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Surface modification of steels and magnesium alloy by high current pulsed electron beam

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Abstract

High current pulsed electron beam (HCPEB) is now developing as a useful tool for surface modification of materials. When concentrated electron flux transferring its energy into a very thin surface layer within a short pulse time, superfast processes such as heating, melting, evaporation and consequent solidification, as well as dynamic stress induced may impart the surface layer with improved physico-chemical and mechanical properties. This paper presents our research work on surface modification of steels and magnesium alloy with HCPEB of working parameters as electron energy 27 keV, pulse duration ~1 μs and energy density ~2.2 J/cm^2 per pulse. Investigations performed on carbon steel T8, mold steel D2 and magnesium alloy AZ91HP have shown that the most pronounced changes of phase–structure state and properties occurring in the near-surface layers, while the thickness of the modified layer with improved microhardness (several hundreds of micrometers) is significantly greater than that of the heat-affected zone. The formation mechanisms of surface cratering and non-stationary hardening effect in depth are discussed based on the elucidation of non-equilibrium temperature filed and different kinds of stresses formed during pulsed electron beam melting treatment. After the pulsed electron beam treatments, samples show significant improvements in measurements of wear and corrosion resistance.

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Keywords: Surface modification; Pulsed electron beam; Microstructure; Microhardness

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1. Introduction

In the last few decades, new methods for surface modification of materials have been developed based on the use of pulsed power beams. As compared with conventional surface treatment techniques, they are characterized by the formation of high-gradient temperature fields concentrated in the heat-affected zone (HAZ), and of stress fields located in the depth far beyond the HAZ in the material. As a result, non-equilibrium phase and structural transformations occur in the beam-affected zone and metastable structure or phase states may appear in the surface layer of irradiated materials, which are capable of providing the material with improved physical, chemical and mechanical properties [1–3].

As one kind of high-power charged particle beam, high current pulsed electron beam (HCPEB) has been developed in recent years. When used for surface modification of materials, it exhibits essential advantages over pulsed laser and ion beams by its high efficiency, simplicity and reliability [4,5]. To explore the features and regularities of the modification of structure and properties under the action of HCPEB, we have investigated the HCPEB treatment of pure aluminum, stainless steel 1Cr18Ni9Ti and bearing steel GCr15 [6]. And the results of numerical simulation by solving temperature and stress equations were used to interpret the relative experimental data [7]. This paper reports mainly our recent work on pulsed electron beam melting of carbon and mold steels, as well as magnesium alloy.

2. Experimental

A schematic diagram of our HCPEB source of type Nadezhda-2 is given in Fig. 1. It has the operating parameters as follows: electron energy 10–40 keV, pulse duration 0.5–5 μs, peak current density 10^2–10^3 A/cm^2 and cross-section area 30 cm^2. The electron beam is generated at explosive emission graphite cathode. Spark plasma sources are placed evenly in a circle behind the anode, providing anode plasma that conducts the beam to the collector. An external magnetic field

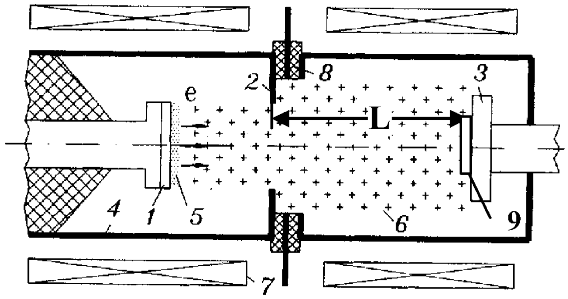

Fig. 1. Schematic diagram of the HCPEB source (L signifies the distance between anode and target): (1) cathode, (2) anode, (3) collector, (4) vacuum chamber, (5) cathode plasma, (6) anode plasma, (7) solenoid, (8) spark plasma sources and (9) specimen.

is applied to confine the beam. The accelerating voltage, magnetic fields strength and the anode-collector distance control the beam energy density. For more details about the HCPEB system, the readers can refer to [5].

Three kinds of metallic materials including carbon steel T8 (Fe; 0.8 C-wt.%) preliminary quenched to martensite, mold steel D2 (Fe; 1.5 C; 12 Cr; 0.5 Mo, 0.2 V-wt.%) previously subjected to standard heat treatment (heating at 1020 °C for 30 min, water quenching and tempering at 200 °C for 3 h), and magnesium alloy AZ91HP (Mg; 8.9 Al; 0.6 Zn-wt.%) as cast state, were selected as substrate materials and irradiated with HCPEB of working parameters as electron energy 27 keV, pulse duration ~1 μs and energy density ~2.2 J/cm^2 per pulse. To explore the effect of rapid surface alloying treatment on the wear resistance of D2 mold steel, chromium and TiN powders, less than 10 μm in particle size was suspended in ethanol solution and sprayed on the sample surface before HCPEB irradiation.

Microstructures formed in the near-surface layer of treated specimens were examined with optical microscopy and scanning electron microscopy (SEM) from the surface and on the cross-section. X-ray diffraction (XRD) measurements were carried out to detect the phase composition changes. In the property characterizing, the depth distribution of microhardness, wear resistance and corrosion resistance of irradiated samples were measured and compared with their original states.