ELECTRICAL RESISTANCE, COMPRESSIONAL STRENGTH, AND EXTENSION OF Ni – Mo and Ni – W ALLOYS

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An experimental study has been made of the temperature dependences of the compressional strength of Ni alloys with 5 and 10 at. % Mo and 5 at. % W, of the kinetic curves for the electrical resistance during annealing at 400 °C, and of the nature of the tensile deformation at various temperatures. The mechanism primarily responsible for the anomalous behavior of the temperature-rate dependence of the strength of these alloys may be the formation of microscopic carbide inclusions and Cottrell carbon atmospheres at dislocations during the deformation. Presence of the K state amplifies the jumps on the flow curves.

In several solid-solution alloys (Ni – Mo, Ni – W, Ni – Cr, etc.) annealing after quenching or deformation gives rise to a K state whose basic characteristic is an increased electrical resistance (see, e.g., [1–4]). A similar effect – an increase in the electrical resistance – is observed during the initial stages of ordering and decomposition in alloys of these system [4–6]. Structural studies have shown [3–6] that the increase in the electrical resistance (the K state) is due to short-range ordering and to small ordered zones. Only the first of these factors operates in single-phase alloys under equilibrium conditions. At annealing temperatures near the solubility boundary and in the two-phase region, this first factor may be suppressed because of the high energy barrier for the nucleation of ordered phase. However, deformation before annealing can lead to a two-phase state by lowering the nucleation barrier.

The K state has been shown to increase the strength [2, 7, 8]. In addition, in the temperature range in which the K state is formed, an anomalous temperature-rate dependence is observed for the strength, and the deformation becomes discontinuous [9–16]. All these effects were initially attributed to short-range ordering [9, 10, 14]. The strengthening role of short-range order was demonstrated in [17]. The data of [3, 18, 19], on the other hand, apparently imply that short-range order increases the strength only in the microdeformation region, and the increase in the macroscopic strength resulting from K state formation is due to the formation of ordered regions or of incomplete long-range order.

Cottrell atmospheres of carbon atoms can form in Ni – Fe – Cr, Ni – Fe – Mo, and Ni – Mo alloys and can affect the temperature dependence of the mechanical properties near 200 °C [12, 13, 15, 16]. Deformation aging due to carbon is easily detected in nickel [20, 21].

In an attempt to determine the roles of various mechanisms in the anomalous temperature-rate dependence of the strength of alloys having a K state, we studied alloys differing in the effectiveness of the K state.

EXPERIMENTAL MATERIALS AND METHOD

We studied nickel alloys containing 5 and 10 at. % Mo and 5% W. Some information on the alloy with 10% Mo was taken from [16]. The alloys were fused from standard-purity components in corundum crucibles under a fusing agent. After a diffusion annealing (at 1200 °C for 50 h), the ingots were forged into rods, from which wire samples and samples for the compression tests were prepared.

We studied the dependence of the electrical resistivity on the time during a 400 °C annealing, the temperature and rate dependences of the compressional strength at 20–600 °, and the nature of the deformation.

Fig. 1. Kinetic curves for the electrical resistance during annealing at 400°C of the following alloys: 1, 4) Ni + 5% Mo; 2, 5) Ni + 10% Mo; 3, 6) Ni + 5% W. 1-3) Tests at 20°C; 4-6) at -183°C.

RESULTS AND DISCUSSION

Figure 1 shows kinetic curves for the electrical resistance. The resistance of the alloy with 5% Mo remains essentially constant during the annealing; there is some increase in the resistance at -183°C, but none at all at room temperature. Accordingly, only a very slight amount of K state is formed during annealing of the quenched alloy with 5% Mo. At any rate, the K state in this alloy is formed to a much lesser extent than in the alloy containing 10% Mo (curves 2 and 5), in agreement with the data of [4]. From our results and from those of [4] we can thus conclude that there is extremely little short-range order in the annealed alloy containing 5% Mo. In the alloy containing 10% Mo, on the other hand, the short-range order is well-defined.

Figure 1 shows that the resistance of the alloy with 5% W decreases during the annealing, so the K state is apparently not formed here. This result would have been expected on the basis of [4]. The decrease in the resistance of the alloy with 5% W is apparently due to the runoff of quenching vacancies into sinks and to the formation of tungsten carbide.

Figure 2 shows the temperature dependence of the compressional strength at various degrees of deformation for all three alloys. In the temperature range 150-500°C the \( \sigma(T) \) dependences are oscillatory, and maxima are clearly defined at some degrees of deformation \( \varepsilon \). In the alloy with 10% Mo, e.g., two maxima are observed at moderate deformation degrees, in addition to a plateau (curve 6). At large and small deformation degrees, the second maximum (400-500°C) is replaced by a plateau (curves 5 and 7). The first maximum also disappears at small deformation degrees (curve 5).

Figure 2 shows that the behavior of the compressional strength of the alloy with 5% Mo (curves 1 and 2) is extremely similar to that of the alloy with 10% Mo. The only difference is that the third plateau in the overall decrease (or anomalous increase) of \( \sigma \) with increasing \( T \) is defined more poorly in the alloy with 5% Mo than in that with 10% Mo.

The data obtained with the alloy with 5% W are illustrated by curves 3 and 4 in Fig. 2. A peak corresponding to temperatures of 150-400°C is clearly displayed on the \( \sigma(T) \) curves for this alloy. At higher temperatures and for small deformation degrees, there is also a maximum (curve 3), which is replaced by a plateau at larger \( \varepsilon \).

This \( \sigma(T) \) behavior shows that deformation aging occurs in all three alloys at temperatures above 150°C and strengthens the alloys. Further evidence for this is the anomalous effect of the deformation rate on the strength, observed in all three alloys and illustrated by curves 7 and 8 in Fig. 2 for the alloy with 10% Mo. Moreover, the behavior of the deformation aging implies a discontinuous deformation (Fig. 3). The minimum temperature at which jumps appear is 200°C; at this temperature, jumps are evident at higher deformation degrees. A deformation occurs discontinuously for \( T \approx 200°C \).