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Cleaning of steel surface from scale by compression plasma flows

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ABSTRACT

The investigation of compression plasma flow treatment parameter effect (the number of pulses and the energy absorbed by the surface layer) on cleaning efficiency of the steel surface from scale ($Fe_2O_3/Fe_3O_4/FeO$) is the main aim of the research carried out in this work. The results of the phase and element composition, cross-section morphology investigations are presented. The findings showed that efficiency of plasma cleaning increased with the growth of the pulses number (1–3) and the energy absorbed by the surface layer (10–20 J/cm^2 per pulse). Evaporation and cracking of scale due to the difference in coefficients of linear expansion of Fe_2O_3, Fe_3O_4, FeO and steel are supposed to be the main reasons for scale removal by plasma flow impact.

1. Introduction

Different types of surface treatment techniques based on the impact of laser, cluster and plasma beams can be used for cleaning the surface from contaminants, oxides, coatings, etc. [1–10]. Generation of shock waves [5,6], evaporation and ablation[5], difference in coefficients of linear expansion [7], physical sputtering [8] and etching [8–10] are the main mechanisms that are considered to be responsible for cleaning depending on a beam type and its energy. The impact of high-power ($\geq 10^6$ W/cm^2) pulsed electron, ion and plasma beams on materials results in ablation and rapid heating of the surface layer [11–16]. These processes can also be applied for surface cleaning or removal of surface layers.

Earlier it was found that treatment by compression plasma flows (CPF) could be used for refinement and homogenization of surface layer structure, alloying by additional elements thus resulting in substantial improvement of steels mechanical and tribological properties, their thermal stability [17–19]. The findings also showed that CPF impact led to removal of oxide layers from the surface of oxidized samples [20]. Such a cleaning process can be considered as a preliminary operation in the technological process of metal and alloy surface layer modification by CPF.

Short treatment time (10^{-4} s) in comparison with traditional ion-plasma sputtering, lower power inputs (in comparison with continuous ion-plasma treatment) and a possibility of operation at normal pressure (without a vacuum system) are the main advantages of such a type of cleaning technique. The main disadvantages consist of the following: only a flat surface can be effectively treated, plasma flows are less controllable than ion or electron beams, a comparatively small treatment area (~20 cm^2 per pulse).

As a cleaning technique this type of treatment may be used for removal of scale from the surface of thin steel sheet products that cannot be subject to long thermal treatment because of tension and subsequent bending. The investigation of CPF treatment parameter effect (the number of pulses and the energy absorbed by the surface layer) on cleaning efficiency of the steel surface from artificially grown scale was the main aim of the research carried out in this work.

2. Experimental

The samples used (Ø 15 mm) were made of a carbon steel (0.3 C; 0.2 Si, 0.5 Mn wt.%, Fe-balance). The scale formed on steel sheet products with the thickness of the order 10^1–10^3 µm can contain layers of Fe_2O_3, Fe_3O_4 and FeO. That is why to simulate phase composition of the steel scale the temperature of annealing was chosen higher than 843 K (the temperature necessary to form FeO [21]) but less than 1000 K to avoid polymorphic transformation bcc → fcc. The scale layer was formed on the steel sample surface by annealing at 973 K in air for 3 h. Annealing for more than 4 h resulted in scale layer delamination. The samples were cooled in the furnace after annealing. The grown scale must contain Fe_2O_3/Fe_3O_4/FeO (adjacent to steel) layers according to Ref. [21].

CPF were obtained using a gas-discharge magneto-plasma compressor of compact geometry. CPF treatment was performed in a "residual gas" mode in which the vacuum chamber was filled with nitrogen up to the preset pressure of 400 Pa. The discharge device and principles of CPF generation were described in detail earlier [22]. The plasma flow parameters were as follows: pulse duration ~100 µs, flow velocity $(5 \div 6) \cdot 10^6$ cm/s and electron concentration $(4 \div 7)\ 10^{17}$ cm^{-3}.

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