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Changes of superconducting properties due to the unidirectional tensile deformation on Bronze-processed Nb_3Sn multifilamentary wires using various Cu-Sn-Zn ternary alloy matrices

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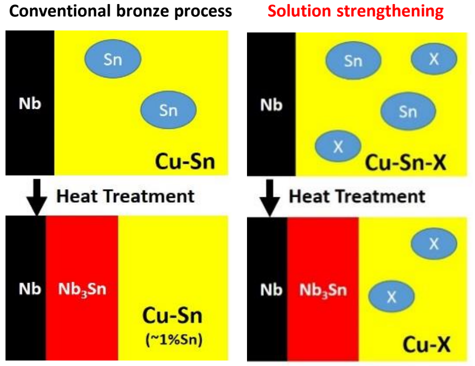
1. Proposal of the internal matrix strengthening using Cu-Sn-X ternary alloy for the bronze-processed Nb_3Sn wire



On the Cu-Sn-X ternary alloy matrix material were required as,

1. Excellent composite workability with Nb
2. The balance between Sn and the solute element in the bronze alloy
3. High melting point above 600°C
4. Solute element remained in the alloy

Several Cu-Sn-Zn ternary alloy matrix for bronze-processed Nb_3Sn wire were investigated.

In the conventional bronze process ････

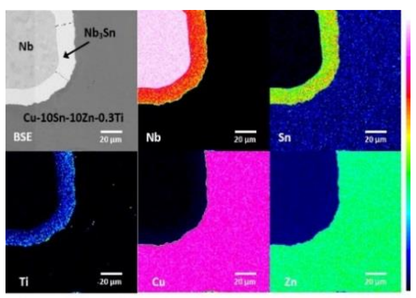
- ✓ Composite between Cu-Sn-(Ti) matrix and Nb was made, and Nb_3Sn was formed by Sn diffusion from matrix.
- ✓ After the Nb_3Sn synthesis, Sn content into the matrix decreased remarkably. (The decrease of mechanical strength)

In the internal matrix strengthening bronze process, ････・

- ✓ Composite between Cu-Sn-X-(Ti) ternary matrix and Nb was made, and Nb_3Sn was formed by Sn diffusion from matrix.
- ✓ After the Nb_3Sn synthesis, solid-solution element was remained to matrix. (Solid-solution strengthening mechanism)

2. Sample Preparations

Code	Composition (mass%)	Quantitative comp (Cu-Sn-Zn-Ti, mass%)
Sample-A	Cu-10Sn-10Zn-0.3Ti	79.97 -9.73 -10.00 -0.30
Sample-B	Cu-12Sn6Zn-0.3Ti	82.04 -11.75 -5.94 -0.27
Sample-C	Cu-13.5Sn-4Zn-0.3Ti	82.25 -13.49 -3.98 -0.28
Ref.	Cu-16Sn-0.3Ti	------------------------------



- ✓ Three kinds of the bronze-processed Nb_3Sn multifilamentary wires using Cu-Sn-Zn ternary alloy matrix were prepared.
- ✓ These Nb_3Sn wires using Cu-Sn-Zn ternary alloy matrix have 0.9 mm of the outer diameter, 7771 Nb-filaments (3 μm), Nb-barrier and stabilized Cu (Cu ratio: 1.3).
- ✓ Homogeneous Nb_3Sn phase was formed around the interface between Cu-Sn-Zn matrix and Nb filament.
- ✓ Thickness of Nb_3Sn layer was increased with increasing Sn content of Cu-Sn-Zn matrix.
- ✓ Zn element remained homogeneously, and distributed in the bronze matrix after heat treatment.

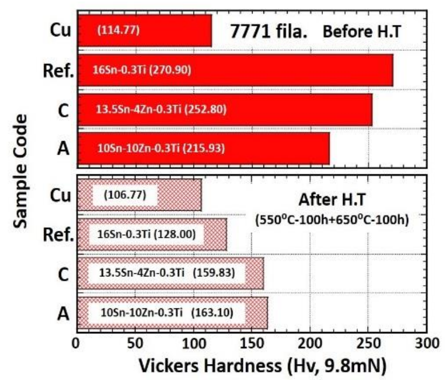
The remained Zn element in the residual bronze will improve the mechanical strength of Nb_3Sn wire after the heat treatment

Conclusions

- ✓ Zn element could act as a solid solution strengthening factor of the (Cu, Zn) solid solution in the matrix after Nb_3Sn synthesis.
- ✓ The optimum adjustment between Sn and Zn contents in Cu-Sn-Zn ternary alloy was necessary to progress the solid solution strengthening due to the Cu-Sn-Zn ternary bronze matrix.

3. Comparisons of mechanical properties between Nb_3Sn wires with various Cu-Sn-Zn ternary bronze matrices

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



The remained Zn element into the matrix could be acted as the solid solution strengthening factor on the Cu-Sn-Zn ternary matrix after heat treatment.

- ✓ Vickers Hardness test condition was 9.8 mN (10 gf) for 30 sec (5 points, MITSUTOYO HM-200).

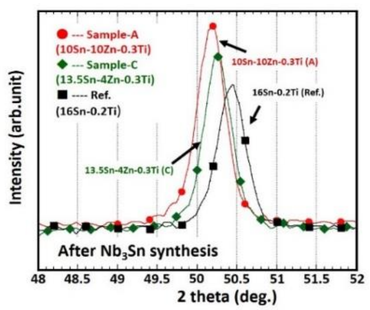
Before the Nb_3Sn synthesis,

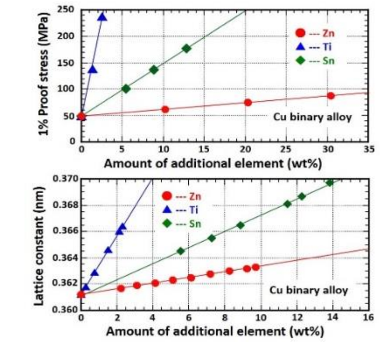
- ✓ The reference showed the highest Vickers hardness, and then the hardness was increased with increasing of nominal Sn content into matrix. (Sn was effective to increase Vickers hardness compared with Zn)

After Nb_3Sn synthesis,

- ✓ The sample-A showed the highest Vickers hardness after Nb_3Sn synthesis, and the hardness was increased with increasing Zn content.

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

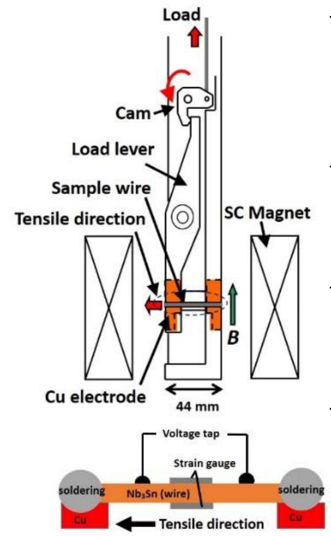




- ✓ The diffraction peak around 50.4 degree was identified to Cu (200).
- ✓ On the reference (conventional bronze matrix) wire, Cu-Sn bronze matrix was transformed to Cu phase by the Sn diffusion from the matrix to form Nb_3Sn phase.
- ✓ On the cases of Cu-Sn-Zn matrix samples, the matrices were transformed to the (Cu, Zn) solid solution phase, the shifted angle of the diffraction peak on the (Cu, Zn) solid solution was increased with depending on the Zn content (Increase of the lattice constant).

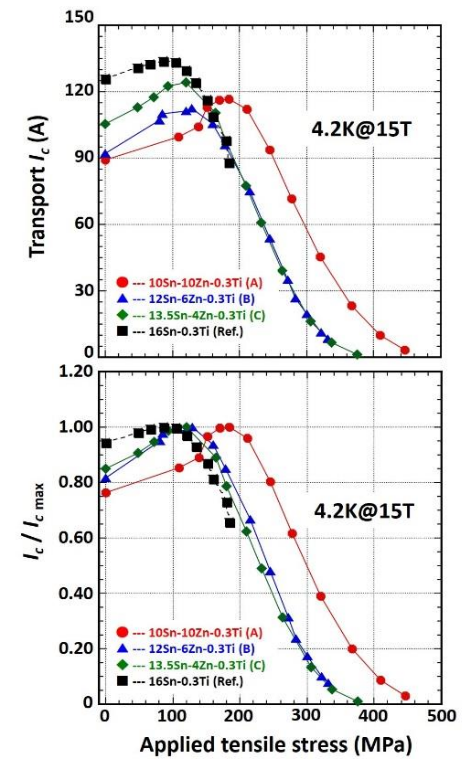
The (Cu, Zn) solid solution caused to increase Vickers hardness of the matrix,
The (Cu, Zn) was possible to contribute to enhance mechanical strength of the bronze-processed Nb_3Sn wire after the heat treatment.

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



- ✓ I_c measurements under unidirectional tensile deformation at 4.2 K and 15T were performed at IMR of Tohoku Univ.
- ✓ 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.

The solid solution strengthening technique was simpler method than the reinforcement method, and the internal matrix strengthening became one of the attractive high mechanical strengthening methods in the bronze processed Nb_3Sn wire.



Sample Code	$I_c\varepsilon$=0 (A)	$I_c$max (A)	Peak tensile stress (MPa)	Peak tensile strain (%)
Sample-A	89.00	116.67	183.64	0.25045
Sample-B	91.98	112.60	128.49	0.20946
Sample-C	105.56	124.17	121.79	0.20526
Ref.	126.00	133.63	85.912	0.18391

- ✓ 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_cmax was increased with increasing Zn content.
- ✓ The peak tensile stress obtained to the normalized I_c (I_c/I_cmax) was also increased by Zn addition.

(Ref.: 86, 4%Zn: 120, and 10%Zn: 180 MPa)

- ✓ The (Cu, Zn) solid solution could contribute to enhance mechanical strength of the bronze-processed Nb_3Sn wire.
- ✓ The maximum peak stress was obtained almost similar to the high-strengthening Nb_3Sn wire using CuNb and ODS-Cu reinforcement technique.

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