Superconducting properties of Nb_3Al wires prepared with rapid heating, quenching and transformation method

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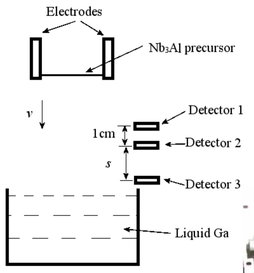
Introduction

Since Nb_3Al has better stress/strain tolerance, higher upper critical field (H_{C2}) and larger critical current density (J_C) under high field than those of Nb_3Sn, it is promising to replace Nb_3Sn in the next-generation high-field superconducting magnets application. However, it is very hard to fabricate Nb_3Al superconductor with stoichimetric A15 phase. Rapid Heating-Quenching and Transformation (RHQT) method is believed to be the most promising way to prepare Nb_3Al long wires. This paper presents the study on the superconducting properties of Nb_3Al short wires prepared by rod-in-tube (RIT), powder-in-tube (PIT), and jelly-roll (JR) method and heat treated by RHQT method.

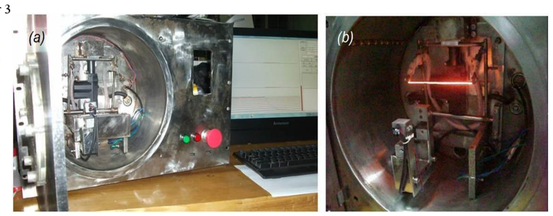
Conclusion

- The onset T_C of RIT, PIT, and JR wire are 17.2 K, 16.6 K, and 17.5 K respectively.
- The J_C of JR wire is the highest among the three types of wires.
- Jelly-roll is the most suitable method to prepare Nb_3Al precursor for RHQT heat treatment.
- The diameter of Al core in RIT wire is 15~20 μm, which is too large for RHQ process. The Al can easily be evaporated, causing low A15 volume ratio and low I_C.
- The Al and Nb powder are hard to deform during the cold-draw process.

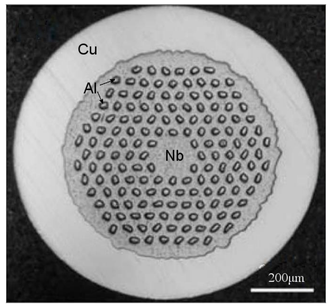
RHQ apparatus



- Δt: time interval of sample passing through detector 1 and 2.
- Sample speed: $v = 0.01 / \Delta t$.
- RHQ duration time: $t = s / v$.
- t can be adjusted by varying s.
- Heating method: Ohmic heating



Precursors



Al rod with 5 at.% Mg

Nb tube: 99.9%

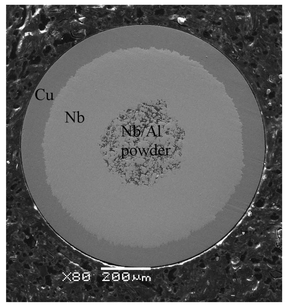
Hot extrusion + cold draw

Final diameter: 0.6 mm without Cu

156 filaments

Nb/Al filaments diameter: 30~40 μm

RIT precursor



Nb, Al powder: -325 mesh

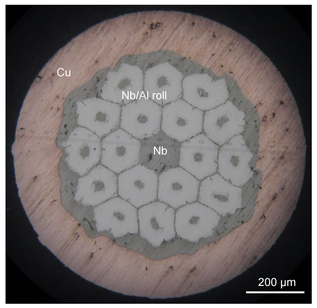
Al:Nb atomic ratio 1:3

Cold draw

Final diameter: 0.74 mm without Cu

Monofilament

in-situ PIT precursor



Initial Al foil thickness: 0.05 mm

Initial Nb foil thickness: 0.15 mm

Hydrostatic-extrusion + Cold draw

Final diameter: 0.6 mm without Cu

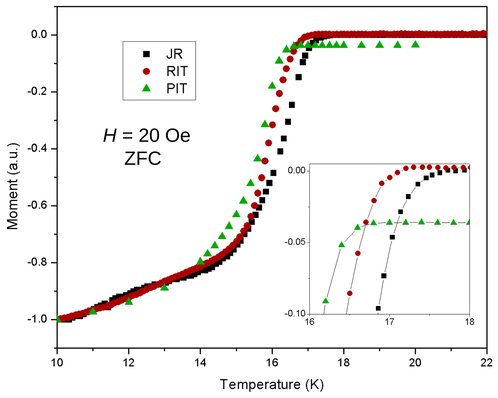
18 filaments

Final Al thickness: 200 nm

JR precursor

Results

Critical temperature

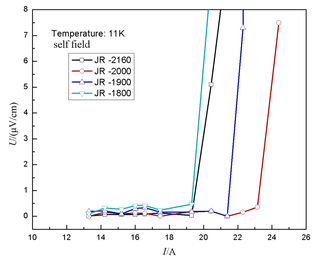


The typical onset T_Cs of RIT, PIT, JR wires are 17.2 K, 16.6 K, and 17.5 K respectively.

In contrast with RHQT method, low temperature diffusion method can obtain T_C lower than 16 K. High temperature diffusion method obtains T_C as high as 18.5 K.

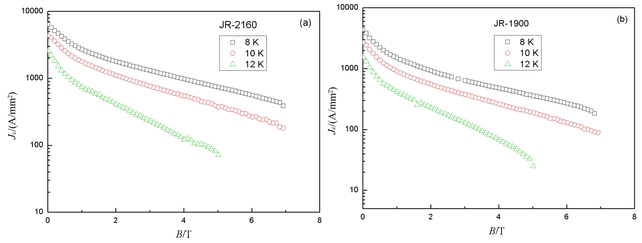
Critical current

JR wire



Transport tests are performed at 11 K, self field without Cu stabilizer.

The corresponding current density is 109~126 A/mm² @ 11 K, self field.

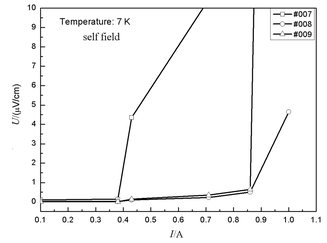


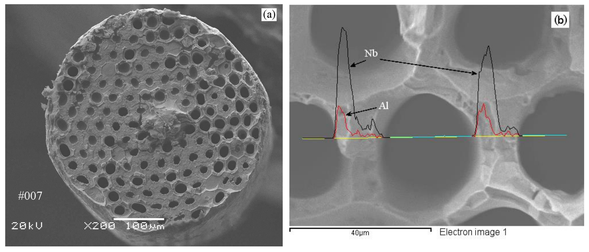
Calculated J_C based on Bean model

RIT wire

Typical transport I_C: 0.86 A @7 K, self field.

The very low I_C is due to low ratio of superconducting A15 phase in samples, as shown in the images below.

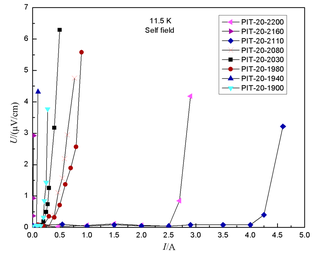




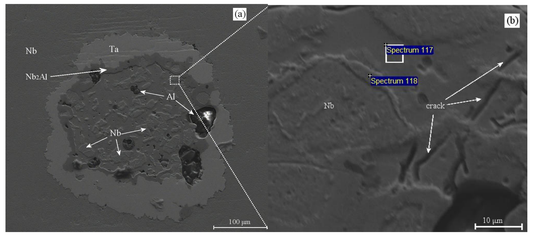
The diameter of Al core is 15~20 μm. The Al is evaporated, leaving lots of holes.

The resistance of Al is much lower than that of Nb. During the RHQ process, the heating current density in Al core is much higher than in Nb. So the temperature of Al is much higher than that of Nb.

PIT wire



Just like RIT samples, the reason for quite transport I_C is the low volume ratio of the superconducting A15 phase.



Spectrum Number	Al (at.%)	Nb (at.%)	Ta (at.%)
117	25.03	73.37	1.60
118	22.11	75.47	2.42

Al and Nb powder is hard to deform in the cold-draw process. So the diffusion distance between them is too far for RHQ process.