MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019
Wed-Af-Po3.21-04

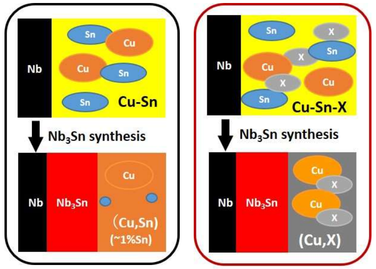
Mechanical Strength Evaluations of the Internal Matrix Reinforced Nb_3Sn Multifilamentary Wires Using Cu-Sn-In Ternary Alloy Matrix

Yoshimistu Hishinuma [1], Hidetoshi Oguro [2], Hiroyasu Taniguchi [3], Satoshi Awaji [4] and Akihiro Kikuchi [5]

1. National Institute for Fusion Science (NIFS), Toki, Japan
2. Tokai University, Hiratsuka, Japan,
3. Osaka Alloying Works Co.,Ltd, Fukui Japan
4. IMR, Tohoku University, Sendai, Japan
5. National Institute for Materials Science (NIMS), Tsukuba, Japan

Corresponding E-mail: hishinuma.yoshimitsiu@nifs.ac.jp

1. Proposal of the internal matrix strengthening using Cu-Sn-X ternary alloy for the bronze-processed Nb_3Sn wire



Conventional bronze process ･･･

- ✓ Composite between Cu-Sn-(Ti) binary matrix and Nb is made, and Nb_3Sn was formed by Sn diffusion from matrix.
- ✓ After the Nb_3Sn synthesis, Sn content in the matrix drastically decreases, and matrix is softened remarkably.

⇒ Decrease of mechanical strength

Internal matrix reinforced process ･･･

- ✓ Composite between Cu-Sn-X-(Ti) ternary matrix and Nb is made, and Nb_3Sn was formed by Sn diffusion.
- ✓ After the Nb_3Sn synthesis, the solute element "X" is remained to matrix and transformed to (Cu,X) solid solution.

⇒ Internal matrix reinforcement

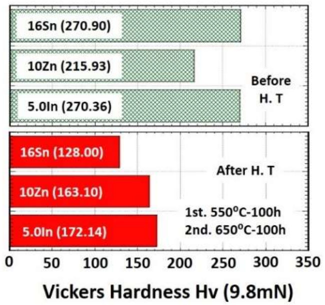
- ✓ Zn element applied as the solute element X in the Cu-Sn-X-(Ti) ternary alloy, and the mechanical properties were improved by (Cu,Zn) solid solution formation [1].
- ✓ For the further mechanical improvement, the Indium (In) element applied as the new solute element.

[1] Y. Hishinuma et al., IEEE trans. Appl. Supercond., 28, 2018, 2794528

We succeeded to cast the Cu-Sn-In-(Ti) ternary alloy matrix for the internal matrix reinforced Nb_3Sn wire.

3. Comparisons of Vickers hardness between the bronze processed Nb_3Sn wires with various ternary bronze matrices

3-1. Vickers hardness in the ternary bronze matrices before and after Nb_3Sn synthesis



- ➢ In element into the matrix could contribute to improve mechanical strength of the matrix after heat treatment.
- ➢ In element would become more effective solute element for the internal matrix reinforcement compared with Zn element.

- ✓ The Vickers Hardness testing condition was 9.8 mN (1.0 gf) for 30 sec (MITSUTOYO HM-200).
- ✓ The Vickers hardness value (Hv) was the average value of 5 points.
- ✓ Hv value of the OFC (Cu) sample was obtained to approximately 110 for the reference.

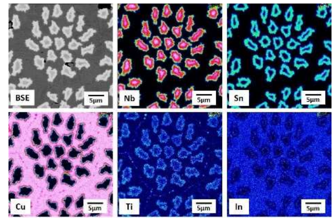
Before the Nb_3Sn synthesis,

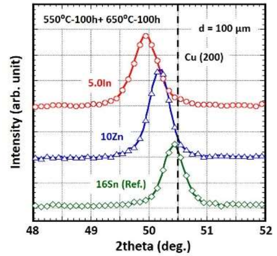
- ✓ Hv values of all matrix was much higher than that of OFC sample.
- ✓ Sn, Zn and In elements contributed to a solid solution strengthening mechanism on the Cu solid solution.

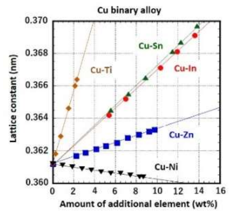
After the Nb_3Sn synthesis,

- ✓ All of Hv values was drastically lower than those of before heat treatment because of Sn diffusion.
- ✓ Hv value of 5.0In sample was higher than those of 10Zn and 16Sn samples.

3-2. Phase identification of the ternary alloy matrix after Nb_3Sn synthesis heat treatment



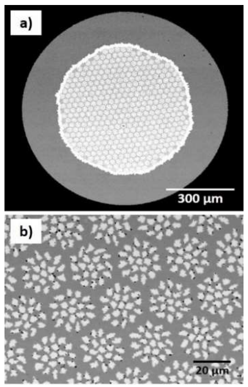




- ✓ In element did not interrupt with Sn diffusion for Nb_3Sn formation.
- ✓ In element remained homogeneously in the matrix after Nb_3Sn synthesis.
- ✓ The matrix of 5.0In sample was transformed to the (Cu, In) solid solution.
- ✓ Formations of the (Cu, In) and (Cu, Zn) solid solution caused to improve Vickers hardness of the matrix after Nb_3Sn synthesis.

The (Cu, In) solid solution was possible to contribute to enhance mechanical strength of the bronze processed Nb_3Sn wire after the heat treatment.

2. Sample Preparations



Typical SEM image of the cross-sectional area on Nb_3Sn multifilamentary wire using Cu-Sn-In-(Ti) matrix

Sample / (Sample code)	10Sn-5.0In-0.3Ti (5.0In)	10Sn-10Zn-0.3Ti (10Zn)	16Sn-0.3Ti (16Sn)
Matrix (sub-multi billet)	Cu-10Sn-5In-0.3Ti	Cu-10Sn-10Zn-0.3Ti	Cu-16Sn-0.3Ti
Diameter of sub-multi (19F)	1.3 mm hex.	1.3 mm hex.	----------------
The number of sub-multi	409	409	----------------
Total number of Nb filament	7,771 (409 × 19)	7,771 (409 × 19)	8,130
Diameter of Nb filament	3.4 μm	3.4 μm	3.5 μm
Barrier Material	Nb	Nb	Nb
Spacer Material	Cu-16Sn-0.3Ti	Cu-10Sn-10Zn-0.3Ti	Cu-16Sn-0.3Ti
Final outer diameter	0.9 mm	0.9 mm	0.82 mm
Cu ratio	1.30	1.30	1.02

- ✓ The bronze-processed Nb_3Sn multifilamentary wires using Cu-10wt%Sn-5.0wt%In-(0.3wt%Ti) ternary alloy matrix were prepared.
- ✓ The Nb_3Sn wires using Cu-Sn-In ternary alloy matrix have 0.9 mm of the outer diameter, 7771 Nb-filaments (3.4 μm), Nb-barrier and stabilized Cu (Cu ratio: 1.3).
- ✓ The 10Zn and 16Sn (non solute X) samples were also prepared for comparisons [1].

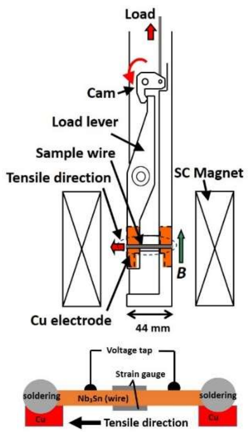
[1] Y. Hishinuma et al., IEEE trans. Appl. Supercond., 28, 2018, 2794528

The two-stage heat treatment (1st. 550 °C for 100 hrs + 2nd. 650 °C for 100 hrs) was performed in order to evaluate under same condition as previous report [1].

Conclusions

- ✓ The internal matrix reinforcement using Cu-Sn-In alloy was attractive method to improve mechanical strength of Nb_3Sn wire.
- ✓ In element contributed to form (Cu, In) solid solution after Nb_3Sn synthesis, and In element also became more effective solute element compared with Zn element for the matrix reinforcement.

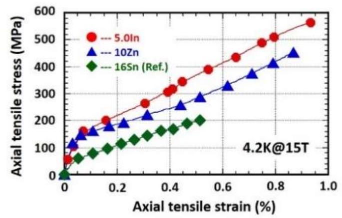
4. Transport I_c degradation by the unidirectional tensile deformation on the Nb_3Sn wires using Cu-Sn-In matrix

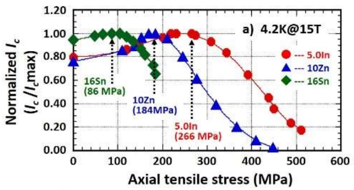


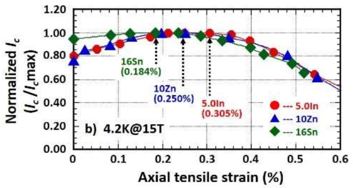
- ✓ Transport I_c measurements under unidirectional tensile deformation at 4.2 K and 15T were performed at IMR of Tohoku Univ. [1].
- ✓ The wire was deformed to unidirectional tensile direction by the moving of the current terminal.
- ✓ The tensile stress value was estimated by the tensile load divided by the cross-sectional area of the wire.
- ✓ Two strain gages to evaluate the tensile strain were attached to wire surface to minimize the influence of the wire deflection.

[1] Y. Hishinuma et al., IEEE trans. Appl. Supercond., 28, 2018, 2794528

- ➢ The solid solution strengthening technique was simpler method than the reinforcement method.
- ➢ The internal matrix reinforcement became one of the attractive to realize the high mechanical strength bronze processed Nb_3Sn wire.







Sample Code	$I_c\sigma=0$ (A)	$I_c max$ (A)	Peak tensile stress (MPa)	Peak tensile strain (%)
5.0In	51.50	64.60	265.89	0.30517
10Zn	89.00	116.67	183.64	0.25045
16Sn (Ref.)	126.00	133.63	85.912	0.18391

- ✓ Young's modulus and 0.2% proof stress were increased by the Cu-Sn-In matrix. (In > Zn)
- ✓ All of I_c values were improved by the release of the compressive stress due to the tensile deformation.
- ✓ The peak tensile stress obtained to the $I_c max$ was increased by the internal matrix reinforcements using Cu-Sn-In and Cu-Sn-Zn ternary alloys.

16Sn: 86 MPa < 10Zn: 184 MPa << 5.0In: 266 MPa

- ✓ The peak tensile strain obtained to the $I_c max$ on the 5.0In sample was also increased compared with the 10Zn and 16Sn samples.
- ✓ The maximum peak tensile stress of the CuNb outer reinforced high strength Nb_3Sn wire was approximately 200 MPa [2].
- ✓ The peak tensile stress using Cu-Sn-In alloy exceeded to the previous CuNb reinforced high strength Nb_3Sn wire.

[2] K. Watanabe et al., IEEE trans. Appl. Supercond., 5, 1993, pp.1905-1908.

Acknowledgements --- This work mainly performed to the Fusion Engineering Research Project (UFFF036) in NIFS, and collaborated with the High Field Laboratory for Superconducting Materials, Institute of Materials Research, Tohoku University (Project No.19H0012), and was also supported financially by JSPS KAKENHI (Grant-in-Aid for Scientific Research (B), 16H04621).