DEPOSITION OF TITANIUM-BASED GRADED COATINGS BY LASER CLADDING

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Investigation of the technology of laser cladding of a titanium substrate and analysis of the properties of graded materials of Ti–Si and Ti–NiCr systems were carried out. Cladding was performed in Trumpf DMD 505 laser system of 5 kW power. A graded change in coating properties was determined by scanning electron microscope, optical microscope and X-ray diffraction. Analysis of hardness variations through thickness of the deposited layers was carried out by *HV* method. The possibility of providing sound graded coatings in order to improve the titanium substrate properties was proved.

Keywords: *laser, laser cladding, graded coatings, titanium base, phase composition, structure, hardness*

Development and introduction of laser technologies today is a promising avenue of progress of science and technology. One of the advanced laser technologies — laser cladding — allows deposition of wear- and high temperature-resistant, thermally-stable, corrosion-resistant graded and composite coatings on part surfaces of a complex geometry [1]. It can be used also for reconditioning of worn surfaces of parts, deposition of protective coatings, and manufacture of 3D objects [2]. In laser cladding powder transportation into the laser impact zone is performed by shielding carrier gas. Material penetrating into the melt pool, which is formed in the subsurface layer by the laser beam, melts, partially mixes with it, and provides a high strength of adhesion of the deposited layer with the substrate. High cooling rates in laser cladding lead to formation of a unique structure and properties in the deposited material [3]. Owing to the fact that in laser cladding it is possible to mix various materials in the specified proportions, graded coatings of different composition are produced [2, 4].

The purpose of this work consisted in obtaining new experimental data on the influence of parameters of laser cladding mode on the structure and properties of coatings of titanium-based graded materials.

Graded coatings were produced on a titanium substrate from materials of Ti–Si and Ti–NiCr systems, which feature higher high-temperature resistance and thermal stability. For this purpose compositions of coating surface layers of Ti–Si (70/30 wt.%), and Ti–NiCr (70/30 wt.%) systems were selected. To reduce inner stresses between the titanium substrate and coating, three intermediate layers were made, thus allowing the difference between the values of the coefficient of thermal expansion (CTE) of the coating and substrate to be reduced, as well as producing a graded coating and highly-alloyed surface layer.

Compositions of coatings, both of Ti–Si and Ti–NiCr system were varied by addition of silicon in the amount from 12 to 30 wt.% with 6 % step. Thickness of each layer was varied from 0.6 up to 2.0 mm, depending on laser cladding mode parameters (Figure 1). Layers were deposited using dispersed powders of nichrome (49.7 wt.% Ni) with particle size d = 60–160 μm, titanium (d = 50–150 μm), and silicon (d = 50–150 μm). Schematic of laser cladding process is given in Figure 2 [5].

Main parameters of laser cladding process, strongly influencing the structure and properties of the cladding material, are powder feed rate (consumption), nozzle displacement speed and laser power. In order to determine their influence on cladding properties, the values of these parameters were varied in the following ranges: rate of powder feeding into the laser impact zone (speed of rotation of the disc injecting the powder) was 3000–5000 rpm, speed of nozzle displacement was 500–1000 mm/min. Laser power was 5 kW. Influence of laser cladding parameters was assessed using X-ray phase and microstructural analyses, electron microscopy, as well as layer-by-layer hardness determination. Microstructural studies were conducted in the optical and electron microscopes. X-ray phase analysis was performed at filming in K_{Cu}-radiation with 15.4 nm wave length, 2° step with 5 s exposure per point. Hardness variation by coating height was determined by *HV* method.

Light optical microscope was used for visual determination of the structural features (grain size, approximate assessment of phase content and their distribution) of graded coatings of Ti–Si and Ti–NiCr system.

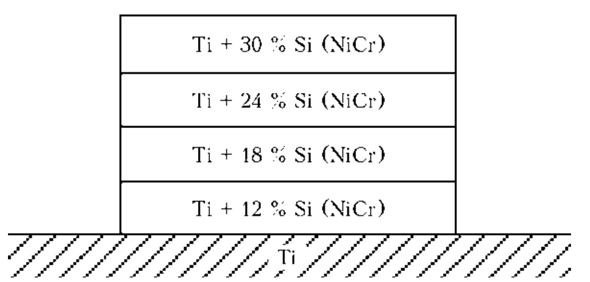

Figure 1. Schematic of the change of layer composition by height of deposit of Ti–Si and Ti–NiCr system coatings

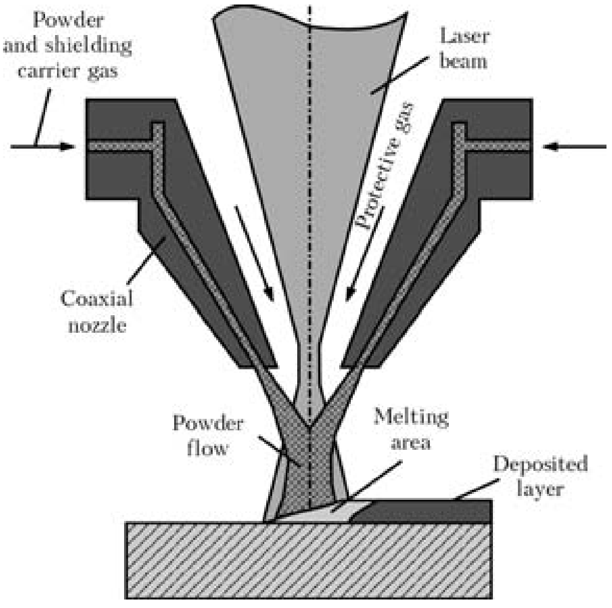

Figure 2. Schematic of laser cladding

Change of coating metal structure was studied by its height, as well as at variable parameters of laser cladding mode. At layer-by-layer analysis of metal structure of Ti–NiCr coating system it is seen that the grain size decreases from the lower to the subsurface layer (Figure 3), which is due to the thermal influence of the above-lying layers that promotes an increase of grain size of the lower-lying layers [6].

Main phases in the coating structure are β-(Ti–Cr) solid solution and $NiTi_2$ intermetallic. Weight fraction *C* of forming intermetallic components increases with increase of the content of NiCr(Si) alloying component (Figure 4).

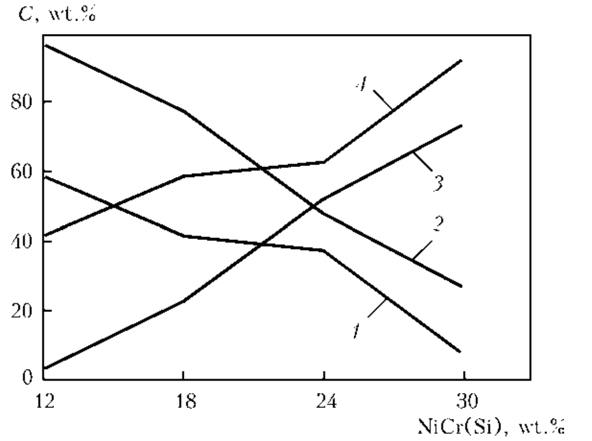

Figure 4. Influence of the content of NiCr(Si) alloying component on phase composition of materials of Ti–Si and Ti–NiCr systems: *1* — α-Ti; *2* — β-(Ti–Cr); *3* — $NiTi_2$; *4* — Ti_5Si_3

Change of variable parameters (powder feed rate v_f, and nozzle displacement speed v_n) has a considerable influence on coating metal structure. At increase of nozzle displacement speed or lowering of powder consumption, grain size is refined [7], which is attributable to increase of cooling rate in connection with decrease of layer thickness. At a high speed of nozzle displacement, unmolten titanium particles remain in the coating structure. X-ray spectral analysis confirmed their presence in the subsurface layer of the coating made at v_n = = 1000 mm/min, and v_f = 3000 rpm.

Alloy phase composition also depends on laser cladding parameters. Weight fraction of precipitating $NiTi_2$ intermetallic phase increases with increase of powder feed rate and decreases with increase of substrate displacement speed. This is connected with that

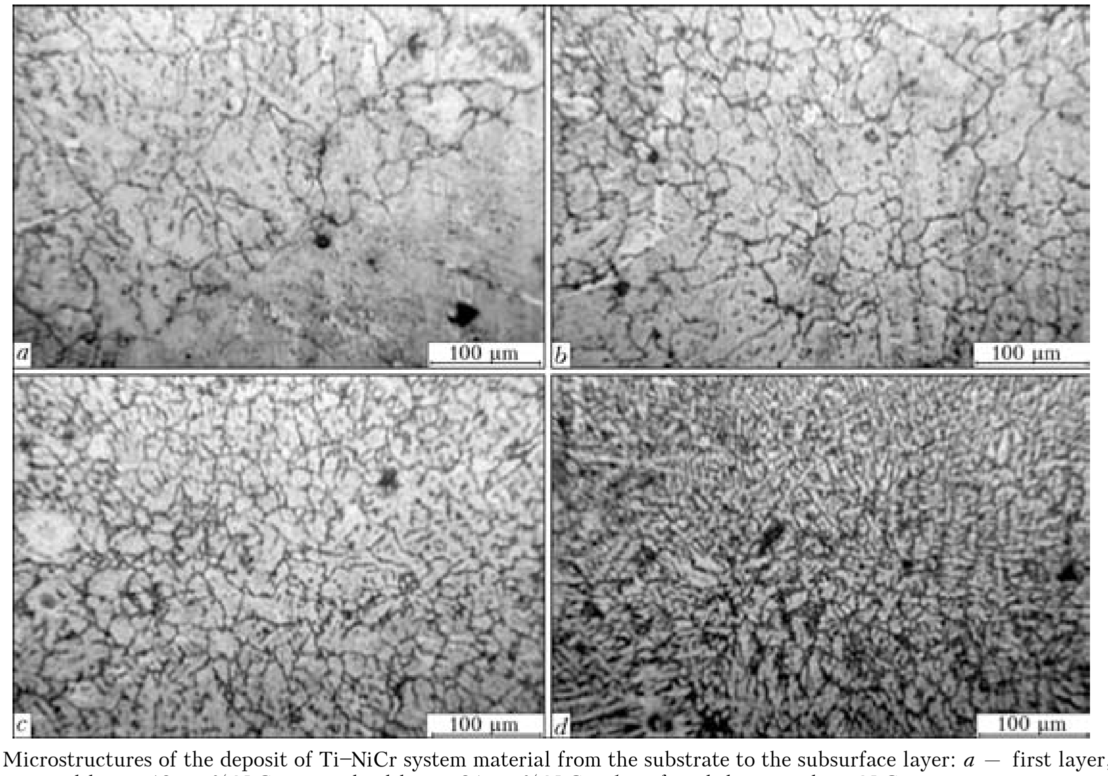

Figure 3. Microstructures of the deposit of Ti–NiCr system material from the substrate to the subsurface layer: *a* — first layer, 12 wt.% NiCr; *b* — second layer, 18 wt.% NiCr; *c* — third layer, 24 wt.% NiCr; *d* — fourth layer without NiCr

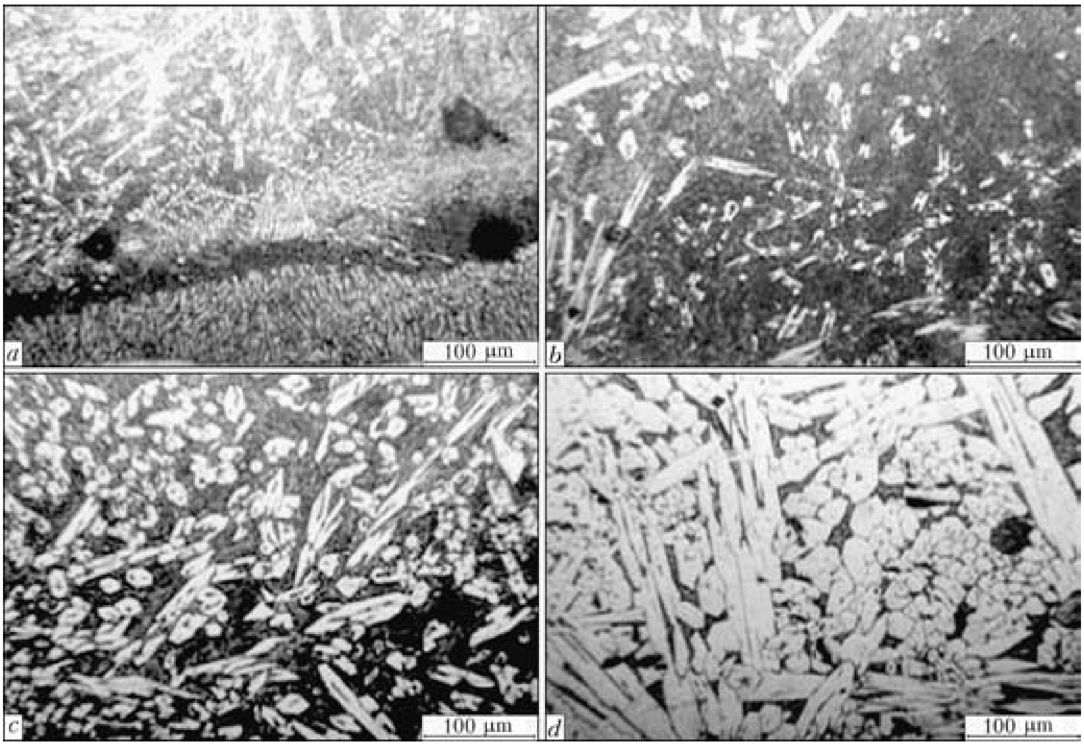

Figure 5. Microstructures of deposit of Ti–Si system material from the substrate to subsurface layer: *a* — first layer with 12 wt.% Si; *c* — second layer with 18 wt.% Si; *c* — third layer with 24 wt.% Si; *d* — fourth layer with 30 wt.% Si

increase of powder feed rate leads to increase of coating thickness and, hence, to its slower cooling. The longer the coating is cooling down, the closer is its phase composition to the equilibrium composition, and the greater the amount of intermetallic phase that is able to precipitate, whereas increase of nozzle displacement speed has a reverse influence.

At layer-by-layer analysis of the structure of Ti–Si system coating metal, an increase of the content of precipitating titanium silicide Ti_5Si_3 and alloying component content from the substrate to the coating was established (Figure 5), which is confirmed by the results of X-ray phase analysis (see Figure 4).

Proceeding from investigation results, the change of phase composition of Ti–Si system materials depending on the varied parameters leads to the conclusion that the content of precipitating titanium silicide Ti_5Si_3 rises with increase of powder feed rate and decreases with increase of nozzle displacement speed. This is related to the fact that increase of powder feed rate leads to an increase of coating thickness and, therefore, to its slower cooling. The longer the coating cools down, the closer will its phase composition be to the equilibrium one, and the greater the amount of titanium silicide that will have time to precipitate. Increase of the nozzle displacement speed leads to a reverse effect.

Change of coating hardness by the height of the deposited layers was studied, as well as the influence of laser cladding parameters on it [8]. Hardness rises continuously from the substrate to the coating surface layer in materials of both Ti–NiCr and Ti–Si systems, which is due to formation of solid solutions and presence of intermetallic and silicide phases in the coating.

Depending on the varied parameters of laser cladding mode, surface layer hardness in Ti–NiCr system coating changes only slightly and stays within instrument error (Figure 6). This leads to the conclusion that variation of the above parameters in a broad range does not affect the deposited coating hardness.

Ti–Si system materials are characterized by a dependence of hardness on laser cladding mode parameters. Surface layer hardness decreases with increase of nozzle displacement speed v_n and increases with increase of powder feed rate (Figure 6), as v_n increase leads to reduction of coating thickness, increase of cooling rate and reduction of weight fraction of Ti_5Si_3 titanium phase, which does not have enough time to

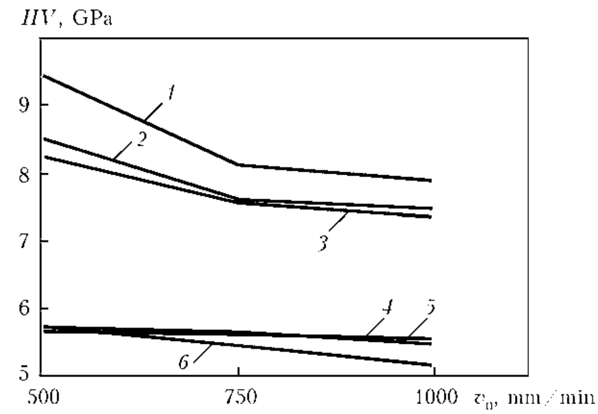

Figure 6. Dependence of coating surface layer hardness on parameters of laser cladding mode for materials of Ti–Si (*1–3*) and Ti–NiCr (*4–6*) systems: *1*, *6* — v_n = 6000; *2*, *5* — 4500; *3*, *4* — 3000 rpm

precipitate, that is confirmed by X-ray phase analysis. Powder feed rate has a similar influence.

CONCLUSIONS

1. Influence of parameters of laser cladding mode (powder feed rate and nozzle displacement speed) on the structure and properties of coatings from material of a graded composition of Ti–NiCr and Ti–Si systems was studied.

2. A refinement of grain size from coating lower layer (Ti–12 wt.% NiCr) to the surface layer (Ti–30 wt.% NiCr) with lowering of powder feed rate (at v_n = 3000–5000 rpm) and increase of nozzle displacement speed up to 500–1000 mm/min is established, as well as increase of intermetallic content from coating lower layer (Ti–12 wt.% NiCr or Si) to surface layer (Ti–30 wt.% NiCr or Si) with increase of powder feed rate and decrease of nozzle displacement speed.

3. An increase of coating layer hardness towards the surface layer is established, and the change of parameters of laser cladding process has only a minor influence on hardness of Ti–NiCr material layers.

4. In Ti–Si system materials surface layer hardness decreases with increase of nozzle displacement speed and increases with increase of powder feed rate.

5. Deposition of layers of Ti–NiCr and Ti–Si system materials by laser cladding can be recommended for improving the hardness and wear resistance of the titanium base.

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ELECTRIC ARC SPRAYING OF CERMET AND METAL-GLASS COATINGS

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Upgraded unit of the electric arc sprayer for deposition of composite coatings is described. The possibility of formation of cermet and metal-glass coatings is shown. Optimal spraying parameters are given. Wear resistance and strength of adhesion of the electric-arc metal-glass coatings are considered.

Keywords: *electric arc spraying, electric metallizator, spraying head, upgrading, cermet and metal-glass coatings, wear resistance, strength of adhesion, optimal parameters*

Composite materials and coatings, obtained using powder metallurgy methods, plasma, flame and detonation spraying [1–4], get wider application in the friction assemblies of different machines and mechanisms. However, process of obtaining of the composite materials by powder metallurgy is sufficiently power-consuming and requires significant power inputs [1, 2].

The cermet coatings, obtained by flame, plasma and detonation methods, are mainly used for strengthening and repair of worn surfaces of the parts, that allows increasing their life time several times [4, 5].

A method of coating deposition depends on requirements making to the coating properties. These requirements, on the one hand, are determined by composition of the material of coating and, on the other hand, by parameters of the process of its spraying and achievable values of heat and kinetic energy of the particles. Others criteria are costs of coating deposition, including cost of power input and consumables per unit of coating being sprayed.

Heat efficiency of a flame torch makes 0.8–0.9 in flame spraying, however, a level of effective application of heat of a jet for heating up of powder particles and their acceleration makes only 0.02–0.10 [6]. Higher level of the coating properties (adhesion strength, porosity) is achieved at supersonic flame spraying, however, process performance requires increased fuel consumption (gas, liquid fuel), that results in rise of the cost of coating unit. The flame spraying has limitations in spraying materials, related to temperature of combustion materials.