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Mechanisms of microstructure formations in M50 steel melted layer by high current pulsed electron beam

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ABSTRACT

In the present paper, surface melting of the M50 steel was carried out by high current pulsed electron beam (HCPEB). The microstructure evolution in the melted layer was observed using TEM. It is confirmed that the dissolution of the carbides and the diffusion of alloy elements play a determining role on the microstructure evolution. After one pulse irradiation, a mixture of twinned martensite and irregular cellular domains of austenite is observed in the melted layer due to the insufficient diffusion of alloy elements around initial carbides. The zone around initial carbides with high alloy elements content keeps as residual austenite, the zone with low alloy elements content transform into twinned martensite. When the irradiation number increases to 30 pulses, the alloy elements will diffuse into the whole melted layer. And the melted layer consists completely of cellular austenite grains with a diameter of about 150 nm. The boundary between austenite grains is amorphous structure with little higher alloy elements content.

1. Introduction

As a relatively new surface modification technology, high current pulsed electron beam (HCPEB) has attracted more and more attention of the researchers [1–5]. It has been demonstrated that the electron beam irradiation causes the formation of ultrafine grains or even metastable phase because of the super fast heating and cooling process [6–9]. Thus, it would improve the corrosion and wear resistance of the material with limited modifications of the chemical composition of the material.

It is well known that the mechanical performance of the material depends on its own microstructure and phase composition. However, even if numerous papers have focused on the corrosion and mechanical properties of the materials treated by HCPEB, the evolution of the microstructure and corresponding mechanism of microstructure evolution comparatively received little attention [10,11].

In this paper, the microstructure evolution at the top surface during HCPEB irradiation of the M50 steel is investigated with increasing the number of pulses.

2. Experimental process

The material used in present study is a commercial M50 steel. The chemical composition (wt.%) of the steel is as follows C: 0.75–0.85 Cr: 3.75–4.25 Mo: 4.00–4.50 V: 0.90–1.10 and Fe: balance. It was austenitized at approximately 1100 °C for 30 min in a vacuum furnace followed by gas quenching. After quenching, the steel was subjected to three tempering cycles at 550 °C for 120 min. The as received steel was in the form of round bars with a diameter of 30 mm. Samples used for HCPEB irradiation were cut perpendicularly to the axis into thin disks with a thickness of 5 mm.

HCPEB treatment was carried out using a 'RITM-M' source [12]. Base pressure of the system was of $\sim 10^{-4}$ Pa, and the working pressure of argon was of 3×10^{-2} Pa. The pulse duration was 2.5 μs, acceleration voltage was 33 kV. Energy density used in our experiment was 6 J/cm^2 and the irradiation numbers were 1 and 30, respectively.

XRD was used to detect the phase changes in the samples. Microstructures observation of the samples was done using a TEM (Technai F30) operated at 300 kV. Thin foils used for TEM observation were prepared as follows: Firstly, a sample foil of ~200 μm thick was spark-cut from the irradiated samples parallel to the surface; then, the foil was grind by sand papers on the side opposite to the irradiated surface to about 50 μm; lastly, ion beam thinning was performed at 4.5 kV with a glancing angle of 10°. This could ensure the observation of the domains locates on the very top layer of the melted and remelted zones.

3. Results and discussion

Phase content in the initial steel is mainly tempered martensite as well as small amount of carbides [13]. Bright field TEM images of

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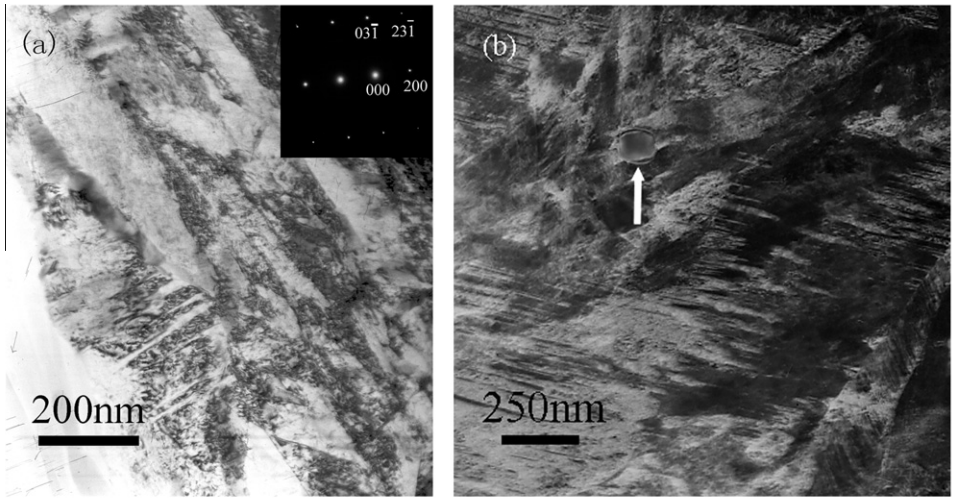

Fig. 1. Bright-field TEM micrographs of the untreated M50 steel (a) Lath martensite (b) Twin martensite.

the untreated M50 steel are shown in Fig. 1. These pictures indicate that the microstructure in the steel was composed of a mixture of lath martensite and twinned martensite. Small round carbides with a diameter of ∼100 nm locates along the boundary of the martensite (as pointed by the arrow) also could be seen in the steel.

Fig. 2 shows the microstructure of the melted layer after one pulse of HCPEB irradiation. This picture shows that, after one pulse irradiation, three types of microstructures formed in the melted layer: 1. a cellular structure with diameter of ∼130 nm (Zone A), which did not exist in initial steel. SADE pattern (Fig. 2(b)) indicates that the cellular structure is austenite. The small satellite

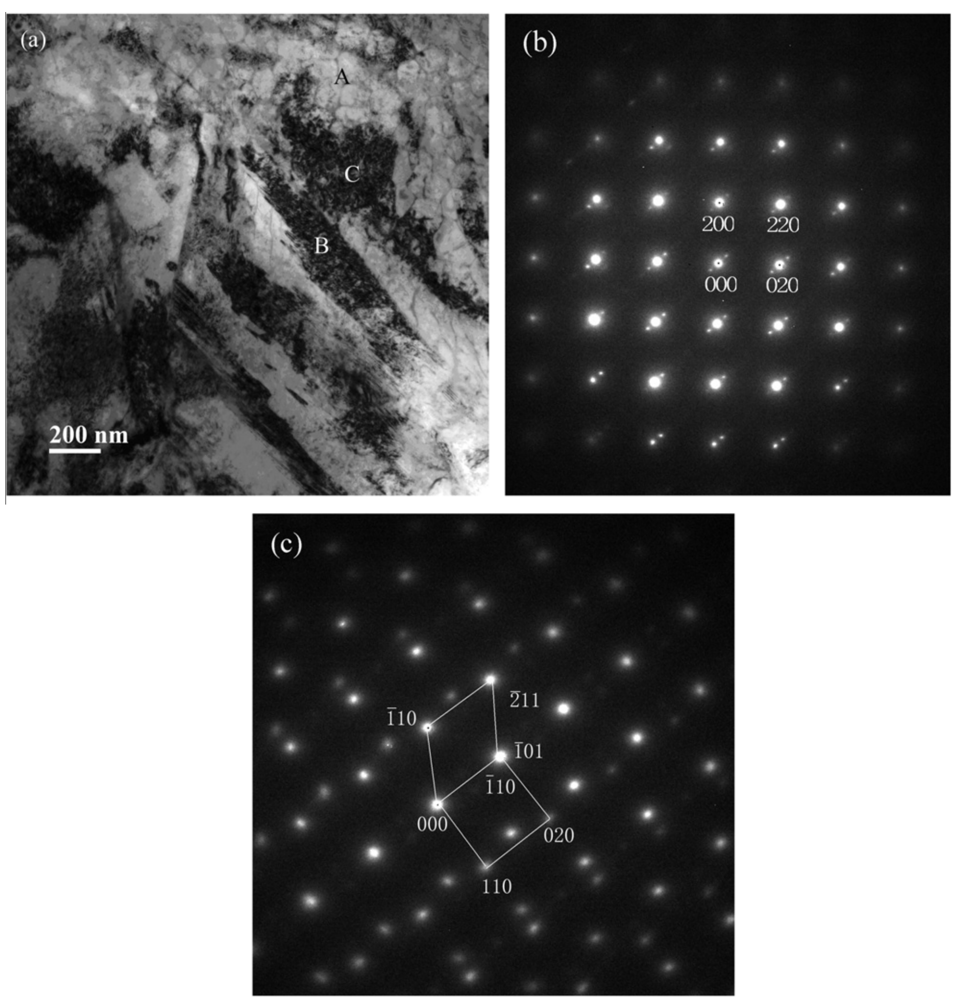

Fig. 2. Microstructure and diffraction patterns of the M50 steel after irradiation number of 1.