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Microstructure Refinement and Property Improvement of Metastable Austenitic Manganese Steel Induced by Electropulsing

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Abstract: Grain refinement efficiency of electropulsing treatment (EPT) for metastable austenitic manganese steel was investigated. The mean grain size of original austenite is 300 μm. However, after EPT, the microstructure exhibits a bimodal grain size distribution, and nearly 70vol. % grains are less than 60 μm. The refined austenite results in ultrafine martensitic microstructure. The tensile strengths of refined austenitic and martensitic microstructures were improved from 495 to 670, and 794 to 900 MPa respectively. The fine grained materials possess better fracture toughness. The work-hardening capacity and wear resistance of the refined austenitic microstructure are improved. The reasonable mechanism of grain refinement is the combination of accelerating new phase nucleation and restraining the growth of neonatal austenitic grain during reverse transformation and rapid recrystallization induced by electropulsing.

Key words: electropulsing; grain refinement; metastable austenitic manganese steel

Metastable austenitic manganese steel, developed in 1963, possesses higher work-hardening capacity and better wear resistance under low stress abrasive wear condition, compared with Hadfield steel[1]. Because of its lower Mn content, the toughness and yield strength are lower[2]. In order to improve its strength and toughness, many inoculants are used to refine the microstructure of metastable austenitic manganese steel. However, the results are not very satisfactory, and some of the inoculants materials are expensive and rare such as niobium, vanadium and rare earths[3]. Further studies are therefore necessary in order to develop a more effective, lower cost and resource conservation technology to refine its microstructure and improve its mechanical properties.

Electropulsing treatment (EPT), as an important instantaneous high energy input processing technique, attracts a lot of attention from material scientists and engineers due to its high efficiency in refining the microstructure and improving mechanical properties of cold worked alloys[4,5]. Zhao et al. [6] reported that the martensitic laths of cold-rolled boron steel sheet was refined from 400 to 150 nm by EPT. Hu et al. [5] found that the grain size of cold rolled silicon steel strips completely recrystallized by EPT was reduced from 2－6 μm to 0.5－2.0 μm. Wang et al. [7] successfully applied electropulsing to refine the microstructure of Cu-Al-Ni shape memory alloys. Electropulsing can enhance the recrystallization rate of cold worked metals and retard subsequent grain growth, resulting in the grain size reduction and enhancement of mechanical properties[8]. Li et al. [9] studied the accelerated decomposition of cementite and size reduction of neonatal graphite in spherical graphite iron induced by electropulsing. However, few attempts have been made to study the effects of electropulsing on steel nonsubjected to cold working. This study aims at investigating the potency of EPT for refining the microstructure and improving the strength and wear resistance of cast metastable austenitic manganese steel.

1 Experimental Procedures

The tested Fe-0.8C-8Mn steel (C 0.81, Mn 7.85, Si 0.40, S 0.013, P 0.044, and Fe balance in mass%)

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was made from high carbon ferromanganese, medium carbon ferromanganese and medium carbon steel. The molten steel, prepared in a 5 kg medium-frequency induction furnace, was poured into the sand mold. Then, the cast steel was austenitized at 1 323 K for 2 h to produce single-phase austenitic structure followed by water quenching.

Samples with dimensions of 40 mm×10 mm×2 mm for EPT were sectioned from the middle portion of the austenitized material, and then deeply cryogenic treated (77 K) for martensitic transition. At the end of the discharging duration, the sample was quenched by water spraying immediately. Electropulsing was performed under ambient condition by self-made electropulsing generator, which can generate AC pulse current with frequency of 50 Hz. The discharging duration and density of the pulse current were determined by a controllable program on a computer. The temperature of the specimen was measured by the thermocouple which was welded on the surface of specimen. Fig. 1 shows the schematic illustration of the electropulsing system. In this study, the current density j was optimized to 470×10^6 A/m^2 with the duration of 240 ms, where the amplitude of the current density was about 620×10^6 A/m^2. Fig. 2 shows the schematic illustration of EPT process. Time *vs*. temperature curve recording rapid heating and cooling is shown in Fig. 3. In order to obtain the refined martensitic microstructure, the sample needs to be further cooled by liquid nitrogen for martensitic transition after EPT.

After polishing, the samples were etched with the ethanol+4vol.% nitric acid solution for microstructure observation. The martensitic plate was observed using a JEM-2100F transmission electron microscope (TEM). The phase components were analyzed by X-ray diffraction (XRD). The abrasive wear was tested under a load of 38 N using an ML-100 pin-on-disc apparatus. Both the original austenitic and the refined austenitic steel cut into bulk specimens with the sizes of 10 mm×4 mm×4 mm were loaded against a disc having contact area of 16 mm^2 and used as pin materials, while SiC abrasive paper of 360 grit was used as the counterface. Every mechanical property value is the mean of three tested samples with corresponding treatment.

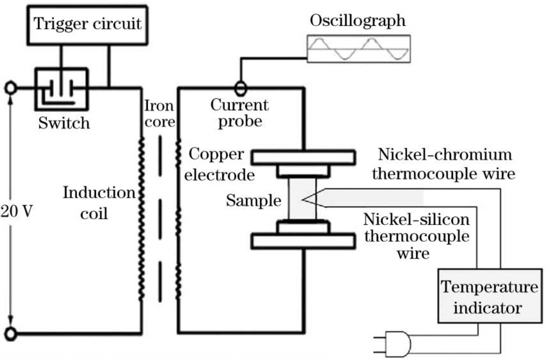

Fig. 1 Schematic illustration of electropulsing apparatus

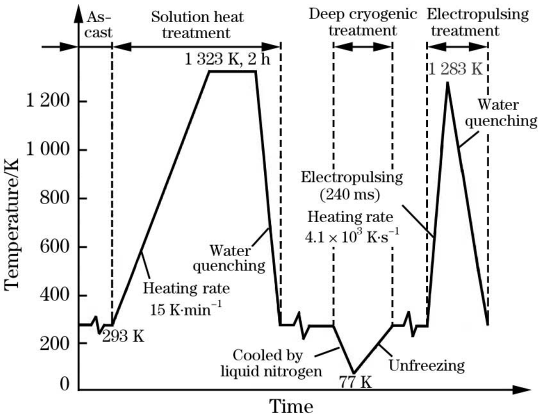

Fig. 2 Schematic illustration of solution heat treatment and EPT process

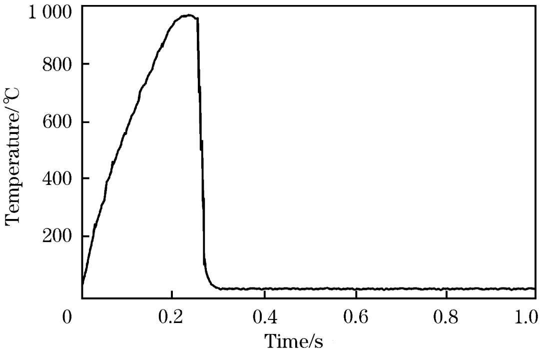

Fig. 3 Time *vs*. temperature curve recording of rapid heating and cooling

2 Results

2.1 Microstructure refinement

XRD patterns of the samples are shown in Fig. 4. The solution heat treated sample consists of single-phase austenite. After deep cryogenic treatment (DCT), the sample consists of martensite and retained austenite. The electropulsing treated sample consists of single-phase austenite again, indicating that the martensite phase was transformed to austenite completely, and there was no occurrence of phase transformation and precipitation on rapid cooling. Microstructure of solution heat treated sample is shown in Fig. 5 (a). The mean grain size of the coarse austenite is about 300 μm. According to em-