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Magnetism in Ni-W textured substrates for coated conductors

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Abstract – **The magnetic properties of a series of both annealed (biaxially textured) and as-rolled (non-textured) Ni-*x*W alloy tapes with compositions x = 0, 1, 3, and 5 at.%, were studied. Characterization methods included XRD analyses to investigate the biaxial cube texturing of the annealed Ni-W alloy tapes and studies of the magnetization *M* for both annealed and as-rolled Ni-W alloy tapes. Both the isothermal mass magnetizations *M(H)* of a series of samples at different fixed temperatures and *M(T)* in fixed field, employing a PPMS-9 (Quantum Design), were measured. The Ni-W alloys have shown much reduced ferromagnetism as W-content *x* increases. Both the saturation magnetization M_{sat} and Curie temperature T_c decrease linearly with W-content *x*, and both M_{sat} and T_c go to zero at critical concentration of x_c ~ 9.50 at.% W.**

Keywords : Ni-W alloy tapes, mass magnetization, saturation magnetization, Curie temperature, critical concentration.

1. INTRODUCTION

Second generation HTS (High T_c superconductor) ReBCO coated conductors are attracting much attention for practical applications of superconducting electrical and magnetic devices that operate in liquid nitrogen temperature. To satisfy the requirements needed for the practical applications, the HTS coated conductors should be highly textured to conduct large current.

There are several methods, such as RABiTS (Rolling Assisted Biaxially Textured Substrate) [1-3], IBAD (Ion Beam Assisted Deposition) [4-6], and ISD (Inclined Substrate Deposition) [7-8], to obtain biaxially textured metal substrates. One route to fabricate the HTS coated conductor is to use textured metal substrate prepared by RABiTS approach. In this method, pure nickel tape has been used to fabricate (100)[100] textured metal tape needed for the coated conductors.

However the pure nickel may not be the best textured metal substrate because of both the ferromagnetism and poor mechanical properties. It is clearly desirable to develop suitable alloys with reduced ferromagnetism and enhanced mechanical property that can also be successfully biaxially textured. Therefore, in the last few years, new Ni-based alloy substrates, such as Ni-Cu, Ni-Cr, Ni-Fe, Ni-Mo, Ni-V, and Ni-W, were developed [9-13]. The Ni-based alloys of the best choice, however, are fcc Ni-Cr or Ni-W alloys [14-15].

In this paper, both annealed (biaxially textured) and as-rolled (non-textured) Ni-*x*W alloy tapes with compositions x = 0, 1, 3, and 5 at.%, have been prepared, and the effect of the x at.% W on the magnetic properties was investigated.

2. EXPERIMENTAL ASPECTS

Pure Ni and Ni-W alloy ingots were made from 99.99% purity Ni and W chips by melting them in a plasma arc furnace. The fabrications of Ni and Ni-W alloy tapes have been described in detail elsewhere [16]. The thickness of the tapes was 100 μm after cold rolling. Thermo-mechanical processing was used to produce the desired (100)[100] cube texture. In the final step, the tapes were recrystallized by annealing at 1000°C for 30 min. in 96 % Ar and 4 % H_2 atmosphere. Then, a series of both annealed (biaxially textured) and as-rolled (non-textured) Ni-*x*W alloy tapes with compositions x = 0, 1, 3, and 5 at.% were prepared.

X-ray diffraction was used to investigate the biaxial cube texturing of the annealed Ni-W alloy tapes. The magnetization studies for both the annealed and the as-rolled Ni-W alloy tapes were conducted using commercial PPMS-9T (USA Quantum Design Cop.). Four pieces of metal tapes (3 mm × 3 mm × 100 μm), which were stacked on top of each other, were used as the samples for magnetization studies. The magnetic field *H* was applied parallel to the sample's surface, in order to minimize demagnetizing effects. The isothermal mass magnetizations *M(H)* of the series of samples were measured at fixed temperatures of 77 K and 298 K in fields up to 6 T, and *M(T)* in fixed field of 1000 G, respectively.

3. RESULTS AND DISCUSSIONS

The biaxial cube texture of the annealed Ni-*x*W alloy tapes with compositions x = 0, 1, 3, and 5 at.%, was investigated using X-ray diffraction. All Ni-W alloys studied were in-plane and out-of-plane textured. Fig. 1 shows a (002) ω-scans to show the degree of out-of-plane texturing in the Ni-W alloy tapes. Fig. 2 shows (111) ϕ-scans to reveal the degree of in-plane texturing in the same Ni-W alloy tapes as shown in Fig. 1. The FWHM's determined from both the ω-scans and ϕ-scans were 4.0^o ~ 5.8^o and 8.2^o ~ 10.9^o, respectively, depending on x.

For magnetization study, the Ni-W alloy tapes were cut into pieces with the size of ~ 3 mm × 3 mm × 100 μm. The magnetizations for both the annealed and the as-rolled Ni-W alloy samples were investigated using PPMS. Fig. 3 shows the mass magnetization M plotted versus applied field H for all Ni-W alloy tapes studied. The isothermal mass magnetization $M(H)$ was measured at fixed

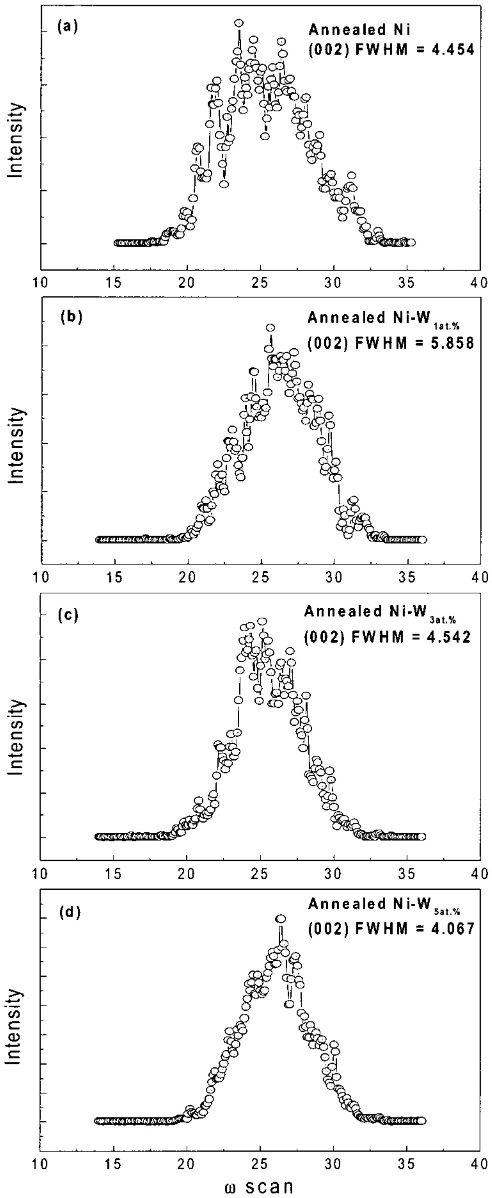

Fig. 1. (002) ω-scans showing the out-of-plane texturing in the Ni-W alloy tapes with compositions (a) x = 0, (b) x = 1, (c) x = 3, and (d) x = 5 at.% W.

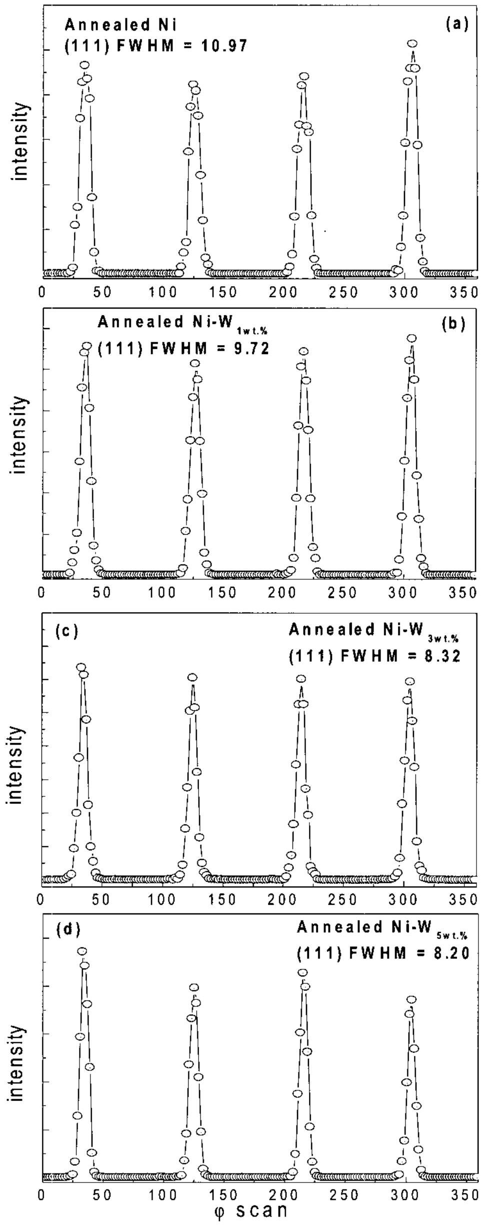

Fig. 2. (111) ϕ-scans showing the in-plane texturing in the Ni-W alloy tapes with compositions (a) x = 0, (b) x = 1, (c) x = 3, and (d) x = 5 at.% W.

temperatures of 77 K and 298 K, in magnetic fields up to 6 T, in order to obtain the saturation magnetization M_{sat}. Fig. 4 shows a plot of M_{sat} versus W-content x. Results reported from Marian [17-18] and ORNL [19] are included in the Fig. 4 for comparison. As shown in Fig. 4, the values of M_{sat} linearly decrease with the addition of W in Ni-W alloy tapes. The straight line is a linear fit of the obtained M_{sat} data from Fig. 3. A simple linear extrapolation to the axis at $M_{sat} = 0$, at both T = 77 K and T = 298 K, intersects at a critical W concentration of 6.50 ~ 6.72 at.% and 9.25 ~ 9.30 at.%, respectively.

The temperature dependence of the mass magnetization $M(T)$ was measured in a fixed field of 1000 G. The Curie temperature T_c for Ni-W alloy tapes can be estimated from the $M(T)$ data. There is a relation between the temperature and spontaneous magnetization; $M \propto (T_c - T)^\beta$ with $\beta \sim 1/3$ [20]. Fig. 5 shows a plot of M^3 versus temperature T for the as-rolled Ni-W alloy tapes. The data above 300 K were obtained from polynomial fitting curve using the data below 300 K, as shown in Fig. 5. The straight lines show the extrapolation to $M^3 = 0$ used to estimate the Curie temperature, for each Ni-W alloy tapes. Therefore, the Curie temperatures T_c = 605 K, 480 K, and 330 K were obtained by a linear extrapolation to $M^3 = 0$, for Ni-1at.%W, Ni-3at.%W, and Ni-5at.%W alloy tapes, respectively. Fig. 6 shows the dependence of Curie temperature T_c of Ni-xW alloy tapes on W-content x. Results reported from Marian [17-18] and ORNL [19] are included in the Fig. 6 for comparison, as well. As shown in Fig. 6, the behavior of T_c for W-content x was

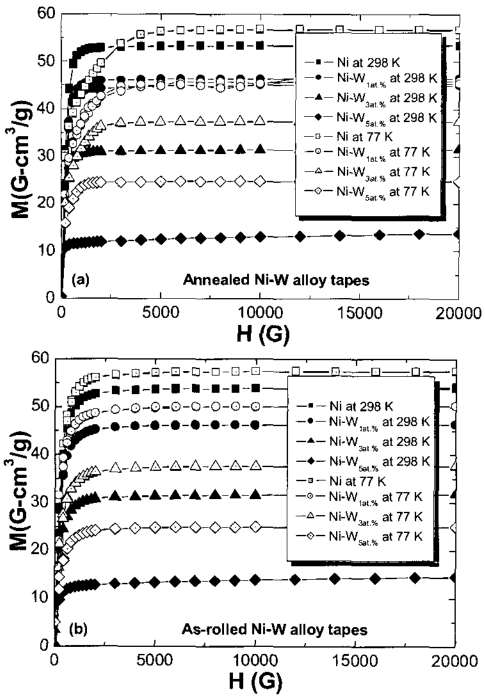

Fig. 3. The magnetization M of Ni-W alloy tapes versus applied magnetic field (H), for both (a) annealed and (b) as-rolled Ni-W alloy tapes studied at T = 77 K and 298 K.

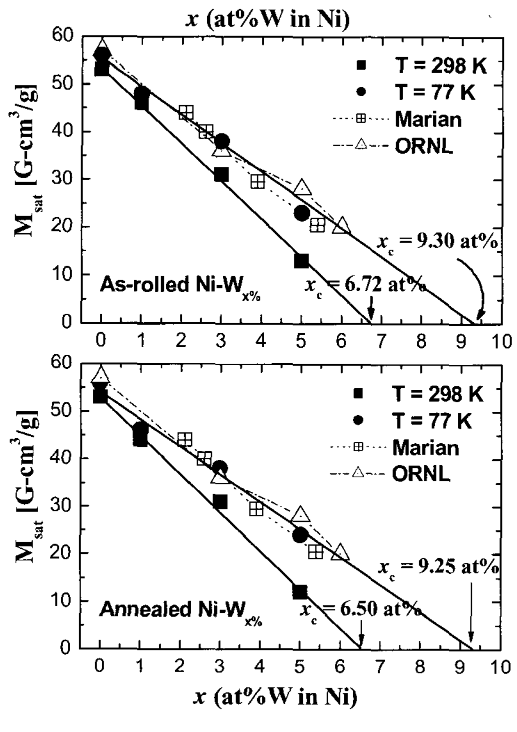

Fig. 4. The saturation magnetization M_{sat} versus W-content x, including our results and those reported by both Marian and ORNL. The fitted linear line extrapolated to the critical concentration x_c.

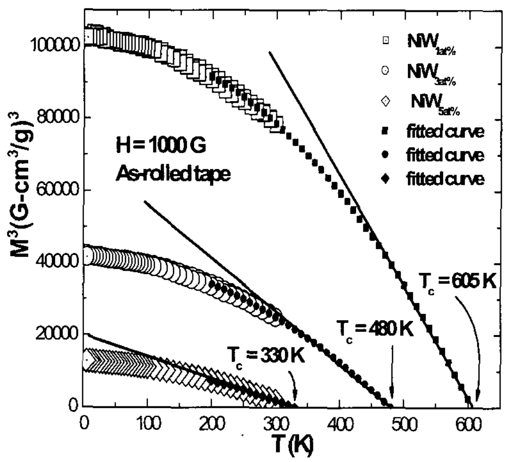

Fig. 5. A plot of M^3 versus temperature T for Ni-W alloy tapes. Solid marks were obtained from polynomial fitting curve using the present data below 300 K. Straight lines show the extrapolation to $M^3 = 0$.

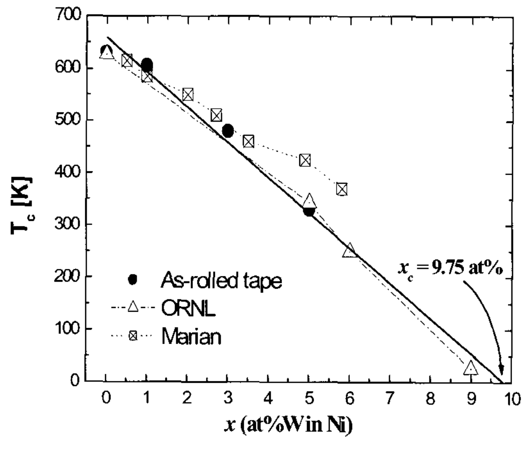

Fig. 6. The Curie temperature T_c versus W-content x, including our results and those reported by both Marian and ORNL. The fitted linear line extrapolated to the critical concentration x_c.

similar to M_{sat}. The values of T_c linearly decrease with the addition of W in Ni-W alloy tapes, as well. The straight line is a linear fit of the obtained T_c data from Fig. 5. A simple linear extrapolation to the axis at $T_c = 0$ gives a value for the critical W concentration of 9.75 at.%. The value of $x_c \sim 9.75$ at.% is consistent within experimental error with the result from M_{sat} at 77 K, as shown in Fig. 4.

The decrease of ferromagnetism as more W is added to Ni, is known to deteriorate the degree of biaxial texture. Works to reduce ferromagnetism while maintaining the degree of biaxial texture of Ni-xW are needed to fabricate coated conductor with improved mechanical properties. The contribution of metal substrate to the ac-loss of the coated conductor is appreciable and needs to be determined, and this work is also in progress.

4. SUMMARY

In summary, the annealed Ni-xW alloy tapes with compositions x = 0, 1, 3, and 5 at.% studied were successfully in-plane and out-of-plane textured. The FWHM determined from both the ω-scans and ϕ-scans were 4.0° ~ 5.8° and 8.2° ~ 10.9°, respectively. Both the saturation magnetization M_{sat} and Curie temperature T_c decrease linearly with W-content x in Ni-xW alloy tapes, with a critical concentration $x_c \sim 9.27$ at.% at 77 K and 9.75 at.% at 77 K, respectively. The results of this study confirm that Ni-W alloy tapes can have much reduced ferromagnetism as W-content x increases.

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