FRI-CR-1-CT(R)-01

STUDY OF THE FORMATION OF CERAMIC-METAL COATINGS FOR SPECIAL ALLOYS

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Abstract: *The main advantages of ceramic-metal thermal insulation coatings are resistant to virtually all aggressive environments, high strength, wear resistance, hardness, low density, and stability of mechanical properties over a wide temperature range. The paper reviews the process of forming ceramic-metal coatings on a chromium-nickel alloy. The analysis of the effect of the composition of the ceramic-metal coating on crack formation and surface quality of the coating is carried out. The basic properties of the developed ceramic-metal coatings are given.*

Keywords: *Ceramic-metal coatings, Chromium-nickel alloy, Protection, Burning*

INTRODUCTION

The relevance of the invention and use of high-temperature materials and coatings resistant to high and ultra-high temperatures in an oxidizing gas environment is due to the extreme conditions of the movement of reusable aerospace aircraft in dense atmospheric layers (Solntsev S., 2014).

The main advantages of ceramic thermal insulation coatings are resistance to the effects of almost all aggressive environments, high strength, wear resistance, hardness, low density, and stability of mechanical properties over a wide temperature range.

The necessary conditions for the effective protection of special alloys are (Solntsev S., 2014).:

- the formation of a continuous protective coating layer at a relatively low temperature in order to prevent intense oxidation of the alloy during the initial stages of heating;
- dissolution of oxide films formed on the metal when heated, with the maintenance of protective properties of the coating;
- sufficiently high viscosity and density of the protective layer in order to reduce the diffusion of gases from the furnace atmosphere;
- strong coating-to-alloy adhesion due to the formation of transitional diffusion layers, which provides high reliability of operation of the products under sharp temperature variation;
- general refractoriness of the entire coating system in order to ensure long-term operation of components and parts of gas turbine engines at high temperatures.

Thus, the development of protective coatings should be based on the following basic provisions (Solntsev S., 2014).:

- a protective advanced coating is a complex (in chemical and phase composition) composition, which is formed by heating metal billets and parts;
- the alloy surface is not only an object of protection but also a factor affecting the formation, composition, and protective effect of coatings, changing in accordance with the laws of multiphase heterogeneous surfaces;
- the protective effect of coatings is determined by a combination of extreme processes that depend on the composition of the protective layer, the characteristics of the influence of furnace gases on the coating and the surface to be protected, interactions on the interfaces of the contacting phases, the conditions of the thermomechanical treatment of the coating-alloy system, and factors typical of metal processing technology.

EXPOSITION

To obtain a coating, a mixture of finely ground metal powders (nickel, chromium, aluminum, etc.), oxides (Al_2O_3, Cr_2O_3, etc.), glass, refractory compounds such as borides (TiB_2, ZrB_2, etc.), silicides ($MoSi_2$, $ZrSi_2$, B_4Si, etc.) were sintered for 1 hour at a temperature of 860°C in an oxidizing medium directly on the surface of the protected product (Shvagireva V., Soloviova G., 2003).

The metal samples before applying the slip were prepared by sandblasting using corundum, after which they were degreased with isopropyl alcohol. Compositions were applied on a metal substrate by sprinkling.

The following characteristics affect slip quality:

- grinding fineness;
- moisture content;
- amount of suspending additives.

The grinding fineness for obtaining a high-quality ceramic-metal coating should ensure the passage of the slip through a sieve No. 0056-0063.

The experimentally established grinding time of the experimental slip in laboratory settings is 16-18 hours for 100 g (based on the dry mix).

As a result of grinding, a slip was obtained with the granulometric composition presented in Table and in Figure 1.

Table 1 – Fractional composition of the experimental slip

No.	Fraction, μm		Fraction content, %
1	[0+2]		10.39
2	[–2+10]		33,89
3	[–10+20]		24,04
4	[–20+30]		17,91
5	[–30+40]		9,66
6	[–40+50]		3,34
7	[–50+60]		0,72
8	[–60+70]		0,05

[–2+10] - passage through a 2 μm sieve, sieve residue - 10 μm

As the differential particle distribution curve shows, the selected grinding mode is optimal. The main fraction consists of particles of 2-30 μm, the weighted average particle diameter is 23-25 μm.

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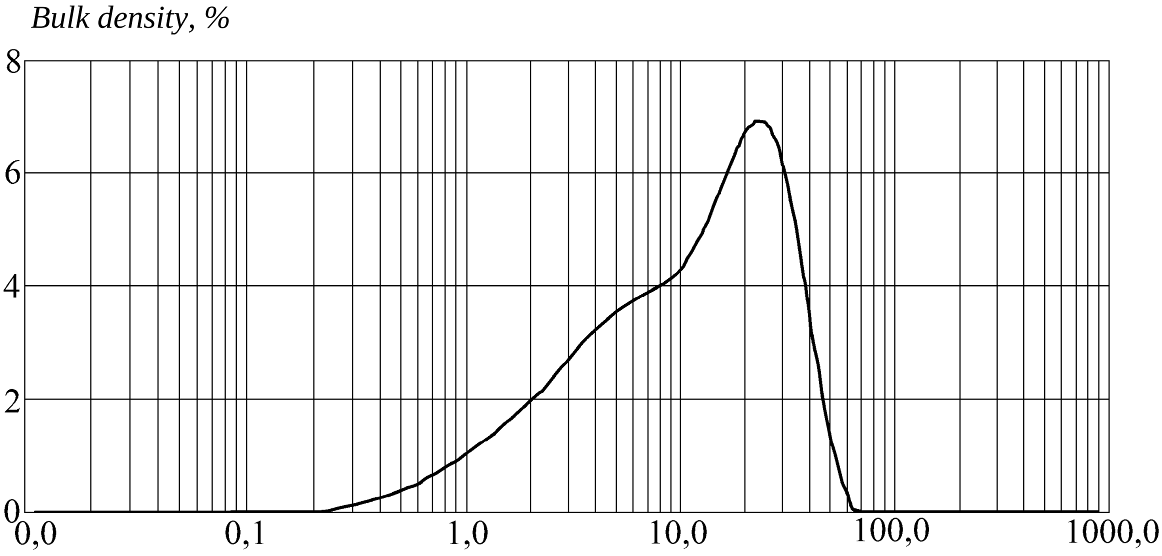

Fig. 1 Differential distribution curve of powder particles of the experimental slip

The properties of the experimental slips depending on the different contents of clay and water are given in Table 2.

Table 2 Properties of the experimental slips

Water added, ml	Clay content, g	Coverage, g/cm^2	Relative humidity, %	Absolute humidity, %	Slip bulk density, g/cm^3
1	2	3	4	5	6
60	4	0,021	33.6	52.3	2.1
		0,017			
	5	0,042	32.5	50.1	2.1
		0,023			
	6	0,092	32.7	48.5	2.1
		0,035			
65	4	0,015	36.7	57.9	2.0
		0,012			
	5	0,034	35.7	55.5	2.1
		0,015			
	6	0,078	34.9	53.7	2.1
		0,029			
70	4	0,012	39.3	64.5	1.9
		0,009			
	5	0,025	37.5	60.0	2.0
		0,012			
	6	0,064	36.2	56.8	2.0
		0,019			
75	4	0,006	42.7	74.4	1.8
		0,005			
	5	0,020	39.6	65.5	1.9
		0,011			
	6	0,035	38.3	62.2	1.9
		0,014			

As a result of the studies, the optimal composition of the slip was determined, which should contain 4 wt.% of clay and 75 ml of distilled water (with the free runoff of slip residues) per 100 wt.% of dry mix. An increase in clay content is impractical because this leads to a heavier slip, an increase in coverage, firing temperature and, as a consequence, worsens coating quality.

The experimental slip with the optimal composition is characterized by the following properties: coverage - 0.005-0.006 g/cm^2, relative humidity - 43%, absolute humidity - 74%, bulk density - 1.82 g/cm^3.

The nature of the formation of ceramic-metal coatings during firing is shown in Fig. 2 - 5.

For the coatings shown in Fig. 2-3, the metal component was introduced in the form of a PG-12-N-01 self-fluxing alloy. The metal component was added to the coating samples shown in Fig. 4-5 as separate powders.

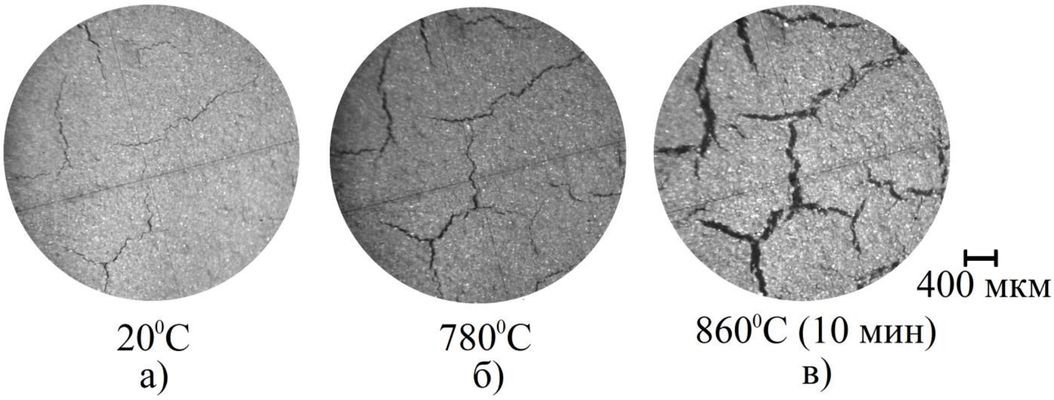

Fig. 2 Crack formation and growth of cracks in the coating

We should note (Fig. 2 (a)) that a significant amount of cracks (20-30 μm) are present in the coating even before firing, which grow more during thermal treatment.

In the temperature range from 760 to 780^{0}C, these defects increase to 40-60 μm, which is associated with sintering and shrinkage of the coating (Fig. 2. (b)), and in the first 10 minutes of firing reach 120-140 μm (Fig. 2 (c)).

A further increase in temperature does not contribute to their growth. At isothermal exposure (T=860°C, τ=1 hour), no autogenous healing of cracks occurs (Fig. 3 (a)). The general appearance of the detected defects during cooling does not change (Fig. 3 (b)). The coating is heterogeneous, with a significant surface relief.

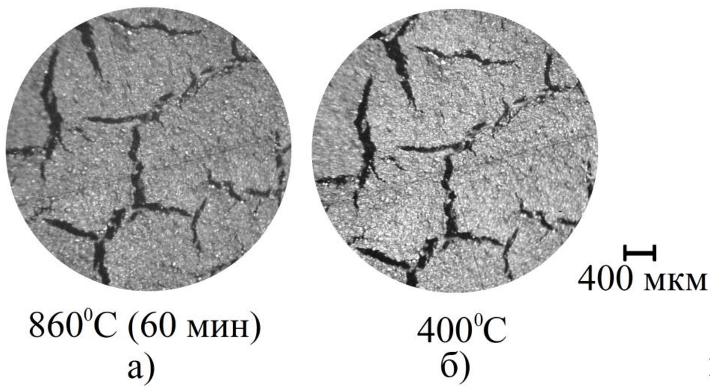

Fig. 3 Formation of the coating during isothermal exposure and subsequent cooling

An experimental coating, consisting of a composition of metallic powders, does not undergo significant changes when heated to a temperature of 620^{0}C. Presumably, in the range of 640-660^{0}C, the base glassy bond becomes softer. Throughout the entire firing period, cracks do not form.

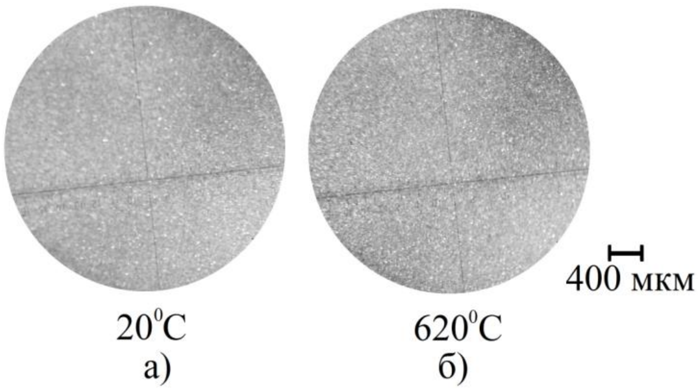

Fig. 4 Softening of the glassy bond of the experimental coating

The coating is characterized by uniformity after the first 10 minutes of firing (Fig. 5 (a)); further exposure at maximum temperature (Fig. 4 (b)) does not lead to a significant change in its structure.

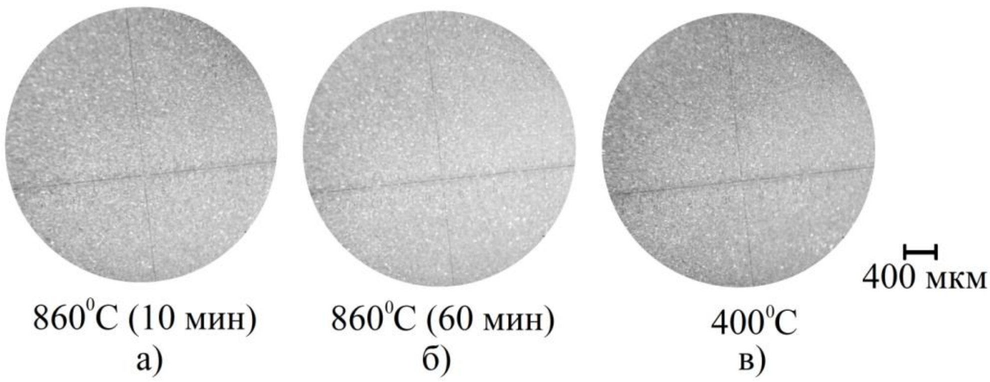

Fig. 5 Formation of the experimental coating during the thermal treatment

CONCLUSION

The quality of the slurry is affected by grinding fineness, moisture content, and the amount of suspending additives. The experimentally established grinding time of the experimental slip in laboratory settings is 16-18 hours for 100 g (based on the dry mix), the main fraction of which consists of 2-30 μm particles. The weighted average particle diameter of the slip is 23-25 μm.

The experimental slip with the optimal composition is characterized by the following properties: coverage - 0.005-0.006 g/cm^2, relative humidity - 43%, absolute humidity - 74%, and bulk density - 1.82 g/cm^3.

The analysis of heat-induced structural changes in the experimental coatings made it possible to recommend the introduction of individual metal powders into their composition. The resulting coating is characterized by a uniform defect-free structure and high-quality adhesion to the metal base.

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