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Rapid anisotropy recovery in deformed FCC metals by high-density pulsed electric current treatment

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ABSTRACT

The {101} texture of deformed face-centered cubic metals, such as 316 stainless steel and Ni-based alloy Inconel 718, was successfully alleviated by high-density pulsed electric current (HDPEC) treatment. Furthermore, the deformed grains recovered after the HDPEC treatment. The HDPEC induced the rapid dislocation motion and grain refinement that resulted in random grain orientation and equiaxed grain morphology, which led to anisotropy recovery in the deformed metals. This method provides a promising way to modify the microstructure of materials with short time and low cost, after forming or during service.

Anisotropy of materials results in the direction-dependence of their properties and is mainly related to the crystallographic texture and grain morphology [1–3]. Texture is observed in nearly all engineered materials and can significantly influence their properties, particularly the anisotropy [4]. Anisotropic grain morphology (e.g., columnar grains) can result in directional properties of materials [5]. The formation of unfavorable textures and anisotropic grain morphology in materials during forming and service can result in defects and their consequent premature failure [6]. A lot of vacuum vessels are made of metallic materials, and their mechanical properties are heavily affected by the anisotropy of the materials [7].

Generally, heat treatment is the most common method for the anisotropy recovery of metallic materials [8,9]. However, it is low-efficient because the anisotropy recovery mainly relies on recrystallization, which involves thermally activated dislocation climb [10]. Some plastic working techniques, such as extrusion and rolling [11,12], can also realize anisotropy recovery, but the complex process limits their applications, and additional heat treatment may still be necessary. In recent decades, the electric current treatment, as a low-cost and highly efficient method, has been used to modify the microstructure of deformed metals. Studies have reported that thermal (Joule heating) and athermal (electron wind force) coupled effects induce rapid microstructure modification [13–15]. However, these studies focused on deformed lightweight alloys, such as titanium and magnesium alloys, which have hexagonal close-packed crystal structures. Although a few studies have reported electric current induced microstructure evolution in deformed face-centered cubic (FCC) metals [16,17], their anisotropy recovery has been rarely studied. Therefore, we investigated the texture and grain morphology evolution of commonly used FCC metals induced by high-density pulsed electric current (HDPEC). In this study, 316 stainless steel (SUS316) and Ni-based alloy Inconel 718 (IN718) were selected as target materials because of their superior corrosion resistance and mechanical properties. They are widely used for vacuum and pressure vessels, and other structures. Grain boundary character (GBC) distributions were used to investigate the crystalline evolution and the grain aspect ratio (i.e., the long/short axis ratio of the best-fitted ellipse of grains) to estimate the grain morphology. Finally, the mechanism of the HDPEC-induced anisotropy recovery was elucidated.

Dumbbell-shaped samples were prepared, and the annealing treatment was carried out on the samples of SUS316 at 900 °C for 4 h followed by furnace cooling, and the samples of IN718 at 982 °C for 1 h followed by air cooling to obtain a uniform microstructure. The deformation of the samples was introduced using a hydraulic-driven tensile testing machine (SHIMADZU) at room temperature (25 °C) under the loading rates of 0.05 mm/s (SUS316) and 0.03 mm/s (IN718). The plastic strains of the deformed samples are 15.0% and 20.0% for SUS316, and 20.5% and 30.0% for IN718, respectively. HDPEC was applied to deformed samples using a transistor-type power source with electric current conditions of 350 A/mm^2 for 60 ms and 55 ms (SUS316), and 300 A/mm^2 for 50 ms and 100 A/mm^2 for 540 ms (IN718), correspondingly. Since similar results were obtained, here, only the ones obtained under the typical conditions, as shown in Table 1, were reported. The initial, deformed, and HDPEC-treated samples of SUS316 and IN718 are denoted by S0, S1, S2, and N0, N1, N2, respectively. The

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