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EFFECTS OF SEVERAL FACTORS ON THE DUCTILITY OF THE Ti-Ni ALLOY

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ABSTRACT

The effects of the following several factors on the ductility of the Ti-Ni alloy have been investigated: Ni-concentration, test temperature and heat-treatment. Tensile tests were carried out for measuring elongation (the fracture strain), which was mainly used as a measure of ductility. The elongation decreased with increasing Ni-concentration in solution-treated specimens. Annealing at a temperature above 873K was effective to increase the ductility of cold worked specimens. It was also found that the martensite phase was more ductile than the parent phase. The elongation of the solution-treated specimen showed a test-temperature dependence. However, the elongation of the age-treated Ni-rich specimen hardly showed test temperature dependence.

1. INTRODUCTION

The Ti-Ni alloy is the most important material among many shape memory alloys for the applications of the shape memory effect or superelasticity. This is partly because the alloy is ductile in a polycrystalline state [1-4]. Since the alloy shows the perfect shape memory effect or superelasticity after heat-treatment at any temperature, the critical stress for slip can be raised by introducing dislocations [5] and/or fine precipitates [5,6]. The fine precipitates can be introduced only in Ni-rich specimens [7], while dislocations in all Ti-Ni specimens. Therefore, cold working is important for introducing enough density of dislocations in order to achieve the stable shape recovery in all Ti-Ni alloys as well as for forming the alloy into any shapes.

Workability or ductility of the Ti-Ni alloy depends on the test temperature [1,2], heat-treatment[4] and Ni-concentration.

However, no systematic understanding about the ductility of this alloy has been attained. The purpose of this paper is to clarify the effects of all the above factors on the ductility of the Ti-Ni alloy by a systematic investigation.

2. EXPERIMENTAL

The alloys were prepared using electron beam melting method. The compositions of the alloys range from 50.0 to 52.0at%Ni. The ingots of these alloys were hot rolled, followed by final cold rolling with 20% reduction. The plates thus obtained were 1.0 mm thick. Specimens were spark cut, the gage portion being of 1.0 mm x 1.5 mm x 15 mm size. They were then subjected to two types of heat-treatments respectively; i.e. (1) annealing at a temperature between 573K and 1273K after cold working (annealing) and (2) solution-treatment at 1273K for 3.6ks followed by quenching into iced water, and then age-treatment at a temperature between 373K and 973K (age-treatment). All specimens were electro-polished after the above heat-treatment and then tensile tested. Tensile tests were carried out with an Instron type tensile machine, Shimadzu Autograph DSS-10T-S type. Test temperatures were controlled by keeping a specimen in ethanol which were heated by a heater or cooled by pouring liquid nitrogen.

3. RESULTS AND DISCUSSION

Basic characteristics of the mechanical properties such as ductility can be examined using solution-treated specimens, because such specimens do not have special internal structure such as dislocations and precipitates. Figures 1 and 2 show the stress-strain curves of the solution-treated Ti-50.5at%Ni and Ti-50.9at%Ni alloys respectively, which were tensile tested to the final fracture at various temperatures between 77K and 473K. The elongations of the Ti-50.5at%Ni and Ti-50.9at%Ni alloys are shown as a function of test temperature in figures 3 and 4, respectively. The elongation obtained at M_s is the largest for both alloys; the elongation decreases with increasing or decreasing temperature. Therefore, deforming at M_s after

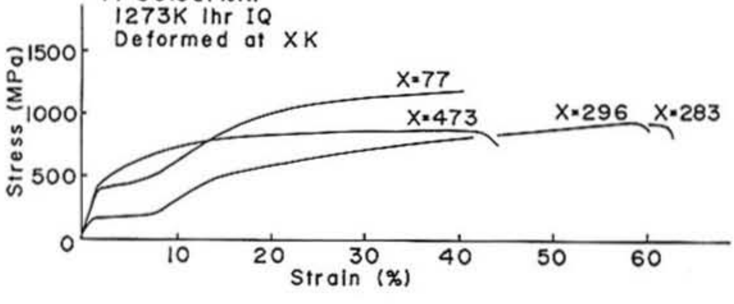

Figure 1. Stress-strain curves of solution-treated Ti-50.5at%Ni specimens which were deformed at various test temperatures.

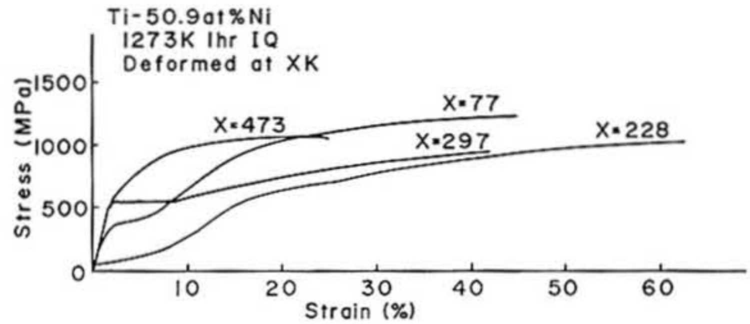

Figure 2. Stress-strain curves of solution-treated Ti-50.9at%Ni specimens which were deformed at various test temperatures.

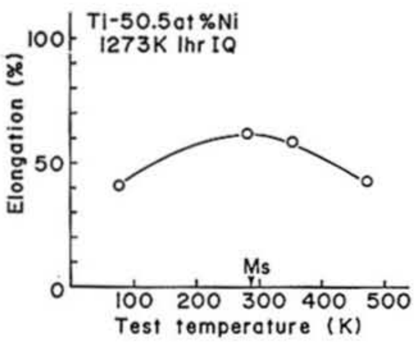

Figure 3. Elongations of solution-treated Ti-50.5at%Ni specimens which were deformed at various test temperatures.

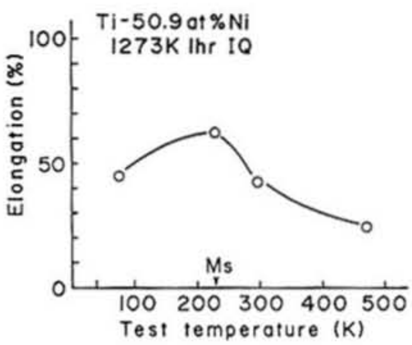

Figure 4. Elongations of solution-treated Ti-50.9at%Ni specimens which were deformed at various test temperatures.

solution-treatment is suitable for deriving the best cold workability.

The ductility of the martensite phase can be determined by deforming at M_s, because the martensite is induced easily at a low stress; while the ductility of the parent phase can be determined by deforming at 473K, because this temperature is higher than M_d, above which the martensite is not stress-induced and plastic deformation occurs in the parent phase. Figure 5 shows the elongation at M_s or 473K as a function of Ni-concentration. The elongation at M_s is always larger than that at 473K for any Ni-concentration. This is because the critical stress for slip at M_s is always lower than that at 473K. It is also found that the elongations at M_s for specimens with Ni-concentrations between 50.0 and 51.0at% are more than 60%, while those for the Ti-51.5at%Ni and 52.0at%Ni alloys are about 20% or less although they were deformed at M_s.

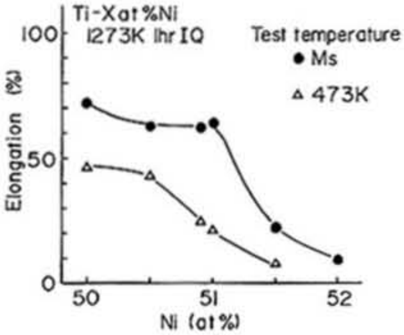

Figure 5. Elongations at Ms or 473K in solution-treated specimens with Ni-concentrations ranging from 50.0 to 52.0at%Ni.

In order to form the alloy by cold rolling or drawing, intermediate annealing is necessary for removing work hardened structure due to the preceding working. In this case, it is important to determine a suitable range of the intermediate annealing temperatures for attaining a high ductility. Figure 6 shows stress-strain curves of the Ti-50.5at%Ni specimens which

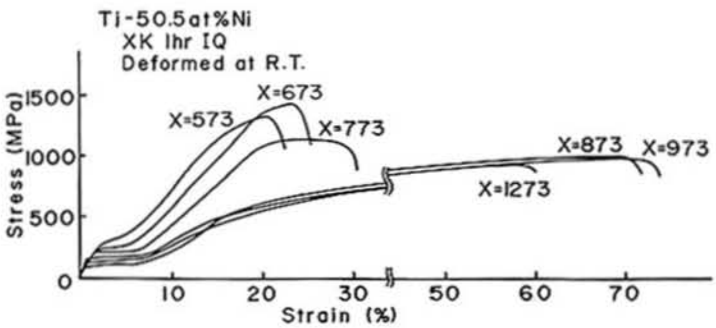

Figure 6. Stress-strain curves at room temperature in Ti-50.5at%Ni specimens which were annealed at various temperatures ranging from 573 to 1273K for 3.6ks after the preceding cold working.

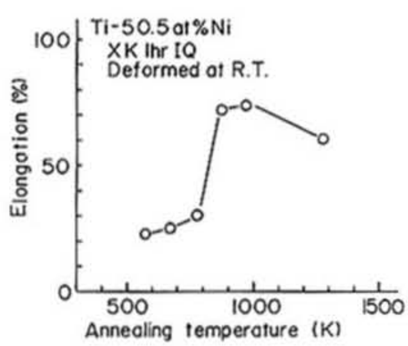

Figure 7. Elongations at room temperature in Ti-50.5at%Ni specimens which were annealed at various temperatures ranging from 573 to 1273K for 3.6ks after the preceding cold working.

were annealed at various temperatures ranging from 573K to 1273K after cold working with 20% reduction and then deformed at room temperature. The elongation vs. annealing temperature relationship is shown in figure 7, where a large elongation is derived by annealing the specimen at a temperature above 873K. Since this critical temperature is a little higher than the recrystallization temperature, many dislocations introduced by the preceding cold working were removed and the grain growth after the recrystallization was promoted, resulting in lowering the critical stress for slip.

The critical stress for slip is also affected by the precipitation hardening in Ni-rich specimens as well as by the work hardening. Therefore, it is necessary to exclude precipitates as well as dislocations in order to attain a high cold workability in such specimens. Figures 8 and 9 show the effects of annealing temperature and aging temperature on the stress-strain curve of the Ti-50.9at%Ni alloy respectively which

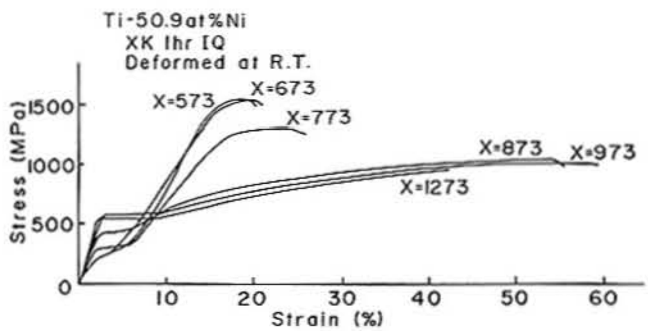

Figure 8. Stress-strain curves at room temperature in Ti-50.9at%Ni specimens which were annealed at various temperatures ranging from 573 to 1273K for 3.6ks after the preceding cold working.

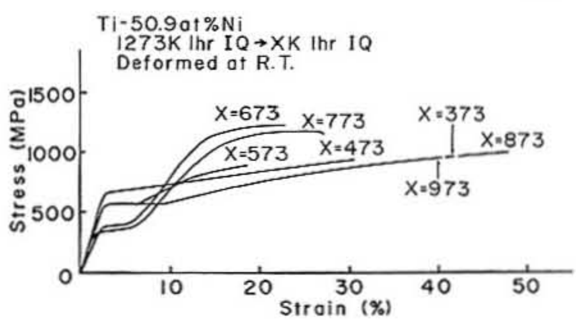

Figure 9. Stress-strain curves at room temperature in Ti-50.9at%Ni specimens which were age-treated at various temperatures ranging from 573 to 973K for 3.6ks after the preceding solution-treatment.

were tested at room temperature. It is clear that both the heat-treatments affect the stress-strain curve. The elongation is shown as a function of annealing temperature or aging temperature in figure 10, where open circles indicate the elongations for the former, while closed circles those for the latter. There is also a critical annealing temperature similarly to the Ti-50.5at%Ni alloy, annealing at a temperature above which being effective to increase the elongation; the critical temperature was almost the same as that in the Ti-50.5at%Ni alloy.

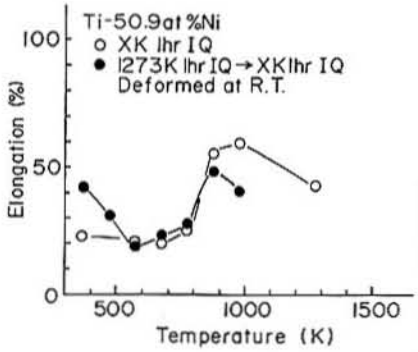

Figure 10. Elongations at room temperature in Ti-50.9at%Ni specimens as a function of annealing temperature after the preceding cold working or a function of aging temperature after the preceding solution-treatment.

Although a high cold workability is obtained by annealing at a temperature above the critical temperature, the elongation decreases by aging in an intermediate temperature range between 573K and 873K as shown by the closed circles. This means that working with a Ni-rich specimen in the intermediate temperature range will deteriorate the workability. The elongation of such an age-treated Ni-rich specimen was almost constant , i.e. about 20% for the Ti-50.9at%Nialloy, irrespective of test temperature.

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