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Mechanical behavior of a bulk nanocrystalline Ni–Fe alloy

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Abstract

The mechanical behavior of a bulk nanocrystalline (nc) Ni–Fe alloy was studied in this paper. The microstructure of the as-deposited nc Ni–Fe alloy was characterized. The compressive and the fatigue properties of the bulk nc Ni–Fe alloy was investigated. The results indicate that bulk nc Ni–Fe alloy shows an extraordinary high strength, good ductility and a low fatigue-endurance limit.

Keywords: Nanostructured materials; Mechanical properties

1. Introduction

Due to their unique mechanical behavior, nanocrystalline (nc) materials have received sufficient interests recently [1–6]. nc materials often show high strengths compared with their coarse-grained counterparts. Moreover, good ductility was recently realized in nc materials, and was summarized by Koch et al. [7]. We will show that an electrodeposited bulk nc Ni–Fe alloy, with an average grain size of approximately 23 nm, also exhibits a combination of high strength and good ductility. In addition, the fatigue behavior of the bulk nc Ni–Fe alloy will be reported.

2. Experiments

The bulk nc Ni–18 wt.%Fe (wt.: weight percent) sheets were produced, using a pulsed-electrodeposition technique on a polished titanium cathode from a bath containing nickel salts, ferrous salts, a buffer, complexing agents and grain refiners. The as-deposited nc Ni–Fe sheet has dimensions of 70 mm × 70 mm × 3 mm. The as-deposited sheet was cut into different geometries for the compressive tests with a dimension of 5 mm × 3 mm × 3 mm and for the fatigue tests with a dimension of 25 mm × 3 mm × 3 mm. A four-point bend test technique was employed for the fatigue tests with $R = \sigma_{\mathrm{min.}}/\sigma_{\mathrm{max.}} = 0.1$. Transmission electron microscopy (TEM) and high-resolution TEM (HRTEM) observations were carried out, using a Schottky field-emission gun FEI Tecnai F20 UT microscope with a spatial resolution of 0.14 nm operating at 200 kV.

3. Results and discussion

Fig. 1(a) shows the bright-field TEM image for the as-deposited nc Ni–Fe alloy. The average grain size is about 23 nm. The electron-diffraction pattern in the inset of Fig. 1(a) indicates the face-centered cubic structure, suggesting that almost all of Fe is dissolved in the Ni lattice in the as-deposited state. Fig. 1(b) is the HRTEM image. Some dislocations were observed in the as-deposited state. These growth-in dislocations are expected to influence the mechanical properties of the nc Ni–Fe alloy.

The mechanical properties of the nc Ni–Fe alloy during the compressive tests were studied. Fig. 2 shows a typical compressive stress–strain curve for the bulk nc Ni–Fe alloy at a strain rate of $10^{-3}\,\mathrm{s}^{-1}$. After the initial elastic region, the sample exhibits some strain hardening, which may be attributed to the lattice-dislocation motion during the plastic deformation. The bulk specimen has an ultimate strength of about 2.5 GPa. In addition to the extraordinarily high strength, the bulk specimen also shows a strain to failure of 11%, exhibiting a combination of high strength and good ductility. A combination of high strength and good ductility was also obtained during the tensile tests [8]. The sample fails along approximately 45° to the loading direction. However, no shear bands were found during the fracture of the compressive nc specimens, in contrast to the previous reports [9,10].

The fatigue stress range versus the cycles to failure (*S*–*N* curve) for the bulk nc Ni–Fe alloy was presented in Fig. 3. With decreasing the stress range, the fatigue-life cycles increase rapidly. The fatigue-endurance limit is determined to be about

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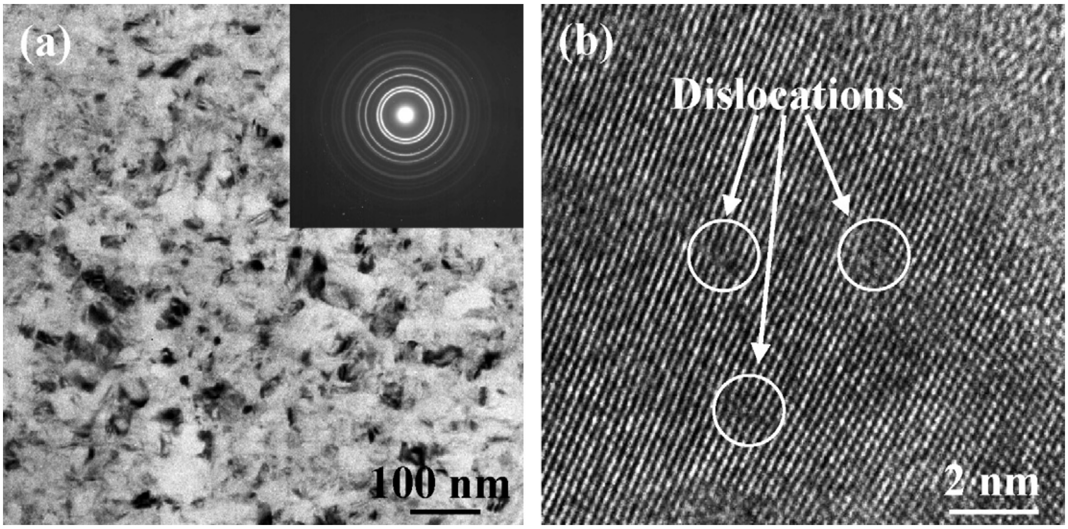

Fig. 1. Bright TEM image (a) and HRTEM (b) for the as-deposited nc Ni–Fe alloy.

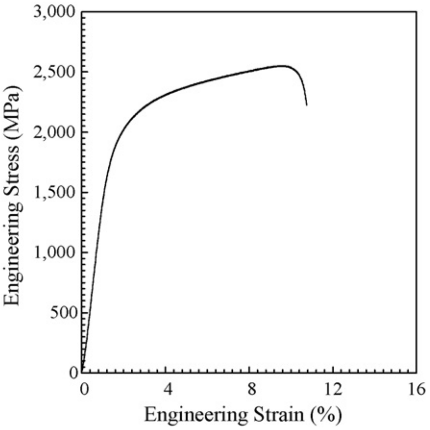

Fig. 2. Compressive stress–strain curve for the bulk nc Ni–Fe alloy at a strain rate of 10^{-3} s^{-1}.

260 MPa, based on the applied stress range, which is about 13% of the yield stress. Note that generally the fatigue-endurance limits of the typical crystalline alloys range from 30 to 50% of the tensile yield strengths [11]. Therefore, the bulk nc Ni–Fe alloy has a low fatigue-endurance limit. Compared with the fatigue behavior of nc Ni during the zero-tension-zero ($R = 0$) reported by Hanlon et al. [12], both high-cycle and low-cycle fatigue lives were reduced for the present nc Ni–Fe alloy. The fatigue-endurance limit (~260 MPa) of the bulk nc Ni–Fe alloy is lower than that (~400 MPa) reported by Hanlon et al. in the nc Ni, although the grain sizes for both materials are comparable.

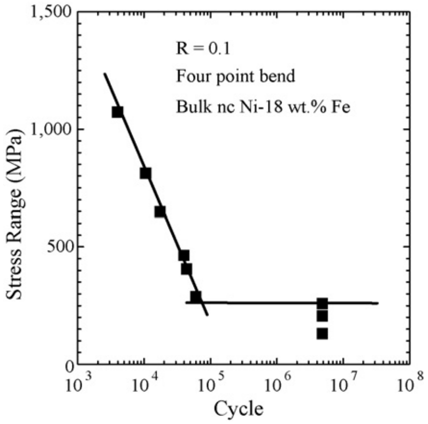

Fig. 3. Fatigue *S–N* curve for the bulk nc Ni–Fe alloy.

4. Conclusions

1. The as-deposited bulk nc Ni–Fe alloy has an average grain size of about 23 nm. The growth-in dislocations were observed in the as-deposited state.
2. The bulk nc Ni–Fe alloy prepared by electrodeposition shows a combination of high strength and good ductility during the compressive tests.
3. The bulk nc Ni–Fe alloy exhibits a low fatigue-endurance limit (~260 MPa) based on the stress range. The investigation is under way to understand the low fatigue limit of this bulk nc alloy.

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