The influence condition of electro-spark alloying by Al and sequent laser treatment on surface layer of steel GradeB A284

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In the present paper structure and properties of alloying by aluminum surface layer of steel GradeB A284, which were obtain by electro-spark alloying (ESA) and sequent laser treatment (LT) are described. The properties of coatings were investigated by SEM and X-ray diffraction, microstructure and microhardness analysis.

It has been shown that next laser treatment can increase the depth of hardened layer doped with 50 to 80…100 μm, but in comparison with ESA, reduces the value of microhardness from 10 to 5 GPa.

Keywords and phrases: electro-spark alloying (ESA), laser treatment (LT), steel GradeB A284, surface layer, hardened surface, microhardness, scanning electron microscopy (SEM).

Introduction

Requirements to construction materials are increasing from year to year. So, searching of optimal solution for hardening surface and obtaining required properties in materials doesn't stop.

Different types of surface treatment, including high-energy pulse vacuum-plasma processing methods of materials treatment are used to achieve the above characteristics. Recent methods for obtaining this type metal coatings have several disadvantages, while, at the same time, high-energy methods, such as electro-spark alloying and laser treatment are still insufficiently known. Also little-studied, in this case, are physical, mechanical and tribological characteristics of coatings, without which analysis is impossible to obtain a coating of a new generation of structural and functional materials. So, the topic of research is modern and relevant.

The aim of this work is to investigate structure, phase composition and microhardness of coatings that are obtained by ESA with aluminum and sequent laser treatment on steel GradeB A284 substrate.

Experimental

Mild (low carbon) steel GradeB A284 (by ASTM classification) or RSt37-2 17100 (by DIN classification) as specimen was chosen. There were ESA of steel GradeB A284 by aluminum, on the air, under the same conditions (current I = 1,8…3 A, voltage U = 60…70 V, capacity C = 360 μF, pulse length $\tau = 10^{-2}$ sec), but with different treatment duration from 180 till 360 sec. Treatment was carried out on device ЭЛИТРОН 22А.

Ingoing size of specimens following: diameter 8 mm and high 6.7 mm. Chemical composition (in wt.%) of steel GradeB A284 following: Fe — base; C = 0,14…0,22; Mn = 0,4…0,64; Si = 0,15…0,3.

Despite of the undoubted advantages of ESA such as local area coating deposition, low power consumption, environmentalism, etc., method of ESA has a number of disadvantages. But many of them was successfully corrected by laser treatment of ESA coatings. The laser beam was used for surface polishing, forming the surface geometry, homogenization of chemical composition alloying coating. This implies that laser treatment (LT) of electro-spark coatings will provide: lower values of roughness, less porous, the better adhesion (coupling) with a basis, better durability and resistance to traction, higher fatigue strength as a result of compressive stresses in surface and higher corrosion resistance [1].

So to test this assumption and compare the properties held laser treatment (with power density of laser irradiation Wp = 2,6 GW/m^2) after electro-spark alloying by aluminum of surface sample.

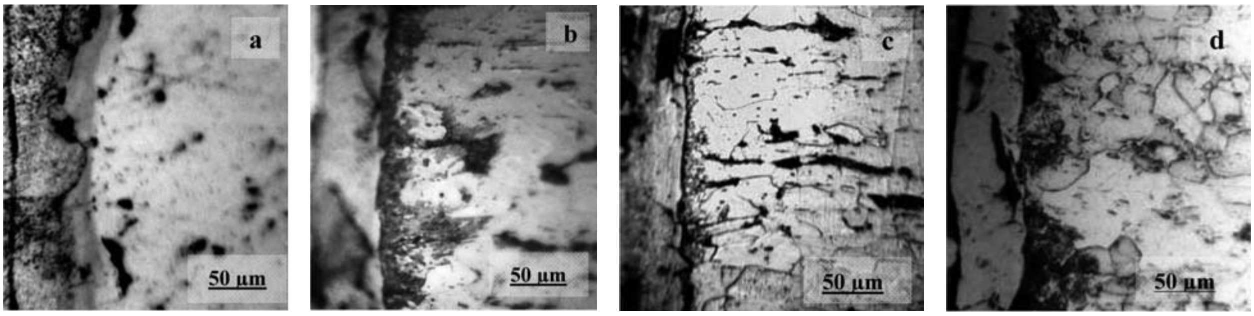

Fig. 1. Microstructure of surface layer. Steel GradeB A284, ESA on the air, anode — Al; I = 2…2,5 A, treatment duration: a) τ = 180 sec; b) τ = 240 sec; c) τ = 300 sec; d) τ = 360 sec.

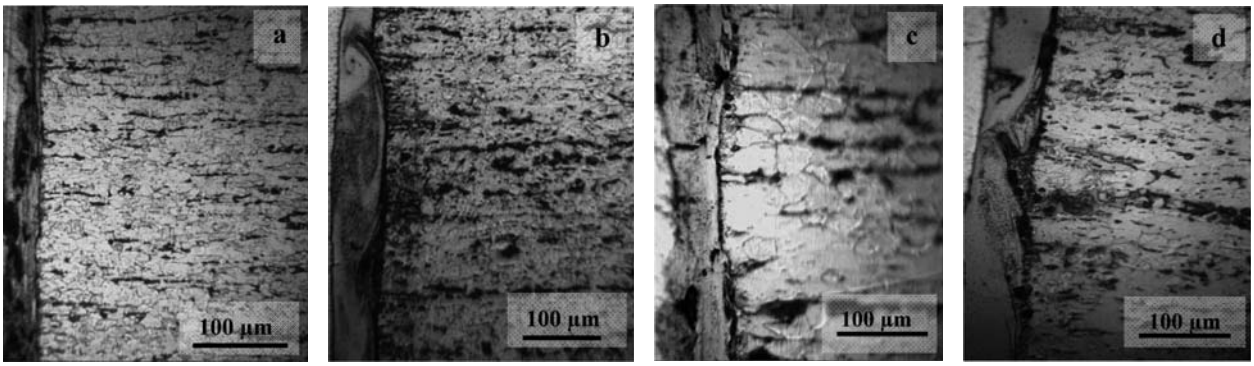

Fig. 2. (a), (c) Microstructure of surface layer of specimen steel GradeB A284, ESA on the air: anode — Al; I = 1,8..2 A; τ = 300 sec; (b), (d) — Microstructure of surface layer of specimen, ESA+LT. ESA: steel GradeB A284, anode — Al; I = 2…2,5 A; τ = 300 sec; sequent surface laser treatment (LT): Wp=2,6 GW/m².

Results and discussion

As a result of microstructural analysis crosscut microsection of samples (Fig. 1) surface layer can be divided into several zones: light-etched area of the newly created layer, an underlayer or transition zone, heat-affected zone and base (original structure).

In all samples observed an underlayer or transition (diffusion) zone on the border between the newly created layer and heat-affected zone. In this part the value of microhardness is higher than throughout the volume of the layer and heat-affected zone: up to 10 GPa for a specimen treated for 300 sec (5 min) to 7 GPa for the specimen treated for 360 sec (6 min) and about 5 GPa in the specimens after treatment for 180 and 240 sec (3 and 4 min, respectively). An underlayer zone width for all samples is about 10 µm. Microhardness of bases (original structure) is about 1.7…1.8 GPa.

Probably the reason for this increase of microhardness in an underlayer is that the transition zone is hold a contact a solid base of layer specimen with the region, which periodically melted and crystallized during electro-spark alloying. These processes occur under high-speed heating and cooling. Since the layers in contact in this place have different chemical composition and, consequently, significantly different coefficients of thermal expansion, then the cooling and heating in the volume, which surrounding the contact surface are high thermal stresses occur which will lead to the appearance and redistribution of dislocations. Dislocation density increase, and thus they may have formed dispersed particles of nitrides or carbides of iron or aluminum or intermetallic. As a result microhardness will increase in this zone. The longer the process of electro-spark alloying will occur, the more the dislocation density and, accordingly, microhardness of this site will develop.

To investigate the influence of laser treatment on the structure and properties of the surface layer after ESA

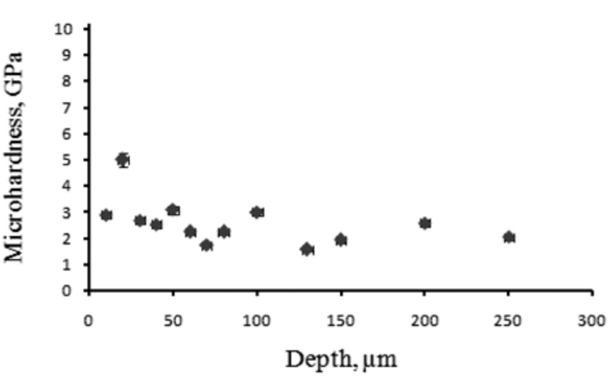

Fig. 3. Microhardness distribution in the surface layer, steel GradeB A284, ESA on the air: anode — Al; I = 2…2,5 A; τ = 300 sec; sequent surface LT on the air: Wp=2,6 GW/m².

were chosen specimen of steel GradeB A284, which had the largest microhardness (10 GPa) after ESA by aluminum (Al) during 300 sec. The thickness of the layer after laser treatment of pre-alloyed by electro-spark surface treatment was about 100 µm, which compared with similar models (following ESA) increased in 1.2 times (Fig. 2).

Microhardness of laser impingement point decreased to 5 GPa (Fig. 3). After the laser surface melting observed a slight decrease over the whole layer microhardness and the thermal influence zone (Fig. 3). This probably indicates removal of internal stress.

As a result of X-ray diffraction analysis of the specimen, after ESA by following regime: anode — Al; I = 2...2,5 A; τ = 300 sec and sequent LT, was determined that surface layer consists of following phase: α-Fe, Al, small amount Al_2O_3 and intermetallic η-Fe_2Al_5.

Fragment area was subjected to intensive etching. A study of scanning electron microscopy (SEM) revealed its detailed microstructure (Fig. 4). A dark color on micrographs obtained in secondary electron corresponds to higher content of light elements — aluminum in the studied object. On the surface area a thin layer (5–7 µm) enriched with aluminum was observed (Fig. 4). We can assume that since LT was held in the air, this aluminum oxide — Al_2O_3, which is proved by X-ray analysis. Zone melting is located below, in which fixed columnar crystals are enriched with Fe and almost perpendicular to the border section between melting area and the foundation.

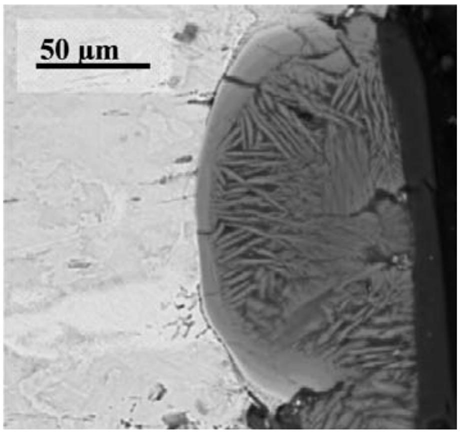

Fig. 4. Micrograph by SEM obtained in secondary electrons of surface layer of steel GradeB A284 specimen, ESA on the air: anode — Al; I = 2...2,5 A; τ = 300 sec and sequent LT on the air (Wp = 2,6 GW/m²).

Top of the crystallites looks like dendrite crystals (Fig. 5). Between these crystals observed plot, which were etched more intensive and which may indicate a greater content of Al in them. At the border with the base observed light etched continuous layer thickness which is between 3 to 6 µm. Given data X-ray diffraction analysis, it is assumed that crystals in the zone melting are intermetallic η-Fe_2Al_5.

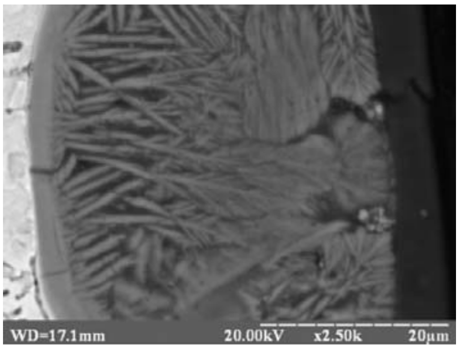

Fig. 5. Micrograph by SEM obtained in secondary electrons of surface layer of steel GradeB A284 specimen, ESA on the air: anode — Al; I = 2..2,5 A; τ = 300 sec and sequent LT on the air (Wp = 2,6 GW/m²).

In this mode processing occur alloying layer, which has a thickness of about 70…80 µm and is characterized by continuity and a small number of cracks. On the surface layer which was not subjected to intense etching, there is a thin layer of slightly etched, which is probably oxide Al_2O_3 (Fig. 6).

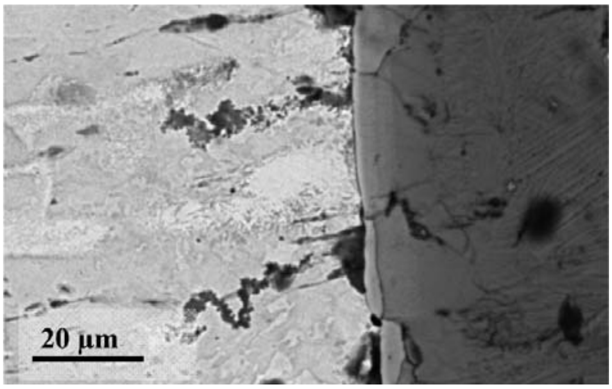

Fig. 6. Micrograph by SEM obtained in secondary electrons of surface layer of steel GradeB A284 specimen, ESA on the air: anode — Al; I = 2…2,5 A; τ = 300 sec and sequent LT on the air (Wp = 2,6 GW/m²).

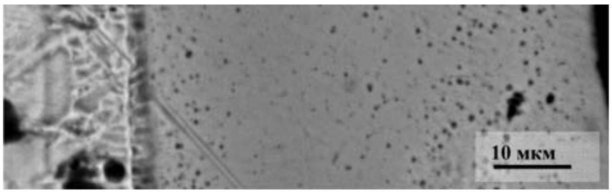

Fig. 7. Micrograph by SEM obtained in secondary electrons of surface layer of steel GradeB A284 specimen, ESA on the air: anode — Al; I = 2…2,5 A; τ = 300 sec and sequent LT on the air (Wp = 2,6 GW/m²).

In other parts of the alloying layer column crystals of similar structure are observed, which was described above (Fig. 6).

In the heat-affected zone, which is 10 μm, a region of refine grains (1 to 2 μm) was observed (Fig. 7).

To sum up, the next laser treatment can increase the depth of hardened layer doped with 50 to 80…100 μm, but in comparison with ESA, reduces the value of microhardness from 10 to 5 GPa.

Conclusions

There are the possibility of the creation on the steel GradeB A284 surface layers of aluminum by electro-spark alloying in air and found that the use of laser treatment after electro-spark alloying can significantly (in 1.2…2 times) strengthen the surface layer. Continuous laser-alloyed layers with more length (80…120 μm) have been shown.

Assuming that, after electro-spark alloying by aluminum, steel GradeB A284 is observed an underlayer with high microhardness (≈ 10 GPa), because of the appearance of stresses in super-fast temperature changes.

Assuming that the optimal regime of ESA by aluminum steel GradeB A284 is in the air mode with duration τ = 300 s (5 minutes) and I = 1,8…2 A, U = 60…70 V, resulting in a transition zone microhardness reached ≈ 10 GPa and length area with high microhardness to 120 μm.

References

[1] Radek, Norbert, Jurji Shalapko, and Maciej Kowalski. “Investigations of the Cu-Mo and Cu-Ti electrospark coatings after laser treatment”. *Вестник двигателестроения.* № 1 (2009): 143–149.