Treatment of plasma coatings by laser remelting

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Abstract. The article analyzes the effect of reflow and thermal cycling by laser beam on the structure and properties of plasma eutectic coatings. The facts of carbon diffusion into the solid phase at a distance of 150-200 microns with a laser pulse duration of 4 ms have been established. This is due to the high deformation rates that occur in the zone of thermal influence under pulsed laser action. This effect is aimed at increasing both the surface and volumetric strength of the sprayed coatings.

1 Introduction

High mechanical performance materials are used to create equipment for oil and gas extraction. Such important characteristics are, for example, wear resistance, strength and durability [1-3]. It is known that the best complex of mechanical and operational properties have such alloys as «natural composites» [2]. Such a structure can be obtained using various modern technologies, such as mechanical alloying or powder and granulated metallurgy. But all these techniques are very expensive technologies. Therefore, innovative technologies for the production of heterogeneous eutectic alloys with simpler technological processes are being developed along with them.

Today, laser technology is an integral part of the areas where functional coatings are applied. There are a number of techniques aimed at increasing both surface and volume strength of dust coatings. These include: surface melting, thermal and thermochemical treatment, solder impregnation and others [1-3]. The aim of the study is to determine how laser beam fusion technology affects the structure and properties of plasma eutectic coatings. The research task is to review technological techniques such as the melting of plasma coatings with laser, plasma-coated coatings and laser thermal cycling. Our hypothesis is that laser treatment of plasma coatings increases their tribotechnical properties over a wide temperature range.

2 Materials and methods

Before conducting the experimental tests, the authors conducted a study of the scientific literature on the use of laser remelting treatment of plasma coatings.

Steel specimens 1080 and 12H18N9T, 1045 were used.

The microstructure of the surface layer was examined in a scanning electron microscope (SEM). Thermocyclic treatment (TCO) of the coating was carried out on the laser

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installation «LATUS-31». The study of the roughness of the sample after the wear test was carried out using the electron microscope JSM-840 in the scanning mode of the selected line «Linescan».

The article makes generalizations about the results obtained during laser treatment of coatings on the basis of metallographic and X-ray phase analyses of structures, measurement of microhardness and porosity of samples, study of surface potential of physico-chemical properties.

### 3 Results

#### 3.1 Laser melting of plasma coatings

Taking into account the results of tests of eutectic coatings covered with laser, the effect of laser melting and thermal cycling on the structure and properties of plasma coatings has been analyzed. Normally, the mode of irradiation shall be such that the melting depth is equal to or greater than the thickness of the coating. The microstructure of plasma coatings on steel 1080 and 12H18N9T, welded with laser, is presented in Fig. 1 [4].

The coating has a column-dendrite structure. Compared to the original microstructure, the metal became liquid under the action of concentrated radiation energy. Under the influence of a large temperature gradient and, as a consequence, a high crystallization rate, the principal axes of the dendrites grew parallel to the direction of the heat sink.

![Microstructure of VTiN laser-coated plasma coating.](image)

Near the surface, the direction of heat removal is less noticeable and is directed parallel to the direction of laser beam scanning. Thus, the orientation of the dendrites in the melt area may be determined by the direction of the heat sink [4].

The technological mode is selected taking into account the most favorable influence on the friction and wear processes of the finely dispersed structure (radiation power, laser scanning speed), which ensures the formation of this microstructure. For this purpose, the molten coating was repeatedly processed using higher continuous laser scanning speeds (more than 1 m/min). The surface layer treated in this mode has no dendritic structure, practically does not poison and has increased hardness - 1,1...1,2 GPa (Fig. 1, b). Research on a scanning electron microscope (SEM) has shown that this layer has a microcrystalline structure.

A characteristic feature of melted coatings is their reduced microhardness compared to
the initial microhardness of dust coatings. The hardness from the surface of the coating to the substrate changes more smoothly than with the untreated plasma-coated coating. The highest microhardness is plasma-molten coating on a substrate of 1080 tool steel compared to coatings on steels 1045 and 12H18N9T. The reason for this is carbon, which is 0.8% for steel 1080; 0.45% for steel 1045 and only 0.12% for alloy steel.

The facts of carbon diffusion in a solid phase at a distance of 150-200 μm with a laser pulse duration of 4 ms have been established. This is due to the high deformation speeds occurring in the thermal influence zone under the pulse laser action. At the same time, the laser irradiation of austenitic steel does not cause significant changes in its structure. The microhardness of the heating zone does not differ from the hardness of the original steel structure and is 2.7 GPa. Melted coatings become almost non-porous (porosity 0.5...1.0%), adhesion strength increases to 400...450 MPa.

3.2 Laser thermal cycling of plasma coatings

Thermocyclic treatment (TTC) of the coating (laser beam heating in the temperature range 1000...600 °C) was carried out on the laser installation «LATUS-31». The temperature of the upper limit of the cycle is selected from the phase equilibrium diagrams (0.75 T). This temperature does not allow any morphological changes in equilibrium eutectic embedding crystals, but can significantly affect the decay of the metal matrix, coagulation of disperse internode phase crystals contained in light areas. It will also be related to the diffusion process at the edge of the «coating-steel» section. The number of thermocycles is selected to obtain levels of structural state close to equilibrium. Thus, the selected TKT temperature and 60-fold number of treatments allow influencing diffusion processes at the boundary of the coating-substrate, structural state and thermodynamic equilibrium of light areas.

In eutectic coatings (VTiNi and CrTiNi), starting with three thermal cycles, light areas begin to break down. In a CrTiNi coating after a three-fold TXT, the amount of gray areas (reacted with the etcher) increases due to the partial decomposition of white areas. As a result of increasing the number of thermal cycles to five, a more complete decomposition of light areas occurs with the release of dispersed particles of interstitial phases. The microhardness of the coating after this treatment is slightly lower than that of the untreated coating, but higher than that of the coating obtained by laser remelting.

3.3 Wear resistance of laser plasma-treated coatings

3.3.1 Laser Melting

According to the results of the tribotechnical tests, the excellent wear resistance of melted coatings compared with the original unprocessed coatings (more than twice at room temperature and 5 times at high temperature) was revealed. Namely, if the specified V TiNi abrasion losses at a temperature of 20 °C are 51.1 mg/cm² and at a temperature of 850 °C 47.5 mg/cm², the reported wear losses for the melted coating are 27.9 and 12.14. mg/cm² respectively. Wear of the counterbody by friction on the coated surface is less than by friction on the molten surface. This can be explained by the more intense formation on plasma coatings of oxide films acting as solid lubricants.

The coated surface is destroyed by friction mainly due to wear of individual particles, presence of pores, high fragility and low relaxation ability. The melting of dust coatings increases their effectiveness in extreme conditions, preventing dents, crushing and bunching.

Double-melted coatings have the highest wear resistance due to their structure providing
a positive gradient of the coating properties (Fig. 1, b). The fine-grained surface layer facilitates the self-organization of friction structures, and the lower layers of column structures of reinforcing phases effectively dampen external normal and shear loads. At high temperature, the column structure of the refractory phases of introduction contributes to high strength, and the surface layer contributes to the formation of dense (optimal thickness) oxide films. The results obtained are consistent with the data of the analytical study of the stress-deformed state of the composite coating, loaded by forces of friction [5].

The study of the friction surfaces of the melted coatings showed that at room temperature friction structures are formed but wear out as a result of fatigue. At elevated temperatures (850°C), friction and wear processes depend on the formation of oxide films (Fig. 2, a). Diffractograms of coating friction VTiNi tested at 850°C showed traces of oxides Fe₃O₄, Fe₂O₃, Cr₂O₃, TiO₂, V₂O₅, B₂O₅, which is consistent with thermodynamic analysis.

The contact melting of the friction surfaces occurs during the high temperature tests of the coatings within a defined range of external loads (T = 850 °C, P = 5 MPa, V = 1.5 m/s). The wear trace includes the flows of solidified metal and crystals of re-hardened eutectic structures (Fig. 2, b). The friction coefficient is drastically reduced to the values of boundary or even semi-liquid lubrication (0.05 - 0.10).

Thus, melting plasma coatings effectively increases their adhesion and wear resistance. However, this is not the best method to improve the properties of gas-thermal coatings. To control the durability of plasma coatings, a part of their surface is melted by laser. Melting is carried out either completely (on the whole surface) or partially (not on the whole surface), but with a total melting area of 5-100% of the total surface. The partial melting of the coating combines the advantages of the original dust coatings - high microhardness of structural components (light areas) with molten areas, which significantly increases the wear resistance of the coatings under heavy dynamic loads. The wear intensity of coatings with different fractions of the melt area varies - it is lower than that of the raw coating. The wear on the melted solid coating is 1.5-2 times less than the unprocessed coating. The most wear-resistant coating is one in which only about 15% of the surface has been cast.

Fig. 2. Microstructure of wear traces of the melted eutectic plasma VTNi coating at temperatures: a) 850 °C, ×43; b) 850 °C, ×750.

The friction surface at the boundary of the melted and untreated areas of the VTNi plasma coating is shown in Fig. 3. On the friction surface of the initial coating there are traces of brittle breakage in the form of splinters, while the melted part is smooth, with no visible signs of breakage. This is confirmed by the friction surface profiles (Fig. 3, b) taken along the scanning line (Fig. 3, a). The study of the roughness of the sample after the wear test was carried out using the electron microscope JSM-840 in the scanning mode of the selected line «Linescan».

Studies have confirmed that plasma-coated coatings with non-equilibrium ultradisperse
structure should have higher tribotechnic properties. However, the low adhesive and cohesive properties prevent the implementation of the friction mechanism with self-organization of plasma coatings.

![Microstructure (a) and Wear Track Profile (b) of a partially melted surface VTiNi coating](image)

**Fig. 3.** Microstructure (a) and Wear Track Profile (b) of a partially melted surface VTiNi coating (10,000 vertical increase, 100 horizontal increase).

### 4 Conclusion

Even a small melting (10%) of a part of the coating contributes to a significant increase in its wear resistance. Recovery of eutectic equilibrium structure during melting increases adhesive properties, but at the same time loses some of the advantages of dust coating: high microhardness, non-equilibrium structure (metastable phases, supersaturated solid solutions of phases in metal matrix). Therefore, this method of plasma treatment of coatings, which will increase adhesion-cohesive properties while maintaining their structural state, deserves attention. It is known that in the case of structural instability under load conditions (i.e. the ability to rebuild), the energy of deformation is spent on favorable relaxation processes and the wear resistance of the material increases.

### References