Enhanced critical current densities in Nb_3Sn superconducting strands prepared by bronze process

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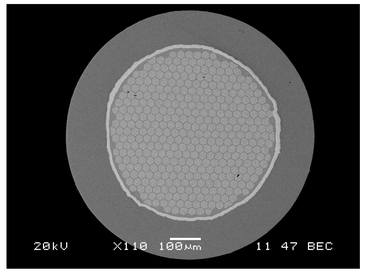
Background

Bronze route is the earliest preparation method for Nb_3Sn superconductor and is still widely use now. The advantages of bronze route are making the best of hot extrusion and stable performance. The bad process workability and Sn resource shortage are the two main disadvantages. The annealing temperature cannot be too high since Nb_3Sn phase can be formed at about 450 ℃ with the existence of copper. Otherwise "sausage" filaments will reduce the critical current density (J_c) of strand. The morphology of Nb_3Sn grain, Nb_3Sn phase volume and stoichiometry of Nb_3Sn phase is known important to the Jc of Nb_3Sn strand. Reaction heat treatments for Nb_3Sn phase forming have great influence on Jc in Nb_3Sn strand.

Multifilamentary bronze route Nb_3Sn strands were successfully fabricated at Western Superconducting Technologies (WST). Influences of strand structures and heat treatments on Jc were investigated in this paper.

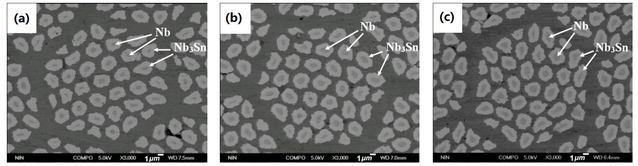
Experiments



- A bronze/Nb composite billet was assembled by inserting Nb rods into bronze matrix. The tin concentration in bronze matrix is 15.5wt.% and 0.3wt.% Ti is added.
- After extrusion and drawing, small size bronze/Nb composite bars were fabricated.
- Assemble bronze/Nb composite bars, diffusion barrier and outside Cu tube and obtain the final billet.
- After the second extrusion and many times drawing and annealing, Nb_3Sn strands with diameter 0.82 mm were fabricated.

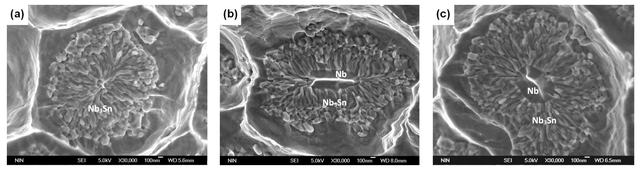
Results

Influence of bronze to Nb volume ratio



Influence of bronze to Nb volume ratio, 2.0, 2.2 and 2.4 on Jc was studied. Jc at 4.2 K and 12 T is 920 A/mm2, 905 A/mm2 and 894 A/mm2 respectively corresponding bronze to Nb volume ratio 2.0, 2.2 and 2.4. The Jc values almost no changes when the bronze to Nb volume ratio changes.

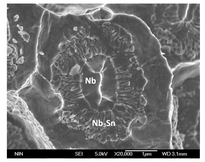
Influence of filament diameter



Three strands with same bronze to Nb volume ratio and different filament diameter were manufactured. The filament diameter is 2.5, 2.3 and 2.1 μm for these strands. J_c is 882 A/mm^2, 920 A/mm^2 and 1001 A/mm^2 respectively corresponding filament diameter is from 2.5 μm to 2.1 μm. Nb filament reacted fully when the filament diameter is 2.1μm which realize more Nb_3Sn volume and higher J_c.

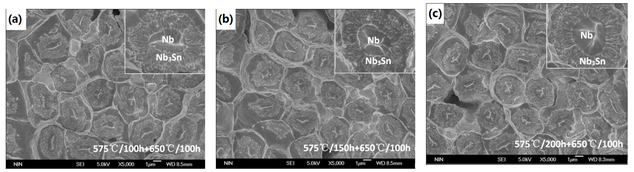
Influence of heat treatment on J_c was researched. The different heat treatment cycles could be divided into three stages. The first stage is 210 ℃ for 50 h, 340 ℃ for 25 h and 450 ℃ for 25 h. The temperature of second stage is 575 ℃ and 650 ℃ or 675 ℃ for the third stage. All heat treatments have the same stage as the first stage above and difference in the second and third stages.

Influence of heat treatment time at 675 ℃



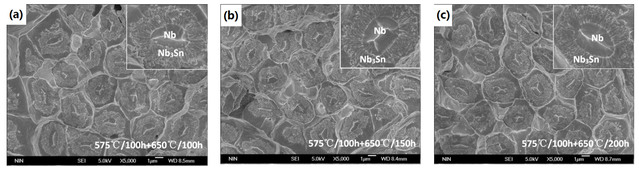
In this part, the second stage is 575 ℃ for 100 h and the third stage is 675 ℃ for 100 h. Compared to Jc is 920 A/mm^2 after heated at 650 ℃ for 100 h, J_c is 785 A/mm^2 after heated at 675 ℃ for 100 h. The average grain size is 150nm and some grains more than 300 nm are formed.

Influence of heat treatment time at 575 ℃



In this part, the third stage is 650 ℃ for 100 h and the second stage is 575 ℃ for 100 h, 150 h and 200 h. The J_c values of strands are around 920 A/mm^2 and the variation is only 2% when the holding time at 575 ℃ changes from 100 h to 200 h. Figure 3 is the microphotograph of the cross section of a broken strand after heat treatment. The bronze to Nb volume ratio is 2.0 and Sn is short in the strand. Residual Nb core could be seen almost every filament and the residual Nb ratio is about 20%. The morphology of grains of Nb_3Sn layer is similar in strands after different holding time at 575 ℃.

Influence of heat treatment time at 650 ℃



In this part, the second stage is 575 ℃ for 100 h and the third stage is 650 ℃ for 100 h, 150 h and 200 h. The J_c values of strands reduces from 920 A/mm^2 to 875 A/mm^2 while the holding time at 650 ℃ increasing from 100 h to 200 h. The Nb_3Sn reaction degree is same as figure 4 and a big Nb core is remained in the center of the filament. The average grain size increases from 112 nm to 166 nm when the holding time increases from 100 h to 200 h. Even grains more than 300 nm could be observed after 650 ℃ for 200 h. The last plateau is for Nb_3Sn grain growth. Extend the holding time will make Nb_3Sn grains grow bigger and result in a lower J_c.

Conclusions

- Bronze to Nb volume ratio ranging from 2.0 to 2.4 has slightly effect on J_c.
- Smaller filament diameter means fully reaction and a high J_c 1001 A/mm^2 at 4.2 K, 12 T was achieved.
- Extend the holding time from 100 h to 200 h has no influence at 575 ℃. A longer duration at 650 ℃ and a higher temperature of 675 ℃ will will make Nb_3Sn grains grow bigger and result in a lower J_c.

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