Characterization of OST 10019 Nb_3Sn Superconductor Wire for the 30T Serial-Connected Hybrid Magnet

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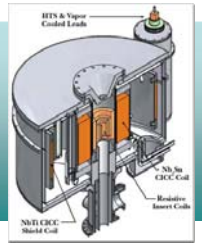
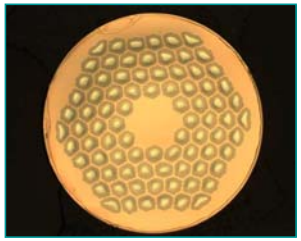


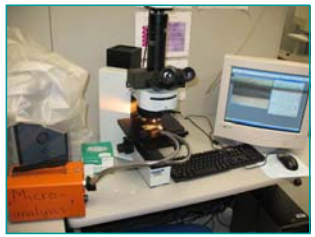
ABSTRACT:

Working under the direction of Dr. Yan Xin and Dr. Jun Lu, a number of tests were performed in order to characterize OST 10019 Nb3Sn superconductor wire for use in the 30 Tesla Serial-Connected Hybrid Magnet.[1] The following tests and measurements were performed on the OST samples: the strand twist pitch, the Cu to non-Cu ratio, magnetization tests at different locations in the wire, and optical and SEM EDX (Scanning Electron Microscope Energy Dispersive X-ray Spectroscopy) analysis and comparison of heat treated samples at different temperatures to untreated samples.



Strand Twist Pitch:

The strand twist pitch was determined by first taking a cross-sectional image of a Nb_3Sn strand, then the total number of outer rim sub-bundles are counted. Next, a short sample of strand (~ 30 mm long) was etched with Nitric Acid to remove the copper stabilizer so that the outer rim sub-bundles became visible. The bundle of filaments was then observed under an optical microscope at 50x magnification. Image-Pro 6.2 software was used to analyze the micrograph. Utilizing the calibrated measuring tool on the software program, the distance between a number of the visible bundles was measured from consecutive points along the center of the strand (see illustration below). Three distance measurements were taken at separate positions along the length of the sample. The average of the three measurements was divided by the fraction of total outer bundles to the number of strands measured to obtain the twist pitch of the wire sample. The expected twist pitch of the OST sample as supplied by the manufacturer was 15 mm.[2] The measured result was 13.5 mm $\pm$ .5 mm.



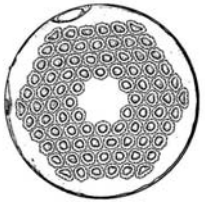
Optical Microscope and External Light Source

Etched Wire Sample Showing Outer Bundles at 50x

Cu/NonCu Ratio:

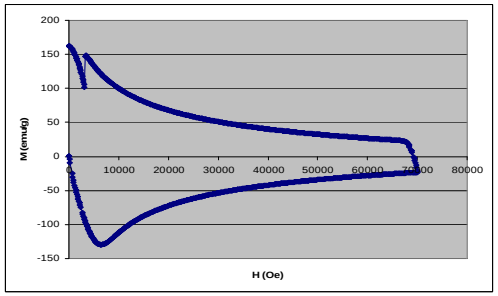
Determining the Cu/nonCu ratio was achieved by taking a micrograph of the wire cross-section and using ImageJ software to measure the area of five wire bundles. The average of those five measurements was then multiplied by the total number of bundles in the wire (84) to get the total area of the nonCu. Subtracting the nonCu area from the total area of the wire gives the area of the Cu regions. The ratio was measured to be 0.77.

OST Data for Cu/nonCu Ratio			
Bundle	Area	Total Area of Wire	
1	0.058	8.301	
2	0.053		
3	0.056	Cu Area	nonCu Area
4	0.058	3.631	4.670
5	0.053		
Average	0.0556	Cu/nonCu Ratio	
Total Bundles:	84	0.777	



Magnetization Test:

According to a simple model, the magnetization of a superconductor in an external field is proportional to its critical current.[2] The magnetization of a reacted OST sample was measured with a PPMS (Physical Properties Measuring System) to examine the end effect of reacted Nb_3Sn wire. Three different locations were in the wire were analyzed: the end of the wire, 6mm next to the end of the wire, and ~200 mm from the end of the wire to see if possible leakage of the Sn core near the end of the wire would cause a change in critical current. The graph below shows the magnetic moment of the sample next to the wire end as a function of the external field. All three samples displayed nearly identical results.

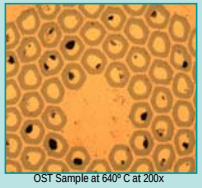


Optical Analysis:

Five wire samples were heat treated at the respective temperatures of 610º C, 620º C, 630º C, 640º C, and 650º C. A micrograph of the sample cross sections were compared with micrographs from a non-heat treated sample. The comparison showed a number of characteristic differences in the heat treated samples. The observations included voids in the Sn cores, expansion of the Nb strands due to the diffusion reaction, and grain crystallization in the cores at 610ºC and 620º C due to partial partial diffusion (see illustrations below). The diffusion process involves both the Sn being diffused into the Nb wires and the Cu between the wire filaments diffusing out into the center of the bundle. This produces the superconductive Nb_3Sn phase. At temperatures 620º C or below, only part of the Sn diffused out. But at temperatures above 640 º C, all the Sn in the core diffused into Nb to form Nb3Sn, or to create bronze between the filaments.

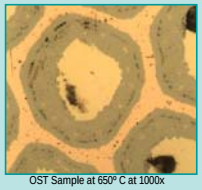
Optical Micrographs of Heat-Treated Samples

Voids in Sn Cores



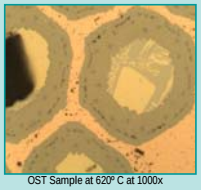
OST Sample at 640º C at 200x

Nb Strand Expansion



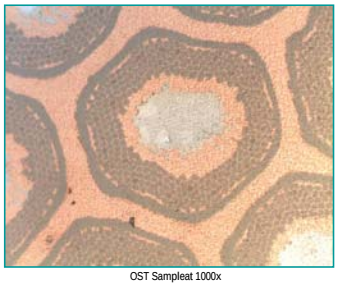
OST Sample at 650º C at 1000x

Grain Crystallization



OST Sample at 620º C at 1000x

Micrograph of Non-Heat Treated Sample

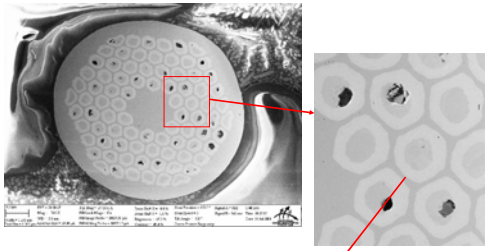


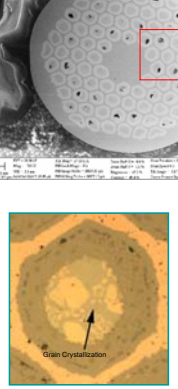
OST Sampleat 1000x

SEM EDX Analysis:

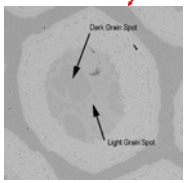
Images were made of each heat-treated sample using a field emission Ziess 1540ESB SEM and an EDX analysis was done at various points of interest to obtain quantitative elemental composition. The graphs below show the analysis results of two differing regions inside the core of a wire bundle heat treated to 610º C that displayed regions of different contrast.

Dr. Yan Xin and the RET using the SEM EDX



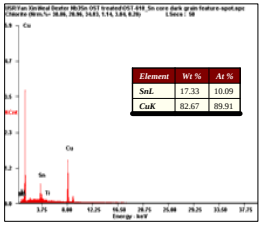


Micrograph of 610º C Sample at 1000x

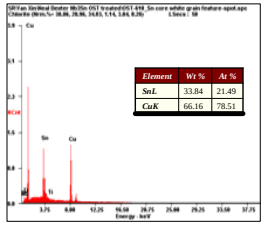


SEM image of 610º C Sample

EDX Analysis Results for Regions of Partial Diffusion in 610º Sample



Element	Wt %	At %
SnL	17.33	10.09
CuK	82.67	89.91



Element	Wt %	At %
SnL	33.84	21.49
CuK	66.16	78.51

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References:

1. Development of the Superconducting Outserts for the Series-Connected-Hybrid Program at the National High Magnetic Field Laboratory, IEEE Trans. Appl. Supercond., 18 (NO. 2, June), 529-535 (2008) Authors: Bonito-Oliva, A.; Bird, M.D.; Bole, S.T.; Cantrell, K.R.; Gavrilin, A.V.; Luongo, C.A.; Dixon, I.R.; Han, K.; Lu, J.; Miller, G.E.; Noyes, P.D.; Painter, T.A.; Weijers, H.W.; Walsh, R.P. and Zhai, Y.
2. Development of internal tin Nb3Sn conductor for fusion and particle accelerator applications Author(s): Parrell JA, Zhang Y, Field MB, et al. Source: IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY Volume: 17 Issue: 2 Pages: 2560-2563 Part: Part 3 Published: JUN 2007