.
Water consumption – 0.012 l/s. ΔT/T=0.06

As follows from the above, in order to achieve the best uniformity of temperature distribution over the surface of the substrate, the cooling system in the considered geometric model must satisfy the following parameters:

– the collector material is copper;

– a gap of 2 mm;

– the thickness of the molybdenum substrate is 0.1 mm;

– water consumption 0.012 l/s.

With a uniform distribution of the power density of the plasma flow, the surface temperature is 805…850°C.

A further reduction of the inhomogeneity of the temperature distribution on the surface of the molybdenum substrate in the considered geometric model of the cooling system can be achieved by providing additional heating of the outer part of the cooling collector to a temperature of ~ 800°C, or in the case of using a collector made of a composite material with variable thermal conductivity along the radius.

3. CONCLUSIONS

Computer modeling of the substrate cooling system in the installation for the deposition of diamond coating by the gas plasma method was carried out. The plasma stream falls on a substrate located at the end of a metal cylinder, in the cavity of which a cooling liquid (water) flows.

Modeling showed that in the case of a uniform distribution of the power density of the plasma flow, it is possible to ensure the uniformity of the temperature distribution over the surface of the substrate in the range of 805…850°C.

Varying the parameters of the cooling system showed that the best temperature uniformity is achieved with a water consumption of 0.012 l/s; copper water cooling collector; the thickness of the molybdenum substrate is 0.1 mm.

At the same time, the inhomogeneity of the temperature distribution by radius is ΔT/T=0.06.

The obtained results are of practical importance for the creation of highly efficient technologies for the synthesis of diamond coatings.

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МОДЕЛЮВАННЯ СИСТЕМИ ОХОЛОДЖЕННЯ ПІДЛОЖКИ В УСТАНОВЦІ ДЛЯ ОСАДЖЕННЯ ПОКРИТТІВ ГАЗОПЛАЗМОВИМ МЕТОДОМ

С.О. Мартинов, О.А. Лучанінов, В.П. Лук'янова, С.І. Прохорець, О.О. Слабоспицька, М.А. Хажмурадов

Ефективність синтезу алмазного покриття залежить від параметрів плазмового потоку й однорідного розподілу температури на поверхні підложки, на якій здійснюється синтез покриття. Проведено математичне моделювання системи охолодження підложки в установці для осадження покриттів газоплазмовим методом с ціллю знаходження оптимальних параметрів, при яких як висока щільність, так і радіальна однорідність енергії і хімічно активних потоків частинок одночасно досягаються на підложки в процесі синтезу алмазних покриттів. Завдання вирішувалося методами прямого пошуку із використанням модуля FlowSimulation пакета SolidWorks.