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Plasma electrolytic saturation of steels with nitrogen and carbon

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ABSTRACT

Studies in plasma electrolysis resulted in development of various surface treatments for metal components. These treatments include formation of protective ceramic layers on some metals (e.g. oxide coatings), saturation of metal surfaces with interstitial elements (e.g. nitrogen, carbon and boron), and plasma electrolytic deposition of extrinsic compounds, heat-treatments (e.g. hardening and annealing), surface cleaning and polishing. The main advantages of plasma electrolytic treatments are high processing speeds and low costs. The treatments enable production of surface nanostructures and local area processing. This review examines recent results in plasma electrolytic carburising, nitriding, and nitrocarburising (as the most common diffusion-based treatments), including treatment modes, electrolyte compositions, structures, and properties of hardened materials. Analysis of the results obtained up to date indicates that pulse plasma electrolytic saturation treatments leading formation of surface nano-structures appear to be the most promising to advance further this type of electrolytic plasma technology. Moreover, electrolytic plasma treatments provide considerable research interest in terms of fundamental science, in particular for development of models of heat transfer on flat vertically or horizontally oriented surfaces and electrochemical processes occurring in the studied systems. These processes include stages of liberation of saturating components, adsorption of active atoms, and their diffusion into the metal surface; therefore understanding associated kinetics and limiting factors is important for gaining proper control over these surface treatments.

Contents

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1. Introduction

Various techniques of electrolytic-plasma surface treatment technology were classified in the review by Yerokhin et al. [1] who also discussed physical and chemical features associated with phenomena and obtained results. By now, a number of research papers on plasma electrolytic treatment (PET) has increased significantly. For this reason, the analysis of relatively new publications seems topical.

Cathode and anode plasma electrolytic carburising (PEC) processes have been studied since the 1960s [2], and later applied for industrial use. Anode PEC units were produced by the Academy of Sciences of Moldova and used industrially in Russia, Ukraine, Belarus, Kazakhstan, Moldova and Romania [2,3]. A new step in development of plasma electrolytic saturation (PES) was provided by pulse technology which enabled formation of nanostructured layers on the surface of metallic substrates. Fundamentals of plasma-assisted cathode electrolysis, including pulse current modes, electrolyte compositions and mechanical and electrochemical properties of resulting coatings were reviewed by Aliofkhazraei et al. [4]. Selected physical, chemical and technological features of PES were discussed elsewhere [3,5,6].

In this article, we review examples of PES of steels. In Section 2, we consider key concepts and physical fundamentals of electrolytic plasma initiation and its existence while no dielectric film is formed on the electrode surface and no substances are deposited from the electrolyte on the substrate. In Section 3, we analyse oxidation and anode dissolution of steel workpieces. We cover PEC conditions, characteristics and properties of carburised layers in Section 4 which is the main section of the review. Sections 5 and 6 are devoted to the nitriding and nitrocarburising of steels. Finally, Section 7 discusses challenges and development prospects of PEC.

2. Physical features of plasma electrolysis

2.1. Formation of the vapour-gaseous envelope

Conventional electrolysis is known to be interrupted at a certain critical voltage U_1 by formation of a vapour–gas envelope (VGE) around one of the electrodes (Fig. 1) [1]. The main cause of VGE initiation is electrolyte boiling [7] while the gaseous products of electrolysis are secondary consideration. The VGE is formed at the electrode where optimum conditions for electrolyte boiling exist [8], e.g. at the electrode