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Plasticity characterization of the modified layer produced by plasma nitrocarburizing of nanocrystallized 18Ni maraging steel

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ABSTRACT

The plasma nitrocarburizing of nanocrystallized 18Ni maraging steel was performed at 460 °C for 4 h. The surface phase composition, cross-sectional microstructure and hardness profile of the nitrocarburized layer were investigated by the X-ray diffractometer (XRD), optical microscope (OM) and microhardness tester. Plasticity of the surface layer of original and nitrocarburized samples was analyzed by Taylor factor obtained by electron backscattering diffraction (EBSD) data and nanoindentation tests. The nitrocarburized surface is composed of α-Fe, Fe_4N and a small fraction of low nitrogen compound $FeN_{0.049}$. The surface and core hardness of nitrocarburized samples are 200% and 130% of that of the original one, respectively. The Taylor factors for different slip systems of α-Fe grains are all decreased after nitrocarburizing and Taylor factors for Fe_4N grains are lower than those of basal slip system of α-Fe grains. Plasticity factor η_p, i.e. the ratio of plastic deformation work to total deformation work dissipated during loading-unloading process, of the surface layer is reduced about 20% after nitrocarburizing. This suggests that plasticity and wear resistance of the surface layer could be decreased and improved after nitrocarburizing, respectively. The surface layer of the nitrocarburized sample also possesses certain plasticity because its plasticity factor η_p is more than 60%.

1. Introduction

Plasma nitrocarburizing is a thermochemical processing that has been applied for many years in surface modification of steel, metals and their alloys, which involves the enrichment of nitrogen and carbon elements in the surface layer of these material components. It is employed to improve the surface properties, such as wear resistance, corrosion resistance, and fatigue strength, of various engineering parts which are used for making dies, tools, automobile and machine transmission parts [1–7]. A mono-phase compound layer with low porosity without mixed Fe_4N and ε phases can be formed on the surface of steel plasma nitrocarburized by properly controlling processing parameters [8]. Research evidences indicate that the mono-phase structure of compound layer is beneficial to the improvement of tribological properties and corrosion resistance duo to its homogeneity and lower residual stress [9,10].

Wear resistance of the nitrocarburized layer is related to its elastic–plastic behavior. The nitrocarburized layer with higher hardness usually possesses higher resistance to plastic deformation [11]. Another important parameter, i.e. Taylor factor which represents the resistance of polycrystals to plastic deformation, can be used as a measure of plastic work in crystal plasticity [12]. It has been shown that variations of the Taylor factors from one grain orientation to the next can help predict failure in materials. Wright [13] found that grains with low Taylor factors next to grains with relatively high Taylor factors are more susceptible to large stress concentrations.

In present work, the authors attempt to study the plasticity of the surface layer of original and nitrocarburized nanocrystallized (NC) 18Ni maraging steel using Taylor factor obtained by electron backscattering diffraction (EBSD) data and nanoindentation tests. The wear resistance of the surface layer of original and nitrocarburized samples is predicted based on the plasticity results.

2. Experimental methods and material

18Ni maraging steel, with a chemical composition (wt%) of 19.08Ni, 9.15Co, 5.06Mo, 0.45Ti, 0.075Al and balance Fe, was entirely nanocrystallized by a complex thermomechanical

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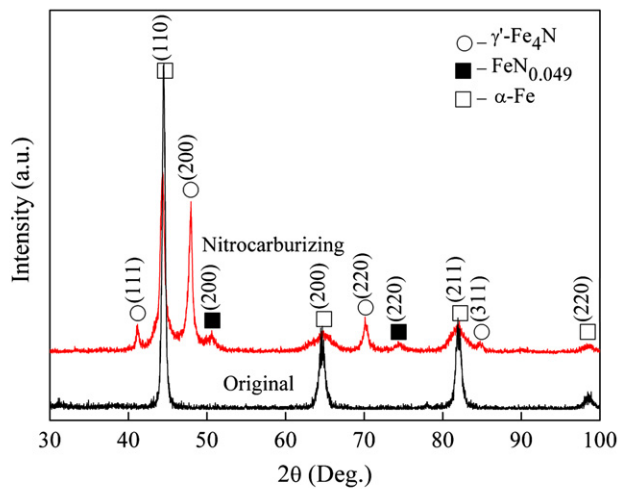

Fig. 1. Surface XRD patterns of the original and nitrocarburized samples.

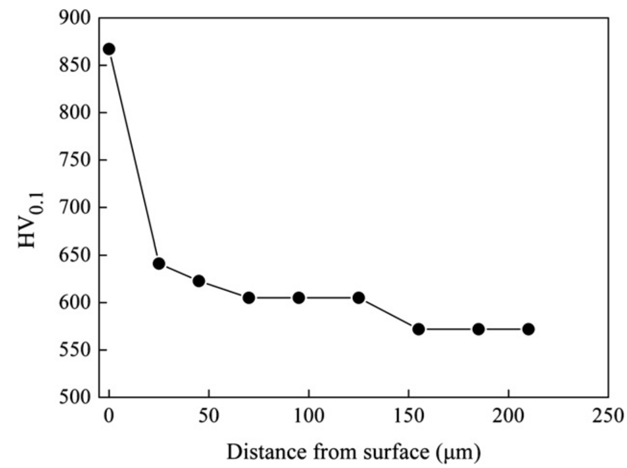

Fig. 3. Cross-sectional microhardness profile of the nitrocarburized layer.

treatment: solid solution, hot-rolling deformation, cold-drawn deformation and direct electric heating. The detailed experimental process and nanocrystallized mechanism have been introduced in reference [14].

The 18Ni maraging steel wire with ϕ 3.4 mm in diameter was cut into segments with a length of 12 mm, and then the segments were sectioned along the length direction. The surfaces to be nitrocarburized were mechanically ground using 240–1200 grades SiC abrasive papers. The experiments were carried out in a 25 kW pulse plasma nitriding unit at 460 °C for 4 h in an atmosphere of 0.1 L/minN_2, 0.3 L/minH_2 and 0.05 L/minC_2H_5OH under a pressure of 400 Pa. The nitrocarburized specimens were directly cooled to room temperature in N_2 gas.

The phase composition in the surface layers of original and nitrocarburized samples was analyzed by XRD (type D/max-rB) with Cu–Kα radiation ($\lambda = 0.15406$ nm) operated at 40 kV and 30 mA. The nitrocarburized samples were mounted, grounded, polished and etched in nital to observe the cross-sectional microstructure under CMM-33E type OM. The microhardness profile in the nitrocarburized layer was tested by HV-1000 type Vickers microhardness tester under a load of 50 g and a loading time of 15 s. Nanoindentation tests were performed in the surfaces of the original and nitrocarburized NC 18Ni maraging steel using a nano-indenter XP (MTS) equipped with a Berkovich diamond indenter. The maximum load and the resolutions of displacement systems are 10 N and 1 nm, respectively.

The EBSD scans were conducted using FEI QUANTI 200F scanning electron microscope (SEM) equipped with an orientation imaging microscopy (OIM) system commercialized by TSL. The OIM was carried out on hexagonal scan grids with a step size of 50 nm operated at 20 kV accelerated voltage, 12 mm work distance and a sample tilt of 70°. The measurements were performed on the surfaces of original and nitrocarburized samples. Thin foils with a thickness of 1 mm were cut from the surface layer of the original and nitrocarburized NC 18Ni maraging steel, respectively, and then the cut surface layer specimens were ground manually with 600–1500 grit SiC abrasive papers to reduce their thickness down to 0.5 mm. The nitrocarburized surface to be detected was left no damage. The original and nitrocarburized surfaces to be detected were finally electropolished in 10% perchloric acid + 90% alcohol solution at 35 V and 10 mA for 30 s to remove the stress produced during grinding. The length and width directions of these samples correspond to the rolling direction (RD) and the transverse direction (TD), respectively.

3. Experimental results and discussion

3.1. Microstructure observation and hardness profile

The surface phase composition of the nitrocarburized NC 18Ni maraging steel are α-Fe solid solution with nitrogen and carbon,

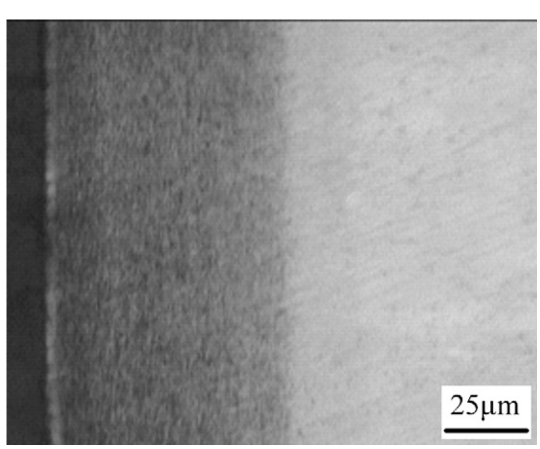

Fig. 2. Cross-sectional optical micrograph of the nitrocarburized layer.

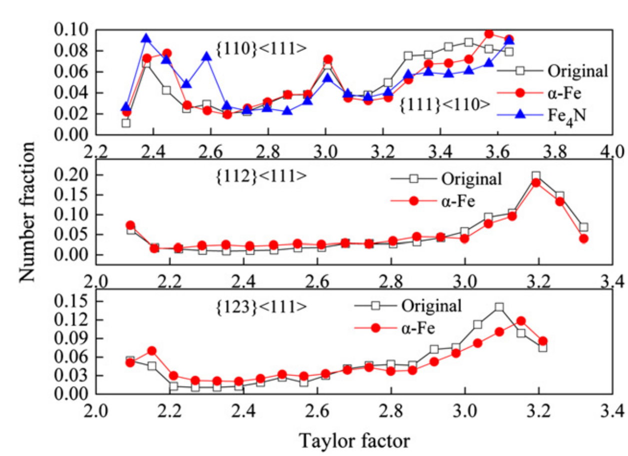

Fig. 4. Taylor factors distributions for different slip systems of α-Fe and Fe_4N grains in the surface layer of the original and nitrocarburized samples.