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EFFECTS OF AGEING ON DAMPING CAPACITY OF TiNi ALLOYS

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Abstract: Young's modulus (E) and damping capacity (SDC) of binary TiNi alloys have been measured between 150K and 375K by a flexural vibration method with a frequency of about 260Hz and strain amplitude of 1x10^-5. Ageing of higher Ni alloys at lower temperatures increases transformation temperatures of the quenched state and yields another critical point at a higher temperature where E decreases and SDC increases sharply, while changes in both E and SDC of lower Ni alloys aged at higher temperatures are small. Ageing process is discussed from these effects of ageing on the temperature spectra of E and SDC which are classified in detail into seven cases.

1. Introduction Mechanical properties which are associated with shape memory effect and pseudo-elasticity of TiNi alloys are reported to be influenced by ageing /1/ and damping characteristics of the alloys are known to depend on their pre-treatments and compositions/2/3/4/. These phenomena must be related to variation of transformation behaviour according to alloy compositions and ageing treatments/1/5/.

The present report deals with systematical measurement of temperature dependence of Young's modulus and damping capacity of binary TiNi alloys as function of Ni contents and ageing treatments. The results are discussed with respect to effects of ageing process on transformation behaviour.

2. Experimental Procedure Alloys were prepared from sponge titanium and electrolytic nickel by argon-arc melting as 100g buttons. They will be named in the following paragraphs by their nominal concentration of nickel as atomic percent. They were processed to sheets 0.75mm in thickness by hot and cold rolling and annealing. Specimens 10mm in width and 100mm in length were kept for 6h at 1233K in argon-sealed silica tubes and quenched by breaking the tubes in water. They were heated to 375K, and frequency of flexural vibration and its free decay were measured on stepwise cooling (cooling run) to 150K and re-heating to 375K (heating run) so that the measurement was made at constant temperatures. The damping capacity (=SDC) was obtained as SDC=100(A_n-A_0)/A_0, where A_n is the nth amplitude of vibration and Young's modulus (=E) was calculated from the resonant frequency. The specimens were aged after the first measurement in an argon furnace and cooled in its cooling zone. They were then measured again, and measurement and ageing were further repeated for the same specimens.

3. Results and Discussion 50.1Ni to 51.2Ni show in the quenched state one minimum
An example of pattern 1. An example of pattern 2.

Pattern 1 (Fig. 1): 49.6Ni shows hence the largest difference between $T_{\text{Emin}}$ and $T_{\text{SDCmax}}$ and the other small peak of SDC is located at $T_{\text{Emin}}(330K)$. A steep decrease of $E$ on cooling at about 340K is made larger by ageing at a lower temperature but the temperature of steeply decreasing $E$ is unchanged, while the larger peak of SDC is made smaller. Pattern 2 (Fig. 2):

In the case of quenched 49.8Ni, a relatively steep decrease of $E$ and an increase of SDC begin on cooling nearly at the same temperature (340K). The corresponding increase and decrease occur on heating at an about 20K higher temperature. When aged at lower temperatures, another steep decrease of $E$ on cooling appears at about 280K. With increasing ageing time, its temperature increases and it becomes indistinguishable from that of the first steep decrease. The corresponding increase of $E$ on heating occurs, however, in two steps. Pattern 3 (Fig. 3): When lower Ni alloys are aged at higher temperatures, $T_{\text{Emin}}$ as well as $T_{\text{SDCmax}}$ are almost not affected. The peak height of SDC only decreases and $E$ at lower temperatures increases a little. These behaviours suggest that not essential but small changes, for example such as segregation of impurities to dislocations and incoherent twin boundaries, have occurred in the structure.
Pattern 4 (Fig. 3): In the case of higher Ni alloys, ageing at higher temperatures makes both $T_{E\text{min}}$ and $T_{SDC\text{max}}$ a little higher. The temperature shift could be explained in terms of decrease of Ni content in matrix by precipitation of a second phase. Boundaries between the patterns are shown in Fig. 7 superimposed on a partial phase diagram of the Ti-Ni system. The phase boundaries are drawn after Honma and Takei/5/ and Hirano and Ouchi/6/. (Precipitation of $\text{Ti}_{2}\text{Ni}_3$ and $\text{Ti}_{11}\text{Ni}_{14}$ are proposed by Honma et al., in Meetings of Japn. Inst. of Metals.)

Pattern 5 (Fig. 4): Patterns 5 and 2 are the same in the sense that ageing makes the steep decrease of $E$ and increase of SDC on cooling appear. The changes are, however, more pronounced in pattern 5 than in pattern 2. Another difference is that $E$ after short ageing decreases on cooling two-stepwise in pattern 2 but one-stepwise in pattern 5. Pattern 6 (Fig.'s 5 and 6): is similar to pattern 5. $T_{SDC\text{max}}$ quenched and aged at 673K, and of 50.8Ni alloy, is, however, increased by ageing in pat-0.4Ni alloy aged at 823K presents a pattern 6, but not in pattern 5. This difference of pattern 7, while 50.8Ni alloy must be also due to the difference aged at 673K another example of pattern 6 of precipitated Ni content in matrix.

Pattern 7 (Fig. 6): This pattern is transitional one between either patterns 5 and 3 or patterns 6 and 4. In the former case(50.4Ni in Fig.6), the spectra of $E$ and SDC are the same as those of shortly aged specimens in pattern 2, namely two-step decrease of on cooling and no shift of $T_{SDC\text{max}}$. In the latter case, $E$ decreases on cooling similarly in two steps but $T_{SDC\text{max}}$ also increases as in pattern 6.

Critical temperatures after long ageing($T_{crit.}$), where the temperature gradient of $E$ on cooling is largest, are summarized in Fig. 8. On cooling in patterns 1, 2, 5, and 6, $E$ decreases and SDC increases sharply at these critical temperatures. In pattern 7, though the increase of SDC occurs together with a less steep decrease of $E$ at a higher temperature(for example at 300K by 50.4Ni in Fig.6), $E$ and SDC change again sharply at $T_{crit.}$ (at 262K by 50.4Ni in Fig.6). That these $T_{crit.}$'s increase
with increasing ageing time and approach certain values which decrease with increasing ageing temperature (Fig. 8) but unaffected by Ni contents, except in the case of pattern 1, namely 49.6Ni, and that the critical phenomena appear under the condition that the temperature of minimum E as quenched state is low enough relative to the saturation value of Tcrit. (Fig. 7) suggest: Ageing yields some ageing temperature sensitive structural changes also, such as atomic ordering. The critical temperature may in the case of pattern 5 and 6 correspond to the incommensurate-commensurate transition temperature as proposed for TiNiFe by Mercier et al. 1/3.

A small hysteresis of the critical temperatures between cooling and heating runs (50.8Ni aged for 32h in Fig. 6) support this point of view. But other possibilities should be further studied for other patterns (for example two-step increase on heating for one-step decrease on capacity in Ni-content-ageing-temperature cooling of 49.8Ni aged for 128h in Fig. 2). The exception of 49.6Ni may be due to its incomplete re-transformation at 375K.

4. **Summarizing Conclusions**

Temperature spectra of Young's modulus (E) and damping capacity (SDC) of quenched and aged TiNi alloys were measured between 150K and 375K. In the quenched state, the alloys with 50.1 to 51.2 at% Ni show one minimum in E and one maximum in SDC, while two maxima in SDC are observed in the 49.6Ni alloy and one but wide maximum in the 49.8Ni alloy. When aged at lower temperatures, the temperature of maximum SDC increases and a sharp decrease of E together with a sharp increase of SDC appears on cooling at a critical temperature. The increase of the temperature of maximum SDC occurs only when that temperature of the quenched state is below 250K, namely when Ni contents are larger than about 50.5 percent. The ageing effects are small when aged above critical temperatures which decrease with decreasing Ni contents. The ageing behaviour of Young's modulus and damping capacity suggests that the ageing yields beside precipitation some ageing temperature sensitive structural changes, such as atomic ordering.

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