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CREEP TESTS OF ELECTRODEPOSITED NANOCRYSTALLINE Ni-W ALLOYS AT ELEVATED TEMPERATURES

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Abstract. High-strength nanocrystalline Ni-W alloys containing about 16.9 at.% W with average grain sizes of about 6 nm in diameter have been obtained by electrodeposition. At room temperature, the nominal tensile strength of the Ni-W alloy was attained to about 1600 MPa, while the plastic strain before fracture was a very low value of about 0.05%. In this case, highly localized shear bands were observed near the fractured surface of the tensile test specimen. When the samples were creep-tested at 300 °C for 120 h under the applied tensile stress of 326.7 MPa, plastic strain of about 0.7% without the formation of localized shear bands was observed.

1. INTRODUCTION

Electrodeposited nanocrystalline Ni-W alloys having high hardness and high bending ductility have been developed and reported in our previous study [1-6]. However, these nanocrystalline alloys have been limited in practical applications because of their low ductility under tensile testing conditions. This may be due to the formation of highly localized shear bands during plastic deformation that is a typical phenomenon in nanocrystalline and glassy alloys [7~11]. On the other hand, we have reported that the notable plasticity without the formation of localized shear bands in the nanocrystalline Ni-W alloys was observed during mold clamp forming at the temperatures of 300 °C and below [5, 6]. This plastic deformation behavior may be useful for forming the high-strength nanocrystalline alloys.

In the present study, the nanocrystalline Ni-W alloys with the average grain size of about 6 nm in diameter have been prepared by electrodeposition, and the plastic behaviors during creep test with various applied tensile stresses have been examined.

2. EXPERIMENTAL PROCEDURES

The plating bath for the electrodeposition of nanocrystalline Ni-16.9 at.% W alloys is an aqueous solution of nickel sulfate and sodium tungstate together with complexing agents. The composition of the bath and other details of the electroplating process were given in our previous papers [1-3]. The Ni-W electrodeposition of about 20 μm in thickness was done on the Cu substrates and then the plating samples were cut with the shapes of the tensile test specimens with the parallel portion of 5 mm in length by using the electric discharge machine. The tensile test specimens were separated from the Cu substrates by immersing the samples in an aqueous solution containing CrO_3 and H_2SO_4. The tensile test was carried out by using an Instron-type machine with a strain rate of $4 \cdot 10^{-6}$ /s. The elongation strain during creep test has been mea-

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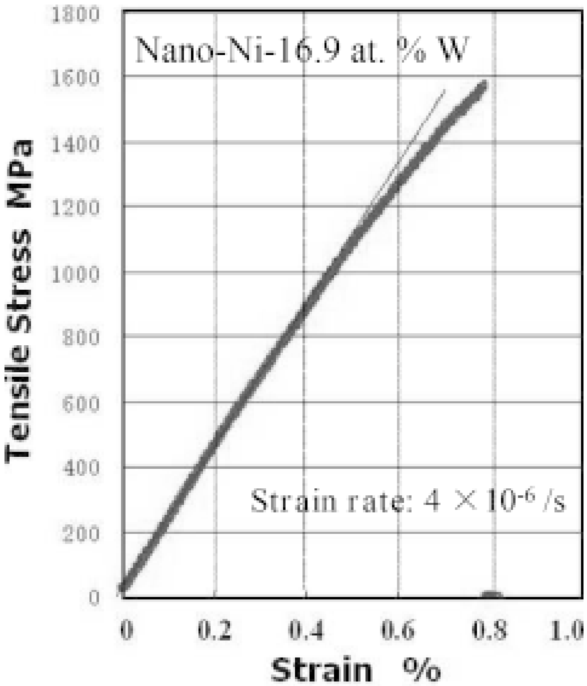

Fig. 1. Stress-strain curves obtained by the tensile test for the nanocrystalline Ni-16.9 at.% W alloy. (Vickers hardness: HV550, Grain size: about 6 nm in diameter).

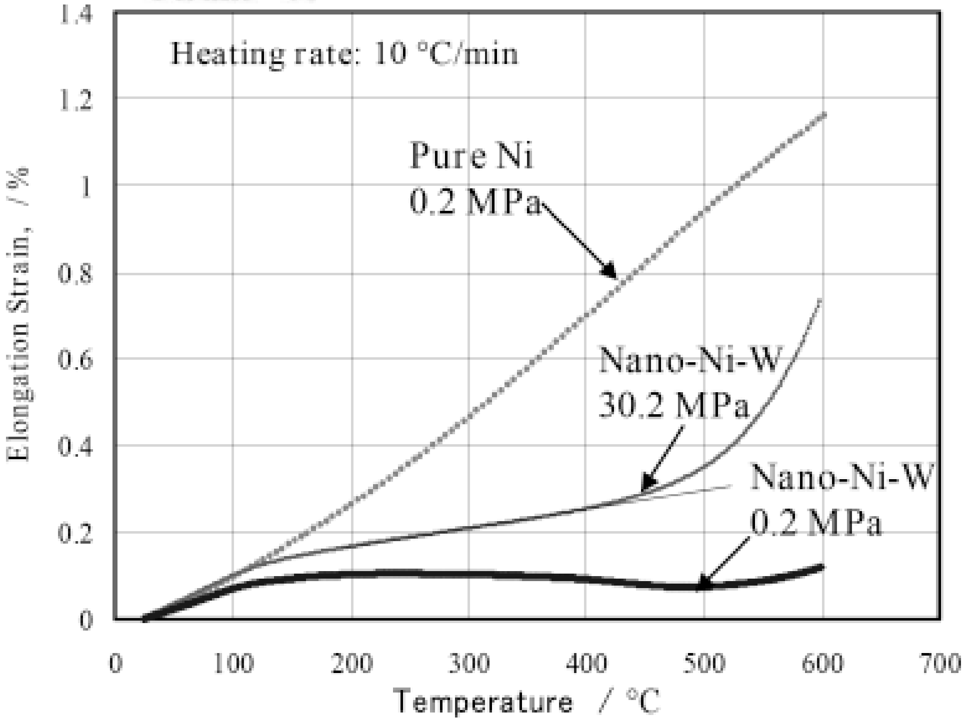

Fig. 2. Elongation strain of the pure-Ni and the naocrystalline Ni-16.9 at.% W alloy as a function of temperature during heating at the rate of 10 °C/min with various applied tensile stresses.

sured by using a dilatometer in tension mode (Rigaku TMA 8310) with various applied stresses between 0.2 MPa and 326.7 MPa (Parallel portion of the specimen is 15 mm in length).

3. RESULTS AND DISCUSSION

Fig. 1 shows the stress-strain curves obtained by the tensile test for the nanocrystalline Ni-16.9 at.%

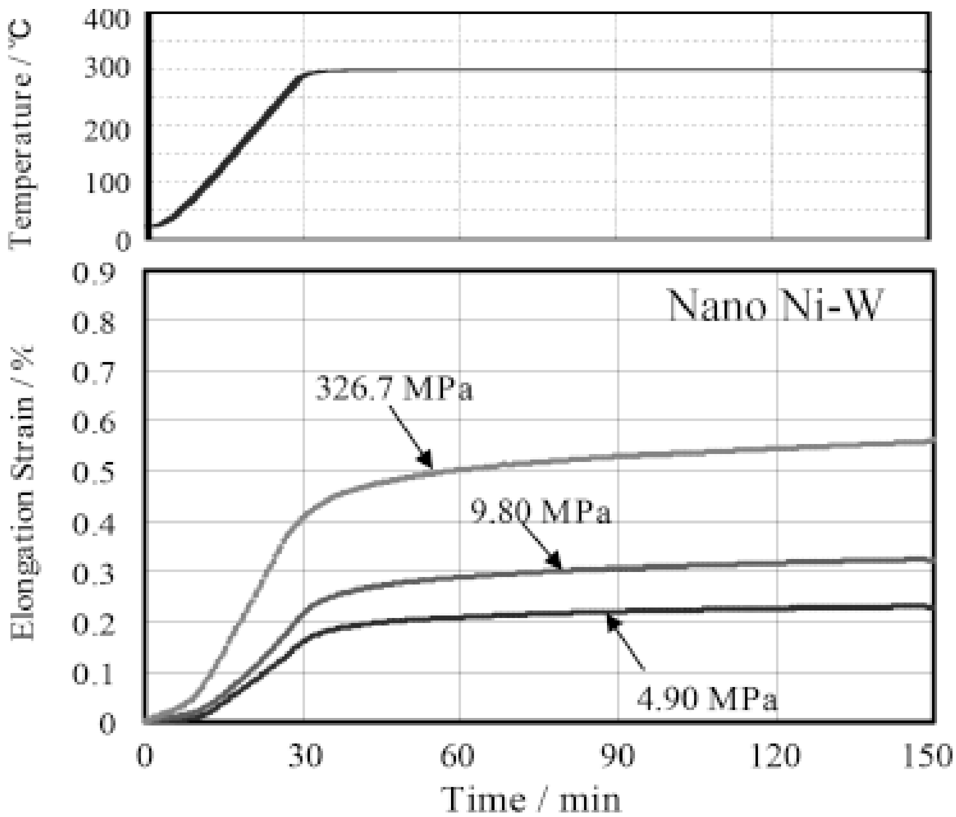

Fig. 3. Elongation strain of the nanocrystalline Ni-16.9 at.% W alloys during annealing at 300 °C with the applied tensile stresses of 4.9, 9.8 and 326.7 MPa.

W alloy with the grain size of about 6 nm in diameter and the Vickers hardness of about HV550. The apparent yield stress, the nominal tensile strength and the total elongation at fracture were attained to 1000 MPa, 1580 Mpa, and about 0.78%, respectively. However, the plastic strain before fracture was a very small value of about 0.05%. In this case, highly localized shear bands were observed near the fractured surface of the tensile test specimen. Fig. 2 shows the elongation strain of the pure-Ni and the naocrystalline Ni-16.9 at.% W alloys as a function of temperature during heating at the rate of 10 °C /min with various applied tensile stresses. In the case of the pure-Ni with the applied tensile stress of 0.2 MPa, an almost linear relationship was observed. While in the case of the nanocrystalline Ni-W alloys, the elongation strain was much smaller than that of the pure-Ni, and a shrinkage behavior was observed at the temperatures of about 100 °C and above. With increasing the applied tensile stress from 0.2 MPa to 30.2 MPa, the elongation strain of the Ni-W alloys increased at the starting temperature of about 100 °C, and the sharp increase of the strain was also observed at about 420 °C and above, indicating that the nanocrystalline Ni-W alloys can be deformed plastically by applying the relatively low tensile stresses such as 30 MPa during heating at the temperature of about 100 °C and above.

Fig. 3 shows the elongation strain of the nanocrystalline Ni-W alloys during creep test at 300 °C with the applied tensile stresses of 4.9, 9.8, and 326.7 MPa. In this case, the elongation strain was corrected by subtracting the amounts of thermal expansion and shrinkage strains that obtained by the standard nanocrystalline Ni-W samples with the applied tensile stress of 0.2 MPa. As shown in this figure, the elongation strain increased with increasing the applied tensile stress during heating from R. T. up to 300 °C and then tended to saturate with increasing the creep testing time at 300 °C.

Fig. 4 shows the elongation strain of nanocrystalline Ni-16.9 at.% W alloys after creep test at various temperatures for 2 and 120 h under

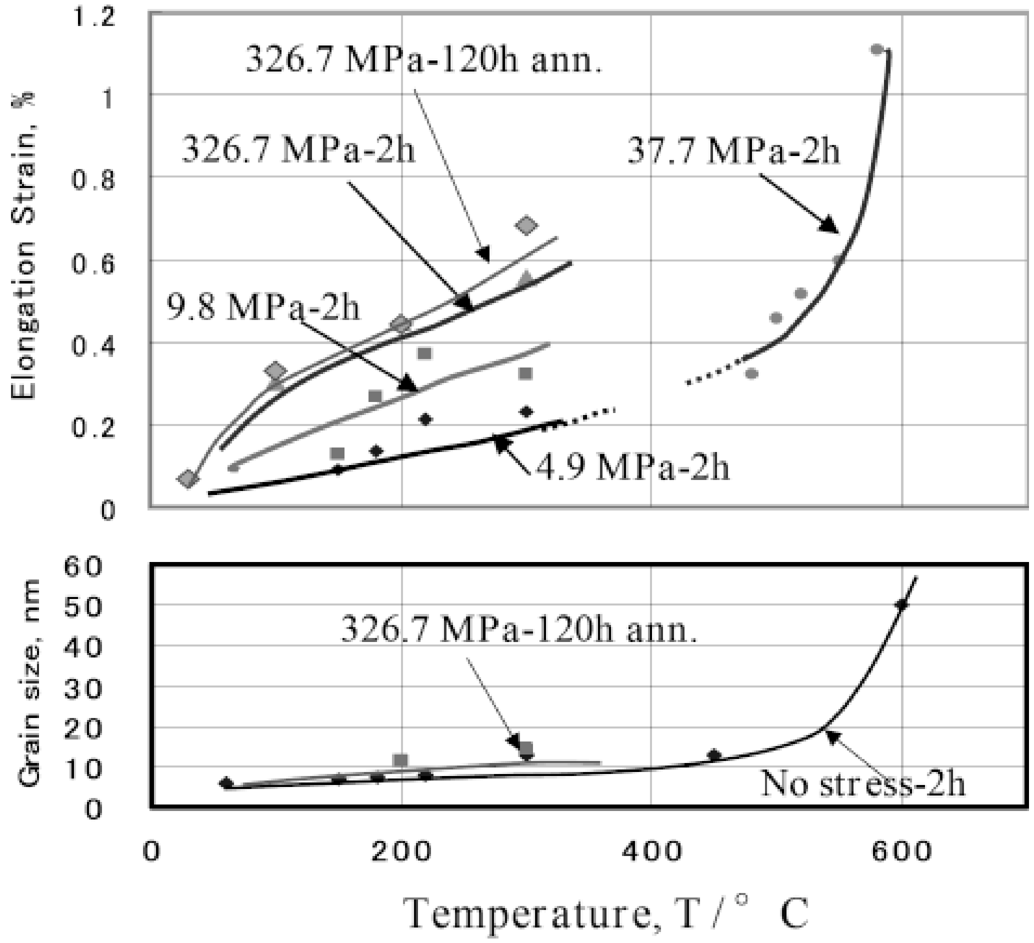

Fig. 4. Elongation strain and grain size of nanocrystalline Ni-16.9 at.% W alloys after annealing at various temperatures for 2 and 120 h under various tensile stresses.

various applied tensile stresses of 4.9, 9.8, 37.7, and 326.7 MPa. For comparison, grain size of the nanocrystalline alloys after annealing at various temperatures under stressing and no-stressing conditions are also shown. At the temperature of 300 °C and below, the elongation strain was increased with increasing the applied tensile stress and attained to a maximum value of 0.68%. However, as shown in the case of the 326.7 MPa, the elongation strain tended to saturate at each temperature only for 2 h and small progress in the elongation strain after the creep test for 120 h. In addition, grain size of the nanocrystalline Ni-W alloys was also saturated to about 10 ~ 15 nm at each temperature for only 2 h under stressing and no-stressing conditions. For example, the grain size increased to 13.7 nm after annealing at 300 °C for 2 h under no-stressing conditions. While, after long-time creep testing at 300 °C for 120 h under a large tensile stress of 326.7 MPa, only slight progress in grain size to 14.2 nm was observed. This may be due to the existence of a metastable specific grain size in the vicinity of 10~15 nm in diameter and correlative relationships between the plastic deformability and the grain growth of nanocrystalline Ni-W alloys. So, the grain size of nanocrystalline Ni-W alloys might be increased speedily up to about 15 nm during the creep test at 300 °C and below, and then tended to saturate, suggesting that the applying high tensile stress during grain growth might be effective to obtain the uniform plastic deformation of nanocrystalline Ni-W alloys. At the temperature of 420 °C and above, grain growth can continue with increasing the annealing time under no-stressing condition, and plastic deformation may also progress.

4. CONCLUSIONS

Plastic deformation of electrodeposited nanocrystalline Ni-16.9 at.% W alloys during creep test under some applied tensile stresses has been examined. At the temperature of 300 °C and below, the elongation strain was increased with increasing the applied tensile stress and attained to a maximum value of 0.68%. However, the elongation strain tended to saturate at each temperature for only 2 h, and the grain size of the nanocrystalline Ni-W alloys was also saturated to about 10 ~ 15 nm at each temperatures for 2 h. It may be expected that the applying high tensile stress during grain growth might be effective to obtain the uniform plastic deformation of nanocrystalline Ni-W alloys.

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