Elastic moduli and internal frictions of Inconel 718 and Ti–6Al–4V as a function of temperature

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In previous papers [1, 2], Young's, shear and bulk moduli, Poisson's ratio and the Lamé parameter* longitudinal and transverse internal friction values and acoustic wave velocity anisotropy factors for four kinds of polycrystalline compounds, α-alumina, (Y)TZP (yttria-stabilized tetragonal zirconia polycrystal) and β'-sialon $(Si,Al)_3(N,O)_4$ and α-SiC were simultaneously measured over a temperature range 295–1818 K, by an ultrasonic pulse sing-around method, using the frequency of 5 MHz. In this study, we report temperature dependence of the elastic moduli, Poisson's ratio, dilational and shear internal frictions for Inconel 718 and Ti–6Al–4V. The former is a representative nickel-based superalloy strengthened by intermetallic compound precipitates containing Nb [3], and the latter is the most commonly used titanium alloy consisting of α and β phases [4]. Both alloys have been used for advanced structural applications such as gas turbine and jet plane components [5, 6]. No research work has been carried out on high-temperature simultaneous measurement of all the parameters for these alloys, as far as we know, although these parameters are extremely important for material design in such applications. The experimental procedure is described in a previous paper [1]. In order to avoid propagation loss due to the high frequency ultrasonics, frequencies of 5 and 2.25 MHz were used for the Ni and the Ti alloys, respectively. The specimens were heated at a rate of 0.25 K s^{-1} to 1385 and 1326 K, at which temperatures the transverse wave disappears, for the Ni and the Ti alloys, respectively. (Determination of all elastic moduli in the high temperature range is limited by disappearance of the transverse wave.)

The four elastic moduli (Young's, shear and bulk moduli, Lamé parameter) of the Ni and the Ti alloys as a function of temperature are shown in Figs 1 and 2, respectively. The four moduli of the Ni alloy decrease substantially as the temperature increases. The modulus–temperature slope of Young's modulus is larger than those of shear and bulk moduli and the Lamé parameter. This suggests activation of the dilational mode at elevated temperature in contrast with activation of shear mode as seen in ceramics such as (Y)TZP and β'-sialon [1]. On the other hand, decrease in the volume modulus is sluggish over the whole temperature range, compared with those of ceramics, α-alumina, (Y)TZP and β'-sialon [1] and α-SiC [2].

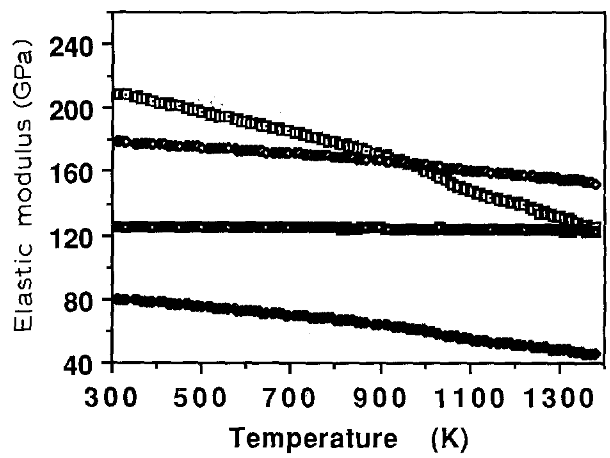

Figure 1 Young's (□), shear (◆), bulk (■) moduli and Lamé parameter (◇) of Inconel 718 as a function of temperature.

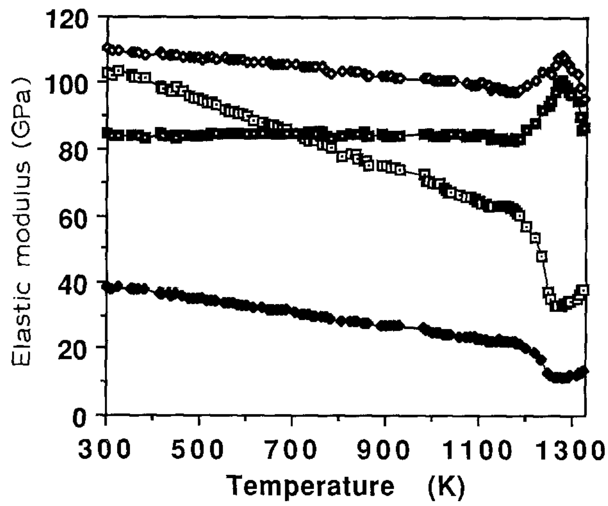

Figure 2 Young's (□), shear (◆), bulk (■) moduli and Lamé parameter (◇) of Ti–6Al–4V as a function of temperature.

By contrast, elastic moduli of the Ti alloy show characteristic behaviours; Young's and shear moduli gradually decrease with increasing temperature and then show drastic decrease from around 1173 K down to minimum values at around 1273 K; bulk modulus and Lamé parameter decrease only slightly between room temperature and 1173 K and then suddenly increase to maximum values at 1273 K.

*Lamé second-order constants in isotropic solids are generally defined by two elastic constants, C_{12} $(=\lambda)$, C_{44} $(=G)$ in the elastic constant matrix which is composed of six rows and six columns. In this study, the Lamé constant is limited to λ. Furthermore, since the Lamé constant is a function of temperature, "Lamé parameter" is used in place of "Lamé constant" in this study.

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There is a possibility that the notable change from 1173 K in the moduli is due to a "strain point" at which superplasticity begins to occur [7]. In fact, a distinct jump by relief of strain was observed in volume modulus, Lamé parameter, Poisson's ratio and dilational friction of (Y)TZP [1]. The temperature, 1273 K, which shows the maximum and minimum points, may correspond to the "β-transus point" which suggests a phase transformation point from β to $\alpha + \beta$ [8]. All elastic moduli of the Ni alloy are about twice those of the Ti moduli. This means superior performance of the Ni alloy at elevated temperature.

Young's moduli (206 GPa and 294 K and 161 GPa at 1033 K) of the Ni alloy are consistent with other data [9]. In comparison with dynamic Young's moduli (109 GPa at 300 K, 92 GPa and 590 K and 72 GPa at 930 K) of the Ti alloy [10], the data in Fig. 1 are somewhat lower. Shear modulus of the Ti alloy at room temperature is also somewhat lower than that reported (43 GPa at 294 K) [9]. On the other hand, to our knowledge, there are no available data for shear and volume moduli and Lamé parameters, especially in the high temperature region.

Poisson's ratio for the Ni and Ti alloys are presented in Fig. 3, where the former shows a monotonic increase but the latter reveals a uniform increase accompanied by one peak at around 1273 K. A peak in Poisson's ratio was also observed in isostatically hot-pressed β'-sialon [1] and hot-pressed β-Si_3N_4 [11]. This may be related to relief of shear stress. Values for the Ni alloy are lower than those for the Ti alloy over the whole temperature range, suggesting high deformation resistance of the former. Poisson's ratios for both alloys are, however, considerably larger than those of α-SiC ($\sim$0.17) [2] and β-Si_3N_4 ($\sim$0.28) [11] and arise from the covalent nature in bonding. There are little data for Poisson's ratio for both alloys; the room temperature value of the Ni and the Ti alloys is somewhat higher than other data (0.293 at 294 K) [9], and is fairly consistent with data which lies in the range 0.33–0.34 between room temperature and 813 K [12], respectively.

Internal friction curves for longitudinal and transverse waves of the Ni and Ti alloys are presented in

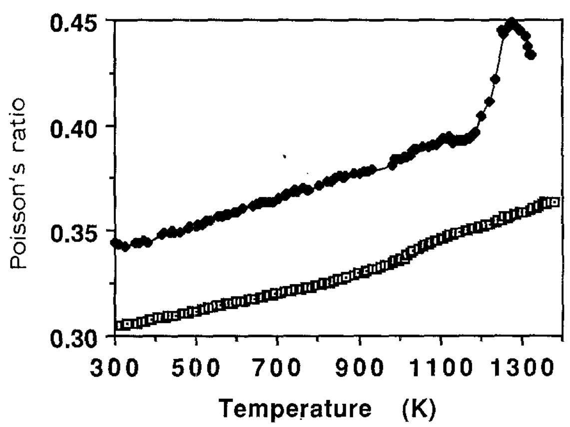

Figure 3 Poisson's ratio of Inconel 718 (□) and Ti–6Al–4V (◆) alloys as a function of temperature.

Figs 4 and 5, respectively, as a function of temperature. The longitudinal curve of the Ni alloy shows a slight increase between room temperature and 1300 K and a small increase from 1300 K, while the transverse curve shows six small peaks at 510, 1010, 1050, 1120, 1270 and 1330 K and one rapid increase at around 1370 K. The increase at elevated temperature suggests that various phenomena of the Ni alloy are sensitive to shear mode. In particular, three peaks at 1010, 1050 and 1120 K may be connected to an increase in the modulus–temperature slope between 950 and 1000 K in the Young's and shear moduli of Fig. 1. However, the reason for this is unclear. The abrupt increase from around 1370 K in shear friction could perhaps be caused by the softening of precipitate phases at grain boundaries, as assumed from the results of Mosher and Raj [13].

As can be seen from Fig. 5, shear friction of the Ti alloy is more active than that of the dilational one. Rapid increase from around 1173 K in dilational friction comes from relief of strain, based on the analogy of the same behaviour as in (Y)TZP [1]. Three peaks in shear friction are observed at 1020, 1120 and 1300 K, but we cannot specify their causes at the present time.

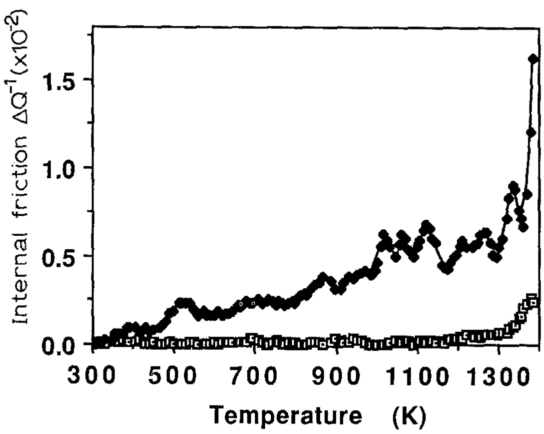

Figure 4 Temperature dependence of increased internal friction for longitudinal and transverse waves of Inconel 718 (□ dilational; ◆ shear).

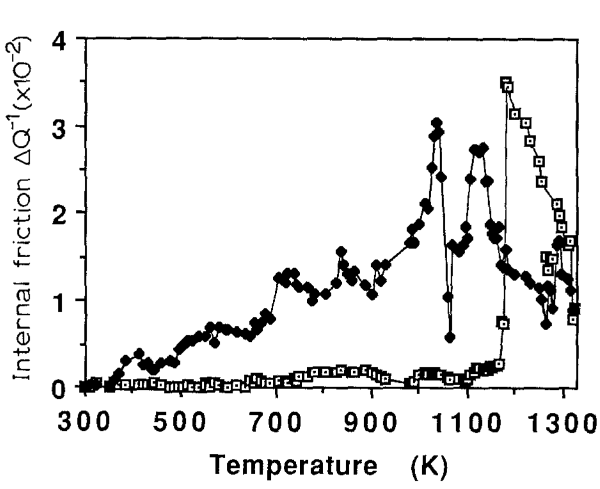

Figure 5 Temperature dependence of increased internal friction for longitudinal and transverse waves of Ti–6Al–4V (□ dilational; ◆ shear).

In this work, we have determined characteristic elastic and damping behaviours in the high temperature range for Inconel 718 and Ti–6Al–4V alloys.

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