Coating of a substrate with surface preliminarily treated with intensive flows of high-speed electrons and plasma using a magnetron

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Abstract. This paper presents results of the research in influence of preliminary surface treatment on adhesion of film to substrate (Si8 or brass- target, CU, Ni-film). The preliminary treatment has been conducted by two methods: first, by compressive plasma flow with charge duration ~100µs, plasma formation rate (15-20)×10⁵ m/s; second, by low-energy high-current electron beams with pulse duration 2-3 µs and electron energy up to 30 keV. The investigation shows the strong influence of preliminary sample treatment and processing parameters on adhesion of film to substrate and final roughness. Experimental investigations have revealed the best adhesion of film to substrate, and the smoothest film is corresponding to the mode with preliminary LEHCEB irradiation with electron energy of 25, 30 keV. It was shown that the alternation of deposition with LEHCEB irradiation has resulted in large-scale surface smoothing: the surface has become glassy whereas craters of 10-20 µm have formed. It was shown that the magnetron-covered samples can withstand the saline mist for twice as long as samples with galvanic coatings.

1. Introduction
Presently, the treatment of materials by intense energy flows [1-5] (ion beams, low-energy high-current electron beams or compressive plasma flows) has become an effective tool for modification of their properties and for improving their operational characteristics such as microhardness, wear-resistance, change of the surface relief, adhesion of film to a substrate.

It is well known [6] that many factors such as surface roughness [7], surface impurities [8] (contamination, oxide films, adsorbed gases), film deposition methods and others have influence on adhesion of film to substrate. According to [6, 7], surface roughness affects film adhesive interaction both during film deposition and its separation. The adhesive strength is directly proportional to real contact area. The real contact area can be increased by extending surface roughness. It should be noted that the adhesion strength is determined by the size of protrusions and depressions on a surface and their shape. As declared in [9, 10], the surface relief roughness of a sample enlarges after treatment by compressive plasma flow (CPF).

Ref [11] has shown that the treatment by CPF and low-energy high-current electron beams (LEHCEB) increases roughness and, as a result, the adhesion of the film to the substrate. In this case, real contact area treated by CPF increases by 5-10% as compared with that treated by LEHCEB. As a result, the adhesive property of film-substrate system after CPF processing is better than that after LEHCEB treatment.
However, it is well known that film roughness depends on substrate roughness, whereas most of technologies show increased requirements to the film roughness. Ref [11-16] have revealed that LEHCEB treatment can tend to smooth the relief. Therefore, LEHCEB is used as a tool to smooth relief in the research.

The paper is devoted to study the influence of preliminary treatment of substrate surface on adhesion of the film-support system.

2. Experimental methods
Samples of brass and carbon steel 8 were taken. Copper and nickel films were applied by magnetron deposition, which was conducted in current stabilization mode; the current was 3 A and overall deposition time ranged from 30 to 60 min.

LEHCEB processing was made by the electron beam generation facility with the pulse duration range of 1-2 μs and electron energy varying from 5 to 30 keV. Electron processing has conducted in smoothing regime (roughness decrease) with the energy up to 20 keV, and in the regime of roughness increase (crater formation) at 25 and 30 keV.

There were two kinds of samples: first, brass and steel 8 samples with deposited nickel films; second, steel 8 samples with copper film. The samples of both types were exposed to preliminary CPF treatment.

The samples of both kinds were also exposed to LEHCEB with the pulse duration of 1-2 μs, electron energy of 25 and 30 keV and 50 impulses. According to [11, 12], such preliminary treatment results in surface layer melting, intense ablation and, as a consequence, surface cleaning from oxides, and increased roughness of the surface.

The film was applied by magnetron deposition in two modes. First, single-film coating with consequent LEHCEB irradiation and alternation of the film magnetron deposition with LEHCEB processing. In the single-coating mode, electron irradiation was carried out with pulse duration of 1-2 μs, electron energy 10, 15 and 20 keV and 20 impulses.

In the other mode, the deposition carried out for 10 minutes. Then, the covered film-substrate system was exposed to LEHCEB with pulse duration of 1-2 μs, electron energy 10-15 keV and 50 impulses. Consequently, the film was deposited with following LEHCEB irradiation. There were 6 equal cycles. Electron energy and deposition time were determined in the case of LEHCEB irradiation. The surface layer of film-substrate melted without intense ablation as compared with smoothing mode.

3. Results and discussion
One of the steel 8 samples after CPF and LEHCEB processing is depicted in Fig.1. The processing was run in roughening mode. The sample treated by CPF has visual distinguished region with the radius of 1.5-2 cm with complex relief. The LEHCEB irradiation of material has resulted in crater formation on the sample surface. Figure 2 illustrates the sample surface with copper film. Film deposition was alternated with LEHCEB irradiation. The figure demonstrates that the substrate is rougher than the film. Thus, the alternative deposition with LEHCEB processing has caused large-scale smoothing and the surface has become glassy, whereas there are 10-20-μm craters.

Fig.3. shows the first type of samples before and after nickel film deposition. The main purpose of nickel film covering of brass samples is the improvement of adhesive properties in comparison with galvanic covering. The samples with magnetron and galvanic coatings were subjected to saline mist. The results of the study have revealed that magnetron coatings can withstand saline mist for twice as long time as compared to galvanic ones.
Figure 1. The sample surface after CPF and LEHCEB processing.

Figure 2. The sample surface with copper film after CPF and LEHCEB processing.

The experiments have demonstrated the best adhesion of the film to the substrate. The smoothest film corresponds to the regime with preliminary LEHCEB irradiation with electron energy of 25 and 30 keV and alternating 10-minute deposition by LEHCEB irradiation by 10-15-keV electrons.

Figure 3. The sample surface before (left) and after (right) nickel film deposition.

4. Conclusion
The research of the influence of preliminary treatment of substrate surface on adhesive property of film-substrate system and final film roughness was conducted.

It was shown that the alternation of deposition with LEHCEB irradiation have resulted in large-scale surface smoothing; the surface has become glassy, whereas 10-20-μm craters have formed.

It was shown that the magnetron coated samples can stay in saline mist for the twice as long as compared to galvanic coatings.
Experimental investigations have revealed the best adhesion of the film to the substrate, and the smoothest film corresponds to the mode with preliminary LEHCEB irradiation with electron energy of 25 and 30 keV.

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