Correlation between T_c-distributions, Microstructures and Performances in Nb_3Sn Wires

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Introduction

Understanding the properties and limits of recent Nb_3Sn wires is of great importance in order to find possible routes to improve their performance. In this work we investigate the correlation between intrinsic Nb_3Sn properties, wire design and resulting microstructure, and the final in-field performances in both RRP® and PIT wires after different heat treatments (HT).

Experimental

Many investigative tools have been employed: specific heat C_p up to 16T (T_c and H_{c2} distributions), VSM up to 14T (J_c and F_p), SEM, EDS, Fractographs (microstructure and chemical analysis), etc…

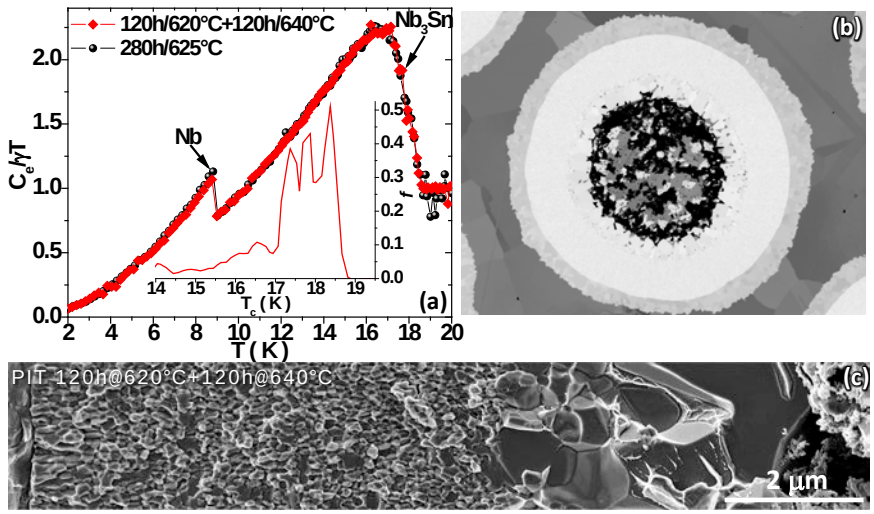

Figure 1 (a) Normalized electronic C_p at 0 T of two PIT wires; in the inset, T_c-distribution of the double heat-treated sample. **(b)** SEM cross-sectional view of a ~50μm-diam. filament revealing residual core, large grain A15-layer, small grain A15 layer and the Nb barrier surrounded by Cu-stabilizer. **(c)** Fractograph of the wire, showing the change in the aspect ratio and grain size through the A15 layer.

Results and Discussion

We consider two PIT wires (1 mm diam., 192 sub-elements of 50 μm diam., Ta-doped) with the following HTs: 1) double HT, 120h/620°C + 120h/640°C; 2) single HT, 280h/625°C. Figure 1a shows the normalized electronic specific heat C_e, revealing a small difference between the two wires. They have a very high T_c onset (18.6-18.7K) for the A15 phase with a relatively sharp transition. The Nb jump at 9K is slight smaller in the double HT case, indicating a stronger reaction of the Nb barrier. The estimated residual Nb is about 13-15%, more than twice the value previously obtained for the RRP wires. The T_c-distribution $f(T_c)$, in the inset of Fig. 1a, shows that the majority of the A15 phases have a T_c over 17 K but a marked peaking is observed suggesting the presence of clear distinct layers with different composition. The estimated superconducting volume fraction at 2 K and 16 T is about 40% in both wires but, when normalized to exclude the Nb barrier, it increases to 52-53%, values found for RRP wires only at much larger HT temperature (750°C/96h) suggesting that the A15 formed in PIT wires have better intrinsic in-field performance and larger H_{c2}. Figure 1b shows the cross-section of a filament with two clear distinct A15 layers: a large grain layer close to the core and a small grain layer outward toward the Nb barrier. The fractograph in Fig. 1c reveals that actually the small grain layer is composed of ~2μm-thick columnar grain region next to the diffusion barrier (on the left) and equiaxed grains in the middle. Analytical microscopy allows us to determine the grain-boundary (GB) density (2.6-2.75×10^7 m^{-1}, slightly larger than in the RRP), the percentage of A15 in the non-Cu layer (54-55%) but also to estimate which fraction of this is composed by small grains (74-75%).

Conclusions

In the PIT the small grain region is supposed to carry most of the current. If the entire A15 layer is taken into account, J_c(12T) just exceeds 4500 A/mm^2 and the specific GB pinning force Q_{GB} is 3980-4160 N/m^2, significantly lower than in the RRP (~4900 A/mm^2 and 5270-7020 N/m^2). However considering the small grains only, which occupy 3/4 of the A15 layer, J_c(12T) increases to 6100 A/mm^2 exceeding the RRP J_c. Similarly, Q_{GB} increases to 5330 and 5640 N/m^2, comparable to the values obtained in the RRP wires heat treated at low temperature.

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