Interdiffusion of Niobium and Molybdenum in Nickel between 900 - 1300 °C

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Introduction

Niobium and Molybdenum are two important alloying elements found in nickel base superalloys. Both elements improve creep resistance by being strong solid solution strengtheners and precipitation hardeners. Because of their significant role in superalloy metallurgy, there is a need to understand the diffusion behaviour of them in Ni. In the case of Nb, studies are rather rare while for Mo, although considerable volume of data exist, there still is a requirement to establish diffusion coefficients more accurately, over an extended temperature range. The survey of Nb and Mo diffusion described here is part of a wider investigation aimed at accurately establishing binary interdiffusion coefficients in the fcc-Ni phase for a range of transition-series elements.

Experimental Procedures

Diffusion couples between pure Ni and 4 wt%Nb-Ni alloy, and also between pure Ni and 10 wt%MoNi were made in vacuum by pressing together (∼2 MPa) polished surfaces of component metals for 3 min at 1200 °C. These couples were then annealed at 900, 1000, 1100, 1200 and 1300 °C for various time periods in a protective atmosphere. After annealing, concentration distribution of Nb and Mo across the bond interface was measured using the electron microprobe (EPMA) with wavelength-dispersive spectrometry. Typical distributions are given below in Fig. 1.

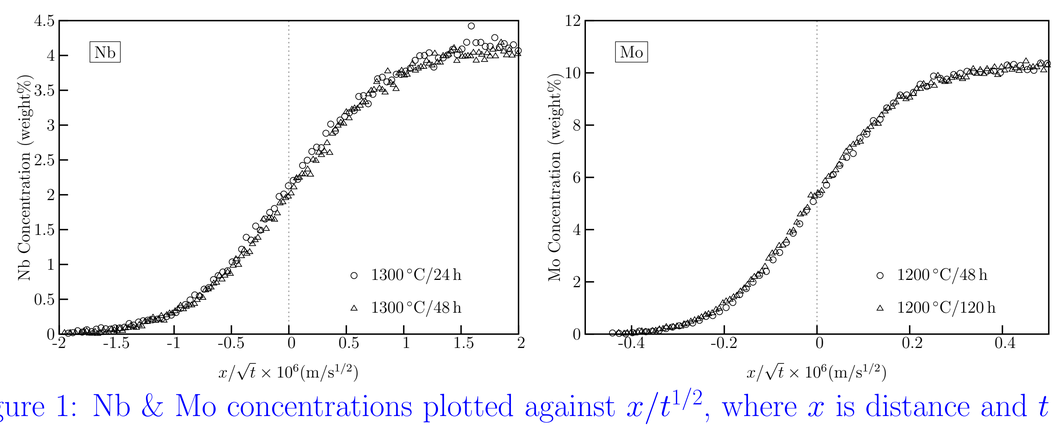

Figure 1: Nb & Mo concentrations plotted against $x/t^{1/2}$, where x is distance and t time, $x = 0$ being the Matano plane.

Analysis Technique

The method given by den Broeder [1] was used to calculate concentration dependent $\tilde{D}$ using the formula

$$\tilde{D} = \frac{1}{2t}\left(\frac{dx}{dY_i}\right)_{Y_i^*}\left[(1-Y_i^*)\int_{-\infty}^{x^*} Y_i\,dx + Y_i^*\int_{x^*}^{\infty}(1-Y_i)\,dx\right]$$

Here, x is distance, t is time, $Y_i = (C_i - C_i^-)/(C_i^+ - C_i^-)$, where C_i is the concentration of diffusant i, C_i^+ and C_i^- are the terminal concentrations of the couple. The terms x^* and Y_i^* are x and Y_i, when $C_i = C_i^*$.

Data Analysis and Results

The calculated $\tilde{D}$ of Nb and Mo are plotted as a function of C_i in Fig. 2. The graphs indicate that $\tilde{D}$ varies only very slightly with alloy composition for both species; this might have been anticipated since the compositional range over which interdiffusion is occurring is narrow ($0 < C_i < 3$ at% for Nb, and $0 < C_i < 6.5$ at% for Mo).

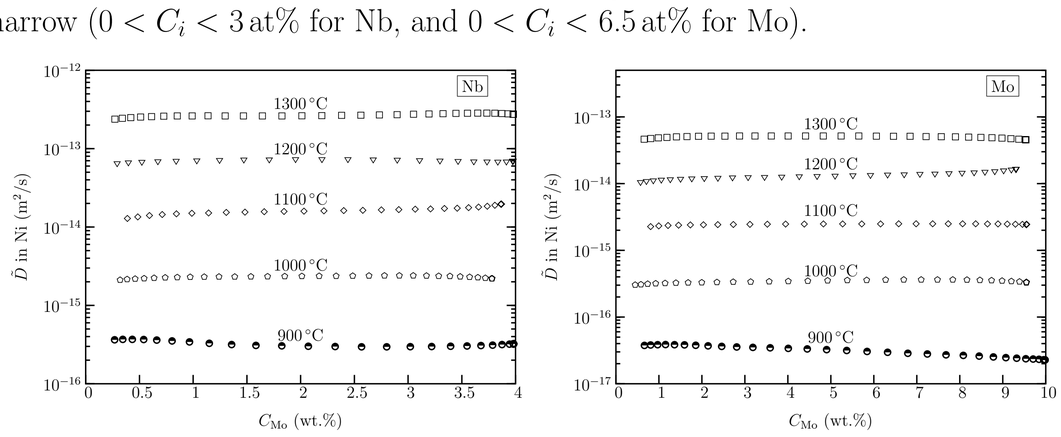

Figure 2: Interdiffusion coefficients determined as a function of concentration for the elements Nb and Mo.

In Fig. 3, Arrhenius plots of average $\tilde{D}$ calculated in this study (solid markers) are compared with data from a number of other sources. Our data, while in good agreement with most of these, also show a strong Arrhenius relationship which can be described by the equations

$$\tilde{D}_{\mathrm{Nb}} = 8.8^{+3.2}_{-2.3} \times 10^{-5}(\mathrm{m^2/s})\exp\{257.0 \pm 3.6(\mathrm{kJ/mol})/\mathrm{R}T\}$$
$$\tilde{D}_{\mathrm{Mo}} = 1.15^{+4.4}_{-1.1} \times 10^{-4}(\mathrm{m^2/s})\exp\{281.3 \pm 3.7(\mathrm{kJ/mol})/\mathrm{R}T\}$$

The solid lines in the graphs of Fig. 3 represent these equations.

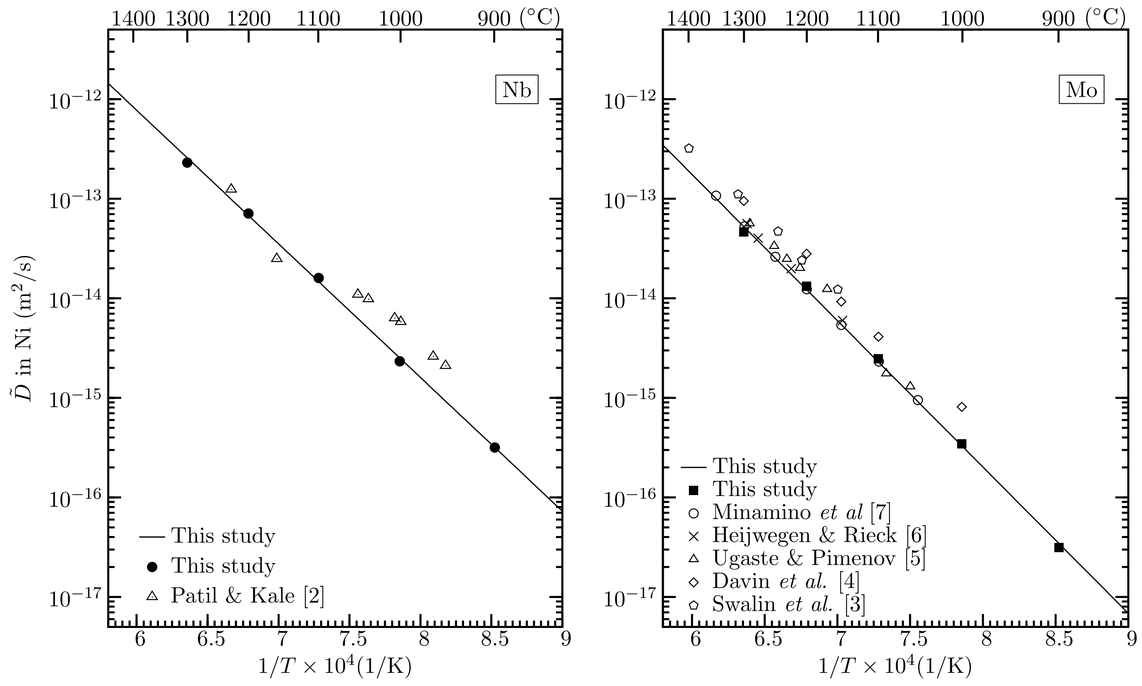

Figure 3: Arrhenius plots for impurity diffusion of Nb and Mo in Ni.

Discussion

In Fig. 4, diffusion coefficients of Nb, Mo and other 4*d* and 5*d* transition elements in Ni are plotted against the atomic number. In both series, the diffusion coefficient decreases to a minimum toward the centre of the period [8]. Although Nb and Mo occupy adjacent positions in the 4*d* transition series of the periodic table their diffusion behaviour in Ni differs quite considerably. In a recent paper by us [8], the correlation of $\tilde{D}$ with the position of the periodic table has been examined across the temperature range 900–1300 °C.

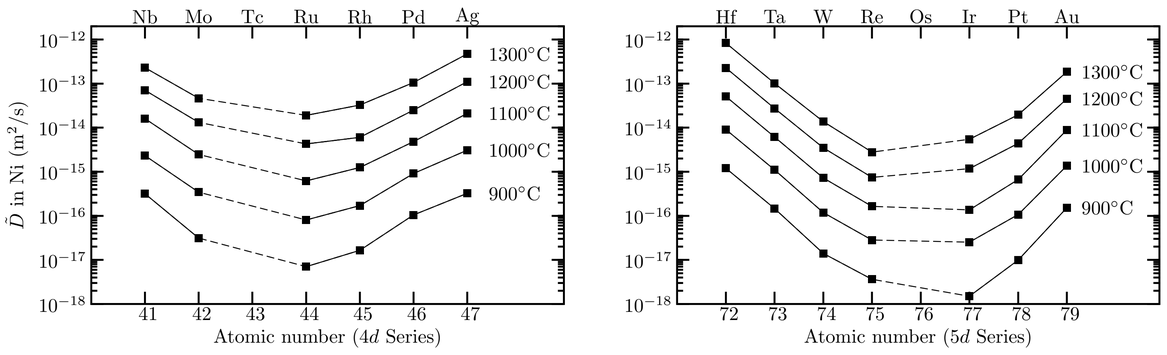

Figure 4: Variation of diffusion coefficient of elements in Ni with the atomic number in the 4*d* and 5*d* transition metal series.

It was shown in [8] that the plot of $\tilde{D}$ *vs.* atomic number reflects the variation of the atomic radius with atomic number. The minimum in the atomic radius arise in the middle of the period, near where the $\tilde{D}$ minimum also occurs. This gives the impression that larger atoms diffuse faster than the smaller ones. Recent first principal calculations, however, have shown that the observed variation of D with atomic number is mainly due to the differences in the barrier energy for the solute-vacancy exchange, and that the misfit strain caused by the size-effect is less significant [9].

Conclusion

Interdiffusion of Nb and Mo with Ni between 900–1300 °C has been determined. Up to 4 wt% for Nb and 10 wt% for Mo, diffusion is only weakly dependent upon composition. It appears that interdiffusion coefficient of 4*d* and 5*d* transition elements correlate strongly with its position in the periodic table.

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