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A Study on Draw-ability of Nb Filaments for Manufacturing Nb_3Sn Strand

Jiman Kim[1,2], Yoon Hyuck Choi[1], Young-Gyun Kim[1], Iksang Shin[2], Subok Yoon[2] and Haigun Lee[1,]*

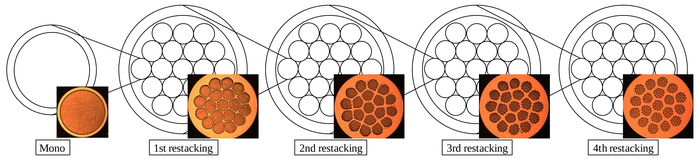
1. Department of Materials Science and Engineering, Korea University, Seoul, Korea
2. Kiswire Advanced Technology Ltd., Daejeon, Korea

Abstract

For the improvement of the critical current density of a multi-filamentary Nb_3Sn strand, a high integrity of Nb filaments should be obtained by the optimal cold-drawing process for reducing the cross-section of the filaments. However, as the number of drawing cycles increases, the strain-hardening exponent of the Nb filaments also increases, which consequently hinders the area reduction, and even incurs the problem of breakage of the Nb_3Sn wires. In this study, the hardness and microstructure of Nb filaments were analyzed to evaluate the strain-hardening exponent changes with respect to the number of the drawing cycles. In addition, the stress analysis using the finite element method was conducted to investigate the effect of the drawing stress on the drawability.

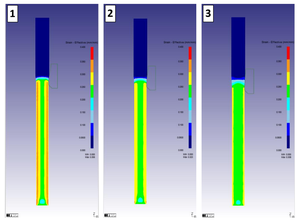
Experimentals

★ Manufacturing process of Cu-Nb multifilamentary wire

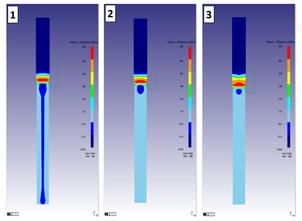


★ Optimization of drawing die by FEM

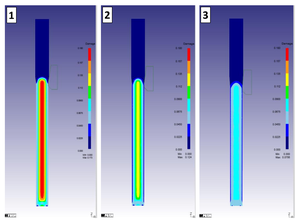
No.	Shape factor of die	Max. Eff. Stress	Max. Eff. Strain	Drawing force
1	2.04	294	0.358	2.65
2	1.50	286	0.323	2.65
3	1.17	280	0.308	3.12



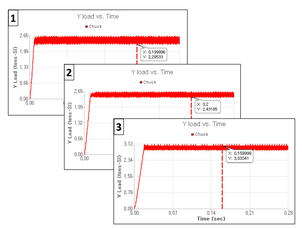
< Effective Strain >



< Effective Stress >



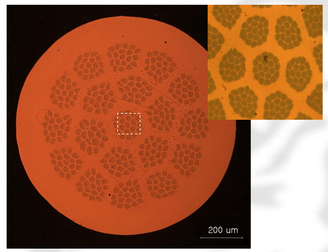
< Damage >



< Drawing force (Y-load) >

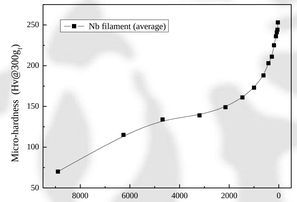
Results & discussion

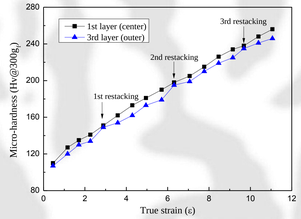
★ Cross sections of fabricated wire



- Final Diameter of Strand : 1.0 mm
- Number of Nb Filaments : 130,321
- Nb Filament Size in Final Dia. : 0.9 μm
- Total (True) Strain in Final Dia.: 18.4

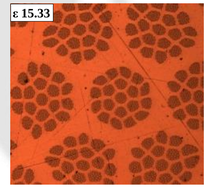
★ Nb filament hardness distribution

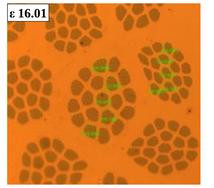




★ Inhomogeneous deformation of Nb filaments

Wire diameter	True strain	Filament size	Filament uniformity
Φ6.30	14.56	6.13 μm	Good
Φ4.45	15.33	4.17 μm	Good
Φ3.14	16.01	2.85 μm	Bad
Φ1.03	18.44	0.88 μm	Bad

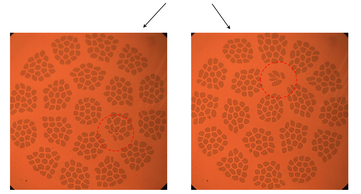




- Inhomogeneous filaments were observed at the strain of 16.

★ Strain limitation (wire breakage)

Wire diameter	True strain	Filament size
Φ1.80	17.16	1.67 μm



- A breakage was occurred at the wire diameter of 1.8 mm due to the inhomogeneous deformation of Nb filaments.

Conclusion

- **Nb filament hardness distribution:** As expected, the hardness of Nb filaments increased exponentially with increasing the filament diameter. In addition, the hardness of Nb filament at centre (located in 1st layer) was higher than that at outer (located in 3rd layer), indicating that the stress was concentrated at centre of the multifilamentary wire.
- **Inhomogeneous deformation of Nb filament:** When the strain applied by the drawing process was > 16, the inhomogeneous deformation between Nb filaments were observed; moreover, the Cu-Nb multifilamentary wire was finally broken at the applied strain of 17.16.
- **Future work:** Optimization of the drawing die design and drawing environments such as lubrication will be investigated to resolve the strain limitation of the drawing process for Cu-Nb multifilamentary wires.

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