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NIOBIUM SEMIPRODUCTS FOR THE SUPERCONDUCTING STRANDS AND SRF CAVITIES IN RUSSIA

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Abstract

The melting regimes of the niobium ingots with high chemical purity and low hardness for the Nb_3Sn, NbTi and other superconducting materials manufacture have been developed at SC "VNIINM". Using this niobium material and by the SC "VNIINM" manufacture regimes at the SC "Chepetsky Mechanical Plant" 220 tons of Nb_3Sn and NbTi strands for ITER and 12 km of Nb_3Sn strands for HL-LHC (CERN) with the required characteristics have been successfully produced. The review of the characteristics of the different semiproducts (sheets, tubes, rods), made in Russia from the special grade niobium, and of the superconducting strands, manufactured with the use of them, is presented in the paper. The ways of the further improvement of the niobium ingots melting regimes and niobium sheets deformation and annealing regimes with the target of achieving RRR > 300 for the SRF cavities application are discussed.

INTRODUCTION

High chemical purity and low hardness niobium is required to fabricate long-length Nb_3Sn and NbTi superconducting strands with high current-carrying capacity [1,2]. Total reduction of niobium (μ) during manufacturing process from the initial ingot to the filament in the final diameter strand can reach $1.2 \cdot 10^{10}$ [1]. High chemical purity niobium is also used to fabricate SRF cavities but it is necessary to reach high RRR values (more than 300 as a rule). Niobium sheets for SRF cavities also should comply to high requirements concerning microstructure, surface quality, mechanical properties, etc. At present there are many ongoing and finished projects connected with construction of the facilties using SRF cavities (FCC, CEPC, ILC, etc). For this reason the development of the technology of niobium sheets production for SRF cavities is very promising and actual problem.

HIGH PURITY NIOBIUM INGOTS

SC "VNIINM" has developed the technology of high chemical purity niobium ingots melting with Brinell hardness less than 50. These ingots are specially intended for the production of Nb_3Sn and NbTi superconducting strands with high current-carrying capacity. These ingots production technology includes an aluminothermic recovery of niobium pentoxide and multiple electron-beam melting. The cross-section of typical structure of electron-beam melted Nb ingot is shown in Figure 1.

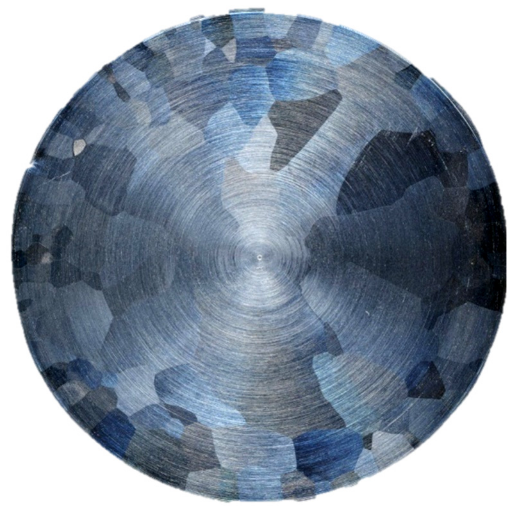

Figure 1: Cross-section structure of electron-beam melted Nb ingot 250 mm in diameter.

These ingots were used to produce 100 tons of Nb_3Sn and 120 tons of NbTi strands for ITER [3], 12 km of Nb_3Sn for HL-LHC and also for other projects.

PROPERTIES OF NIOBIUM SEMIPRODUCTS AND SUPERCONDUCTORS MADE OF THEM

The main semiproducts of niobium for superconductors production are rods to form superconducting filaments and sheets (or tubes) to form diffusion barriers. SC "VNIINM" has extensive experience in production regimes development and fabrication of these semiproducts in particular at SC "Chepetsky Mechanical Plant" (SC "CMP"). Hot extrusion, forging, drawing (rods), rolling (sheets and tubes), intermediate and final recrystallization annealing are generally used for niobium semiproducts manufacture.

In Table 1 the characteristics of niobium semiproducts manufactured for various projects (ITER, HL-LHC and others) are reviewed.

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Table 1: Nb Semiproducts Characteristics

Project (customer)	**Foreign customer**	**ITER**	**HL-LHC**		**-**
Parameter	Rods	Rods	Rods	Tubes	Sheets
Dimensions, mm	Diameter 7.4 mm	Across flats distance 6.3 mm (hexagon)	Across flats distance 2.48 mm (hexagon)	Outer diameter 102.5 mm/ inner diameter 92 mm	Thickness 3.5 mm
RRR	106	-	-	-	-
Surface roughness Ra, μm	≤0.635	-	-	-	-
Tensile strength σ_B, MPa	191.8 ±1.7	-	-	-	-
Yield strength $\sigma_{0.2}$, MPa	59.4 ±0.4	-	-	-	-
Elongation δ, %	42±2.5	-	-	-	-
Hardness, HV	70.5 ±0.9	<60	64÷79	48	50÷65
Average grain size, μm	20±4	23÷36	42÷54	27	59±8
Structure state	Recrystallized	Recrystallized	Recrystallized	Recrystallized	Recrystallized

Typical microstructure of longitudinal section of niobium rods and sheets after recrystallization annealing are shown in Figures 2 and 3.

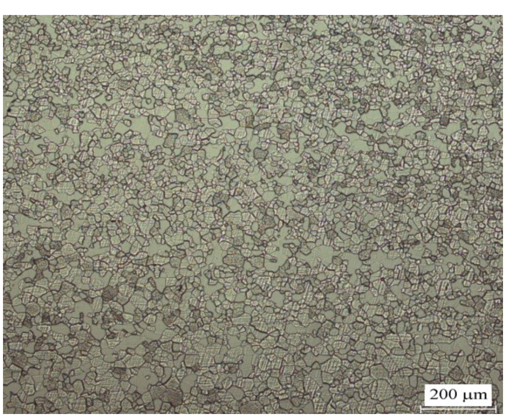

Figure 2: Microstructure of the Nb rod 7.4 mm in diameter after recrystallization annealing, longitudinal section, x100 [2].

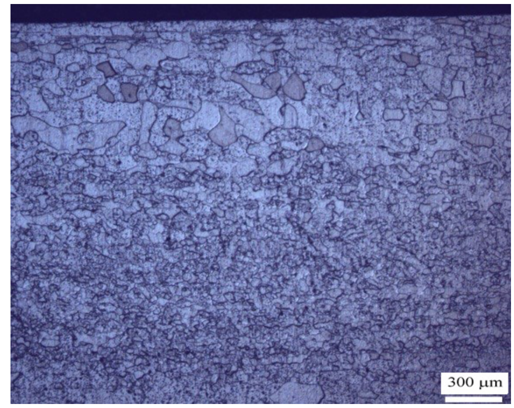

Figure 3: Microstructure of the Nb sheet with 3.5 mm thickness after recrystallization annealing, longitudinal section, x50.

Niobium semiproducts mentioned above were used to fabricate long-length superconducting Nb_3Sn and NbTi strands for ITER project and also Nb_3Sn strands for HL-LHC project. These Nb semiproducts and superconducting strands were manufactured at SC "CMP" industrial facilities using layouts and technologies developed at SC "VNIINM". These superconducting strands completely meet requirements (Table 2). The microstructure of Nb_3Sn strands cross-section for ITER and HL-LHC and grain structure of superconducting phase after the reaction heat treatment are presented in Figure 4.

Table 2: Requirements for the Nb_3Sn Strands for ITER and HL-LHC

Parameter	**ITER**	**HL-LHC**
Diameter, mm	0.82±0.005	1.00±0.003
Cu/nonCu	1.0±0.1	1.2±0.2
Twist direction	Right hand	Right hand
Twist pitch length, mm	15±2	14±2
Critical current, A / Critical current density, A/mm^2 (4.22 K, 12 T)	>190/ >720	>875/ >2450
n index	>20	>20
RRR	>100	>150
Hysteresis loss, mJ/cm^3, ± 3 T	<500	-
Effective filament diameter, μm, ± 3 T	-	≤120

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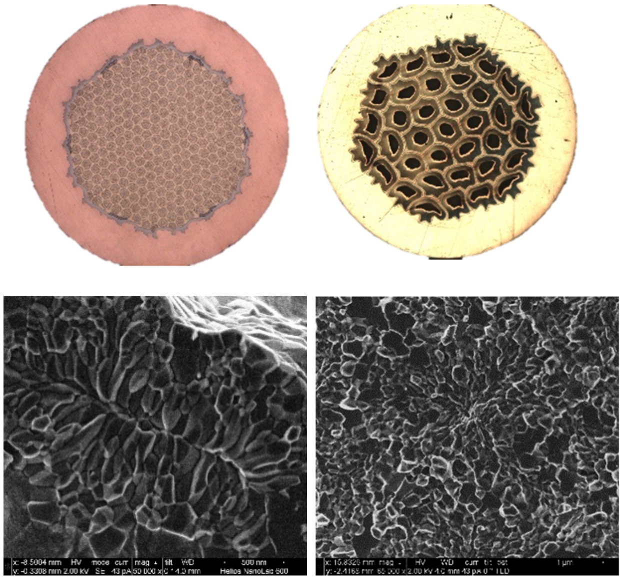

a b

Figure 4: Microstructure of the Nb_3Sn strands cross-section for ITER (a) and HL-LHC (b) and superconducting phase grain structure after reaction heat treatment.

MANUFACTURE REGIMES DEVELOPMENT OF NIOBIUM SHEETS FOR SRF CAVITIES

It is well known that SRF cavities are manufactured of special grade niobium sheet material with high RRR values. RRR parameter indirectly define the chemical purity of the material and quality of its internal structure which are affecting on superconducting properties.

According to the present requirements for SRF cavities niobium sheets RRR should be not less than 300.

At present SC “VNIINM” in collaboration with SC “CMP” have started R&D with the target to develop manufacture regimes of niobium sheets for SRF cavities with RRR > 300. The main targets to fabricate material that meets requirements, taking into account production equipment available at SC “CMP”, were defined:

-use of ultra pure niobium pentoxide (with extremely low impurities content, especially Ta, W, Mo) as initial material;

-development of the recovery and electron-beam melting regimes;

-sheets deformation regimes optimization in order to increase of the total strain for the homogeneous fine grain microstructure formation after recrystallization and also to obtain sheet surface with high purity and low roughness;

-optimization of the final recrystallization annealing regimes to form homogeneous fine grain microstructure and searching of the optimal gettering material in order to avoid niobium contamination during the heat treatment that can lead to RRR decrease.

CONCLUSION

SC “VNIINM” has a wide experience in development of melting regimes for high purity and low hardness niobium and also semiproducts production regimes. SC “CMP” has a many years experience in niobium ingots and semiproducts production for Nb_3Sn и NbTi superconducting strands for various projects.

Fabrication of SRF grade niobium sheets which meet all set of requirements is complex target. It includes works in following research directions: initial materials purity improvement, plastic deformation regimes optimization and also regimes of the recrystallization annealing and niobium sheets surface treatment should be optimized.

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