Communications

The 900 °C Isothermal Section of Ti-Ni-V Alloys

SINN-WEN CHEN, CHUN-SHENG HO, CHIH-HAO LIN, and CHIH-MING CHEN

The AB$_2$-type Ni-based alloys are the most prominent candidates as electrode materials in the recent development of Cd-free rechargeable batteries.\cite{1} Most of these developing AB$_2$ alloys are multicomponent alloys, and the Ti-Ni-V ternary system is one of the most important base systems for the AB$_2$ electrode alloys. The three constituent binary systems, Ti-V, Ni-Ti, and Ni-V, have been studied earlier.\cite{2,3,4} Ti-V is an isomorphous system with a continuous solid solution at high temperatures and there is a monotectoid reaction at 675 °C.\cite{2} For the Ni-Ti binary system, there are three compounds, Ti$_2$Ni, TiNi, and TiNi$_3$.\cite{3} Five compounds, Ni$_2$V, Ni$_3$V, Ni$_3$V$_2$, NiV$_3$, and NiV$_3$, have been found in the Ni-V system.\cite{4} Eremenko et al.’s report\cite{5} is the only report available for experimental investigation of the phase equilibria of the ternary Ti-Ni-V system. They reported a partial 900 °C isothermal section of the Ti-rich side, and no ternary compounds were reported. In the present study, experimental examination has been conducted to complete the determination of the isothermal section of the Ti-Ni-V system at 900 °C.

Proper amounts of Ni, Ti, and V were weighed and placed in a Cu crucible in the arc melter. The chamber of the melter was purged with argon gas to reduce possible oxidation of the alloys. The metal pieces were arc melted together and a button-shape Ni-Ti-V alloy was formed. The button was flipped upside down and remelted in the arc melter at least five times to assure its compositional homogeneity. The alloy button was taken out of the arc melter and weighed to assure that there had been no noticeable weight changes after the arc melting. The button was then encapsulated in an evacuated quartz tube. The sample tubes were heat treated at 900 °C in a tube furnace for 168 to 240 hours before they were quenched in ice water. The quenched alloys were cut into half. One part was prepared for X-ray diffraction analysis, and the other part was examined by using metallography and sometimes electron probe microanalysis (EPMA) and scanning electron microscopy.

Five Ti-V alloys (alloys 1 through 5) were prepared following the aforementioned procedures and were annealed at 900 °C. Nominal compositions of these alloys are listed in Table I and shown in Figure 1. Metallographical examinations reveal no signs of phase separation, which indicate these alloys are single phase. Figure 2 shows the powder X-ray diffraction patterns of these Ti-V alloys. It can be seen that they are single phase with a bcc structure and their lattice constants decrease with increasing V contents. Ti-V forms a continuous ($\beta$Ti,V) solid solution at 900 °C. The lattice constant, a, of Ti is 0.33066 nm and that of V is 0.30282 nm.\cite{2} According to Vegard’s law,\cite{6} lattice constants of the solid solutions can be calculated and then the diffraction angles can be determined. As shown in Table II, the experimental measurements and the calculations are in good agreement.

Figure 3 displays the microstructure of the Ti-10 at. pct Ni-10 at. pct V alloy (alloy 6) annealed at 900 °C for 168 hours. Two phases are observed. An etching solution of the following composition was used: 5 mL HF + 10 mL H$_2$O$_2$ + 85 mL H$_2$O. X-ray diffraction analysis and the compositional analysis using EPMA indicate that the discontinuous phase is Ti$_2$Ni while the matrix is ($\beta$Ti,V) phase. Similar results were obtained and two phases, Ti$_2$Ni and ($\beta$Ti,V), had been observed for alloys 7 through 12, as shown in Figure 1 and Table I. Figure 4 is the microstructure of the Ti-15 at. pct Ni-30 at. pct V alloy (alloy 13) annealed at 900 °C. The specimen was etched by the aforementioned etching solution for 30 seconds, and two phases can be observed as well. X-ray diffraction and metallographical analysis indicate that the bright phase is the TiNi phase while the dark phase is

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Chemical compositions of alloys examined in this study superimposed on the isothermal section of the Ti-Ni-V ternary system at 900 °C.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{X-ray diffraction peaks of Ti-V alloys of various compositions.}
\end{figure}

\begin{table}
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Alloy & Ti (at.%) & Ni (at.%) & V (at.%) \\
\hline
1 & 0.436 & 2.776 & 2.258 \\
2 & 1.523 & 2.141 & 1.749 \\
3 & 1.793 & 1.523 & 1.182 \\
4 & 1.998 & 1.793 & 1.182 \\
5 & 2.608 & 0.789 & 0.679 \\
6 & 5.198 & 0.198 & 0.198 \\
\hline
\end{tabular}
\caption{Nominal compositions of Ti-Ni-V alloys}
\end{table}
the \((\beta \mathrm{Ti}, V)\). Similar experimental procedures have confirmed that the alloys 14 through 19 are all in the TiNi-(\(\beta \mathrm{Ti}, V\)) two-phase region, as shown in Figure 1.

Figures 5 through 8 represent the typical microstructures of alloys in various phase regions, such as \(\mathrm{TiNi}-(\beta \mathrm{Ti}, V)\)-\(\mathrm{Ti}_2\mathrm{Ni}\), \((\beta \mathrm{Ti}, V)\)-\(\sigma\), \(\mathrm{TiNi}-\mathrm{Ni}_2\mathrm{V}\)-\(\sigma\), and \(\mathrm{TiNi}-\sigma\), respectively. The phases formed in the annealed alloys are all summarized in Table I. With all these experimental observations and phase diagrams of the three constituent binary systems, the isothermal section of the Ti-Ni-V ternary system at 900 °C can be constructed, as shown in Figure 1. It has nine single-phase regions, 15 two-phase regions, seven tie-triangles,