Influence of Ti-Hf doping on the Nb_3Sn layer formation for bronze-processed Nb_3Sn wire structure

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Introduction and aim

- Hf-Ta doping to Nb is now of great interest in the field of the Nb_3Sn wire development.
- In this work, we investigated the effect of Ti-Hf doping on the microstructure and superconducting characteristics of bronze-processed Nb_3Sn wire structure.

Specimens and Experiment

Fabrication

- Intermediate annealing at 550 °C every 50 ~ 70 % reduction ratio.
- There was no problem with the drawability of the specimens.
- After the drawing, Heat treatment at 700°C × 100 h.

Experiments

- Microstructure: SEM, EDS, EBSD
- J_c–B: I_c measurement in LHe.

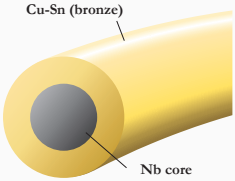


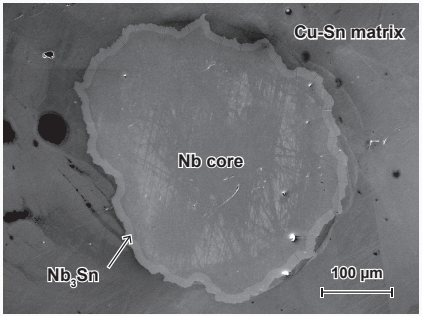
Figure 1: The precursor structure of the specimens.

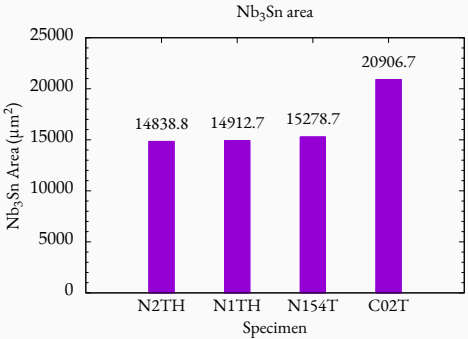
Table 1: Specification of the specimens.

Specimen	N2TH	N1TH	N154T	C02T
Diameter (mm)	0.8	0.8	0.8	0.8
Nb core	Nb-2%Ti-1%Hf	Nb-1%Ti-1%Hf	Nb-1.54%Ti	Nb
Matrix	Cu-8%Sn	Cu-8%Sn	Cu-8%Sn	Cu-8%Sn-0.28%Ti

(% = at%)

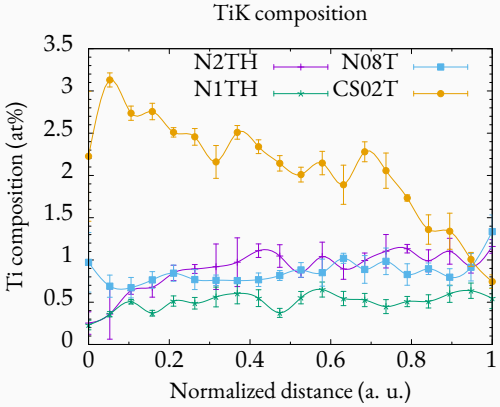
Results – Nb_3Sn layer formation –

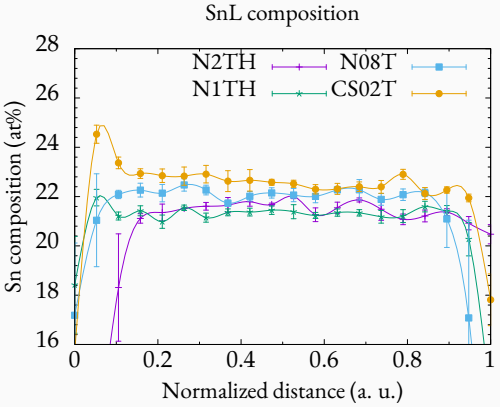




- Ti doping, especially to bronze matrix, promotes significantly Nb_3Sn layer formation, as reported in previous studies [].

Results – Compositional profile of Nb_3Sn layer –

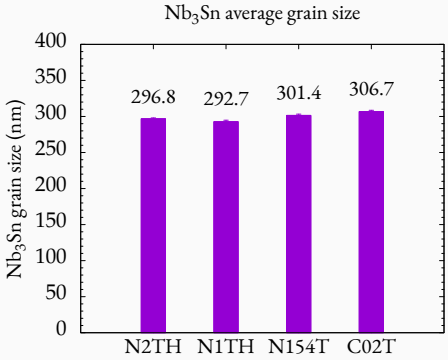


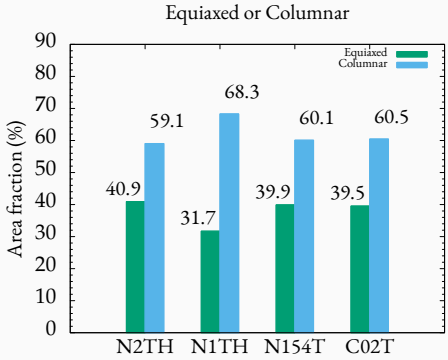


Composition of Nb_3Sn layer

- Ti composition is largest when Ti is doped to Cu-Sn matrix. It would be because large amount of Ti moved from Cu-Sn-Ti matrix, and concentrated at the boundary between Cu-Sn-Ti matrix and Nb core. In other Ti-doping methods, Ti almost stayed at the original position in the Nb core.
- Ti-doping to Cu-Sn matrix also contributes to increase of Sn composition in Nb_3Sn layer.
- Although Nb-Cu-Sn-Ti quaternary phase exists in the boundary when Ti is doped to Sn cores and Cu matrix on an internal-tin processed structure [1], there is no compound layer in bronze matrix structure.

Results – Nb_3Sn grain morphology –





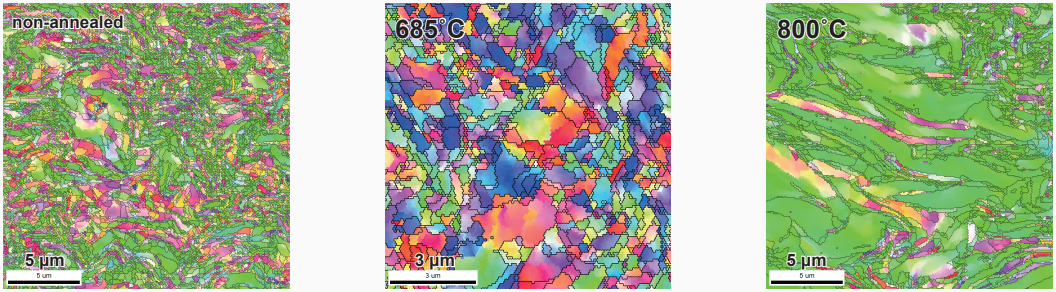
Nb_3Sn grain morphology was analyzed by EBSD.

Results – Nb_3Sn grain morphology –

- There is no significant difference in the grain size among the specimens. Rather, Ti doping to matrix had a tendency to increase the grain size in the wire configuration of this work, although previous studies reported that the smaller grain size can be obtained in Ti doping to Cu-Sn matrix [2, 3, 4]. Presumably, the wire configuration of this work caused an excecive Ti content in the Nb_3Sn layer, which results in grain growth in C02T [5].
- Hf doping did not influence so much te grain size.

Results – The microstructure of Nb-2Ti-1Hf core –

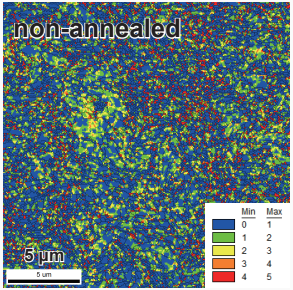
IPF map of Nb-2at%Ti-1at%Hf

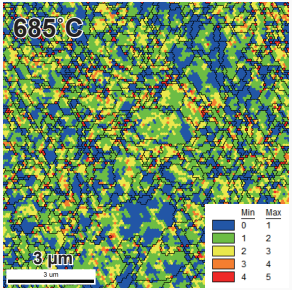


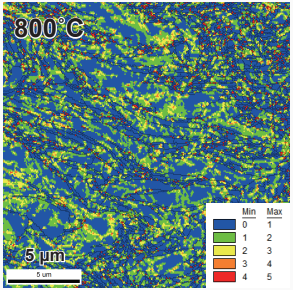
EBSD maps of Nb-2Ti-1Hf alloy with heat treatment.

Results – The microstructure of Nb-2Ti-1Hf core –

KAM map of Nb-2at%Ti-1at%Hf

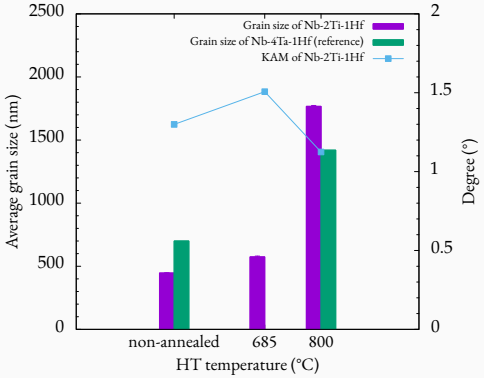






Results – The microstructure of Nb-2Ti-1Hf core –

- Grain size of Nb-2Ti-1Hf core increase with the HT temperature.
- Nb-2Ti-1Hf has similar tendency to Nb-4Ta-1Hf.
- KAM (Karnel Average Misorientation) tends to decrease with increase of HT temperature.



Kernel Average Misorientation (KAM) is correlated with the amount of dislocation and internal strain.

Results – Superconducting characteristics –

- layer J_c in Ti doping to Cu-Sn matrix is the largest, although the specimen has a relatively larger grain size. This could be due to the larger Sn and Ti content in Nb_3Sn layer, resulting in a larger B_{c2}
- Hf doping to Nb core seems to have additional effect to enhance B_{c2} and J_{c2}, because N2TH and even N1TH has a larger B_{c2} than N154T.

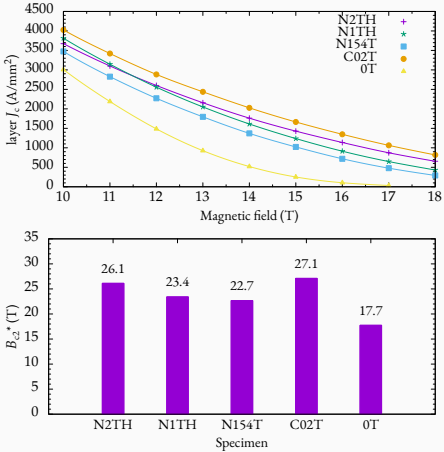


Figure 2: (top) layer J_c–B characteristics and (bottom) upper critical field estimated by Kramer plot for the specimens.

Discussion – Why Hf-Ti addition did not show significant improvement in superconducting properties ? –

- Higher internal strain in a parent Nb core is believed to promote the Sn driving force, and then Nb_3Sn nucleation.
- Ti doping is effective way to improve the Sn driving force.
- According to the results, the effect of Ti doping would be much larger than that of Hf doping in bronze-processed structure: improvement in C02T is larger than that in NTH wires.
- As for the correlation between the internal strain in the parent Nb cores and Sn driving force, it needs to be further investigated in detail.

Conclusion i

- In this study, we investigated that the effect of Ti-Hf doping on the Nb_3Sn microstructure and superconducting characteristics.
- Superconducting characterisitcs is largest in the case of Ti doping to Cu-Sn matrix on bronze-processed structure. The reason would be the larger Sn and Ti content in Nb_3Sn layer. However, in internal-tin processed structure, Ti doping to Cu-Sn matrix is not optimal, because quaternary phase segregates in the boundary of Nb_3Sn when Ti doping to Cu matrix which suppresses Sn and Ti diffusion in Nb_3Sn layer, as we have recently studied in [1].
- Hf doping would be also effective for enhancing B_{c2} and J_c.
- Characterization of Nb-Hf/Cu-Sn-Ti structure is a nect subject to further clarify the effect to Hf doping in bronze processed Nb_3Sn wires.

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