Bending Properties of Nanocrystalline Ni-18 at\% W Alloy Produced by Electrodeposition

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A nanocrystalline Ni-18 at\% W alloy with the grain size of 5.3 nm was produced by an electrodeposition method and its bending properties were investigated in the temperature range between room temperature and 673 K. At room temperature and 373 K, the nanocrystalline Ni-W alloy could be bent to an angle of 180 degrees without fracturing. At 423 K and above, the alloy fractured before reaching 180 degree during bending. Significant springback behavior was observed after 180 degree bending at room temperature under the condition that a compressive load of 9 N was applied during bending. As the compressive load was increased from 30 N to 135 N, the magnitude of springback decreased. Thus, the nanocrystalline Ni-W alloy exhibited excellent bendability at room temperature.

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1. Introduction

The development of nanocrystalline metals has been driven by the scientific view of new materials physics such as novel nanostructure¹ and breakdown of the classical scaling law of Hall-Petch strengthening.² In addition, compatibility of high strength and high ductility in a nanocrystalline metal³ is of technological interest. However, Sanders et al.⁴ showed that ductility in a nanocrystalline metal is lower than that in a coarse-grained metal. The poor ductility of nanocrystalline metal is often attributed to the presence of flaws resulting mainly from the imperfect consolidation of nanocrystalline powders.⁴

Electrodeposition is one of the processes for fabricating a nanocrystalline metal with few or no flaws. The mechanical properties of nanocrystalline Ni and Ni-based alloys produced by the electrodeposition method have been investigated.⁵⁻⁹ Recently, Yamasaki⁷ showed that a nanocrystalline Ni-W alloy produced by the electrodeposition method exhibited a high strength of 2333 MPa and high hardness of 685 Hv. Thus, the nanocrystalline Ni-W alloy is technologically attractive. However, there is little data on the ductility of nanocrystalline Ni-W alloy.

In the present study, the ductility of a nanocrystalline Ni-W alloy produced by an electrodeposition method has been investigated by bending tests in the temperature range between room temperature and 673 K. In particular, the present paper focuses on the investigation of the springback behavior that gives rise to a technological problem in practical applications, such as, press forming for producing high-precision components.

2. Experimental Procedures

Ni-18 at\% W alloy was produced by an electrodeposition method. The details of the preparation procedures have been described previously.⁷,¹⁰ Electrodeposition was conducted on Cu substrates prepared by electropolishing, and an Ir-Ta mesh was used as the anode.

Bending tests were carried out with the crosshead speed of 1 mm/min in air. The samples can be bent 180 degrees using the bending machine, as illustrated in Fig. 1. Specimens of 20μm thickness, 40 mm length and 5 mm width as electrodeposited alloy were prepared for bending tests. Springback behaviors between room temperature and 693 K were observed after 180 degree bending. After 180 degree bending, compressive load of up to 9 N was applied to the bent samples and then released. At room temperature, the springback behaviors were also observed under the conditions that compressive loads were applied up to 30 N and 135 N.

Microstructures of the as-electrodeposited sample and sample tested at 573 K were observed by using a high-resolution transmission electron microscope and X-ray diffraction (XRD) using CuKa radiation in a Rigaku RINT-1500 operated at 40 kV and 200 mA. Surface morphologies
of the samples after 180 degree bending were observed by using a scanning electron microscope.

3. Results and Discussion

The microstructure of the as-electrodeposited nanocrystal-line Ni-W alloy observed by high-resolution transmission electron microscopy is shown in Fig. 2. The average grain size was 5.3 nm. Few flaws such as nano/micro-cracks and -voids were observed in the nanocrystalline Ni-W alloy. XRD pattern for the as-electrodeposited sample revealed that Ni-W alloy were single-phase with an FCC structure, indicating that a solid solution alloy.

The specimens bent at various temperatures between room temperature and 673 K with the crosshead speed of 1 mm/min are shown in Fig. 3. The specimens could be bent to 180 degrees at room temperature and 373 K without fracturing. When the load reached 9 N, the tests were stopped. As shown in Figs. 3(a) and (b), springback occurred after unloading. The magnitude of springback was higher for the specimen bent at room temperature than that for the specimen bent at 373 K.

Schuh et al. investigated the critical grain size in Ni, above which the Hall-Petch equation holds and below which the weakening is followed. They revealed that the critical grain size in Ni is 7–8 nm. Because the grain size of the Ni-W alloy in the present investigation (≈ 5.3 nm) is lower than the critical grain size, the weakening mechanism is suggested to occur. Schiotz et al. showed that weakening in a nanocrystalline material is attributed to sliding at grain boundaries. Therefore, it is likely that the high ductility of the nanocrystalline Ni-W alloy at room temperature and 373 K is related to grain boundary sliding.

On the other hand, some specimens fractured at 423–673 K prior to bending to 180 degrees, as shown in Figs. 3(c)–(f). It should be noted that the nanocrystalline Ni-W alloy exhibited high ductility in a low temperature range below 373 K, however, embrittlement was caused at high temperatures above 423 K.

The microstructure of the specimen bent at 573 K is shown in Fig. 4. No precipitates are observed. Also, XRD pattern reveals that new peak could not observed, indicating that precipitation may not be responsible for embrittlement at high temperatures above 423 K. The grain size was 6.2 nm after testing at 573 K. The grain size strongly influences the ductility of the nanocrystalline Ni-W alloy. The width of boundaries and triple junctions of grains was about ~1 nm for nanocrystalline Ni-W alloy. In this case, grain size expected to attain good ductility is below 7.5 nm. This is larger than that after testing at 573 K, indicating that grain growth is not associated with the embrittlement at high temperatures in this work. It is reported as a result of the detail research that dominant deformation for nanocrystalline...
materials is grain boundary sliding.\cite{12,13} When grain boundary sliding is dominant deformation, pre-exist void is one of the parameters that affect the fracture process. The void features at high temperature are different from that at room temperature for nanocrystalline materials.\cite{14} Therefore, it is surmised that the difference of void feature between room and high temperature is responsible for the embrittlement at high temperature in this work. Further research is needed to understand embrittlement of the nanocrystalline Ni-W alloy at high temperatures.

The occurrence of springback gives rise to a technological problem in practical applications, such as the need for high-precision press forming. Therefore, it is required to reduce the magnitude in spring back. The specimens bent at the large load at room temperature are shown in Fig. 5, where the specimens in Figs. 5(a) and (b) are bent at the loads of 30 N and 135 N with the crosshead speed of 1 mm/min, respectively. Clearly, springback for the specimens was reduced with increasing the load. This suggests that springback is suppressed by loading a large force.

Photographs of the bent part of the specimen bent at the load of 135 N with the crosshead speed of 1 mm/min are shown in Fig. 6. Inspection of Fig. 6(a) reveals that slight springback remains. Cracks were observed at the surface where tensile stress was caused, as shown in Fig. 6(b), indicating that loading of too large a force causes micro-cracking at the surfaces.
4. Summary

A nanocrystalline Ni-18 at% W alloy with the grain size of 5.3 nm was produced by an electrodeposition method, and its bending properties were investigated at room temperature —673 K. The nanocrystalline Ni-W alloy was bent to 180 degrees without fracturing at room temperature —373 K, indicating that the nanocrystalline Ni-W alloy possesses high ductility. However, the nanocrystalline Ni-W alloy fractured before reaching 180 degrees during bending at 423–673 K. Significant springback occurred at room temperature in the specimens bent with a low load of 9 N. The magnitude of springback was reduced by bending with a large load of 30–135 N. However, loading of a large force caused micro-cracking at the surface. Further research is needed to reduce springback and to suppress cracking in the nanocrystalline Ni-W alloy.

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REFERENCES