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STEM Characterization of the Deformation Substructure of a NiCoCr Equiatomic Solid Solution Alloy

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High entropy alloys have attracted increasing research interest due to their exceptional mechanical properties such as high tensile strength, ductility, and fracture toughness [1,2]. These alloys normally consist of five or more components to achieve high configurational entropy. Recent study shows that ternary NiCoCr equiatomic solid solution alloy with "medium entropy" actually has superior properties, especially at cryogenic temperature, as compared with 5 component Cantor alloy [3,4]. Previous study shows that deformation twinning plays an important role in the deformation process of Cantor alloy [5]. However, the origin of the exceptional mechanical properties of ternary NiCoCr solid solution alloy is still unclear.

In this work, interrupted tensile testing was conducted on the equiatomic NiCoCr solid solution alloy at both cryogenic and room temperatures at five different plastic strain levels of 1.5%, 6.5%, 29%, 50% and 70% in order to examine the evolution of deformation substructure with increasing plastic deformation. Diffraction Contrast STEM (DC-STEM) images [6] were obtained on a FEI Tecnai F20 S/TEM operating at 200keV in both bright field (BF) and annular dark field (ADF) modes to reveal the deformation substructure of the alloy after deformation to small strain levels (<6.5%). Figure 1 a) shows a low magnification <001> zone axis bright field STEM image of the deformation substructure. Figure 1 b) and c) are systematic row BF-STEM and corresponding ADF-STEM images using a g vector of (002). At small strain levels, the essential aspects of the deformation substructure at both temperatures consists mainly of planar dislocation slip, and dislocations with both narrow and wide dissociation distances, the latter creating stacking faults as shown in Figure 1. With increasing strain, a novel deformation substructure, nanotwin-HCP lamellae, become a predominant aspect of the substructure, partitioning grains into much smaller subgrain structures as shown in Figure 2a), and thus sustaining large lattice rotations. To reveal the detailed structure of nanotwin-HCP lamellae, atomic resolution STEM imaging was conducted using the probe-corrected and monochromated Titan^3 80-300 STEM in both ADF and high angle annular dark field (HAADF) modes. The nanotwin-HCP lamellae consist of nano-sized deformation twins and narrow HCP laths formed within the nanotwins as shown in Figure 2 b) and c). Most HCP structures form near coherent deformation twin boundaries through the slip of partial dislocations along the twin boundary. The volume fraction of HCP structure increases with plastic deformation at both temperatures. However, at cryogenic temperature, the volume fraction of the HCP structure increases more rapidly. Those nanotwin-HCP lamellae may be responsible for the improved strength and ductility in the equiatomic NiCoCr solid solution alloy [7].

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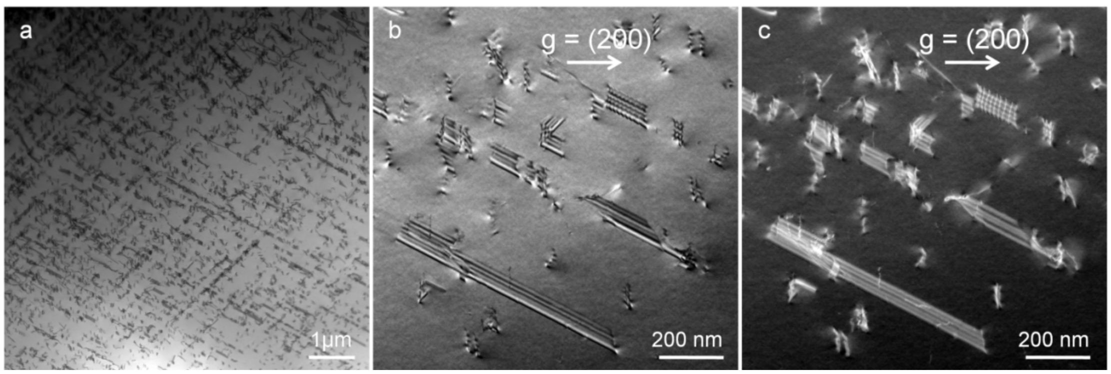

Figure 1. DC-STEM characterization of the deformation substructure of a sample tested to 6.5% plastic strain at room temperature: a) [001] zone axis BF-STEM image, b) systematic row BF-STEM image and corresponding ADF-STEM image.

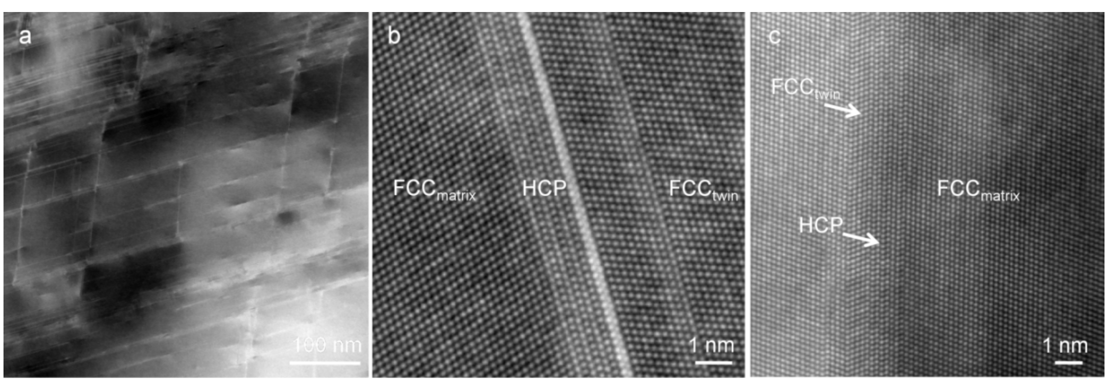

Figure 2. a) low magnification ADF-STEM image showing subgrain structure in a specimen tested to a strain level of 29% at cryogenic temperature, b) ADF-STEM image of nanotwin-HCP lamellae (29% strain, cryogenic temperature), and c) HAADF-STEM image of nanotwin-HCP lamellae (70% strain, room temperature).

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