ANALYSIS OF NIOBIUM QUALITY CONTROL FOR SRF CAVITIY

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Abstract

Clean and smooth surface is important to get low surface resistance for superconducting material. SRF (Superconducting Radio Frequency) cavity made of niobium which is superconducting material and also one of the rare metal. The procedure of niobium quality control was set up to get high performance SRF cavity. The procedure consists of three parts; certificates check, Nb specification verification, and surface inspection and measurements of thickness, roughness, flatness. Three important properties which are RRR value, chemical composition and mechanical properties were verified to conform Nb specification. The range of thickness, roughness and flatness for niobium as SRF cavity raw material were obtained by measurement.

INTRODUCTION

Nb which is one of the rare metal is well known as raw material to build SRF (Superconducting Radio Frequency) cavities. The inner surface of SRF cavity is quite important to get high performance because superconducting material has low surface resistance when it has clean and smooth surface. That is why material quality control is important in SRF cavity field. It has to be controlled to get superior clean and smooth surface. SRF cavity development group in RISP (Rare Isotope Science Project) set up niobium quality control process and it will be described in this paper.

PROCEDURE & RESULTS OF Nb Q•C

The procedure of niobium quality control (Q•C) for RISP cavities was set up. It consists of three parts; certification check, Nb specification verification and measurements including surface inspection. We bought sets of Nb sheet that are bundle of niobium pieces for one cavity from ATI (Allegheny Technologies Incorporated, USA). We are going to build SCL3 section as first linac part for RISP accelerator which is named as RAON. SCL 3 section needs 22 number of QWR, 102 number of HWR for linac section and 4 number of HWR for bending section. The total amount of the sets that we bought from ATI are 30 sets for QWR (Quarter Wave Resonator) and 150 sets for HWR (Half Wave Resonator) because we take cavity yield rate as 80% and series fabrication failure as 10% into account. The niobium manufacture which is ATI has been provided the certificate of niobium to prove the chemical, mechanical and electrical properties and this certificate is from the ingot which has receive heat treatment at the same time.

Table 1 shows Nb specification for RISP cavities.

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Table 1: The Specification of Nb for RISP Cavity

Property	Value
RRR	Minimum 300
Chemical composition	ASTM B393-09$^{\varepsilon 1}$,type5
Yield Strength, Rp 0.2	50 ≤ Rp ≤ 100 Mpa
Tensile Strength, Rm	Minimum 100 Mpa
Elongation, AL30	≥40% (LD), ≥35%(TD)
Hardness, HV10	Average ≤ 60
Grain size	Average ≤ ASTM #5 (64μm)

Certificate Check

All of the certificates of niobium sheet that we have got from ATI up to date are satisfied with RISP Nb specification. Some data narrowly passed the criteria but we think it is not going to be a big problem because it was satisfied with important properties such as RRR value. The total amount of certificates of niobium that we have got until now are 186. It means 186 Nb ingots that receive heat treatment at the same time are used to make Nb sheet for RISP.

The Verification of Nb Specification

Three important properties that are RRR value, metal impurity concentration and mechanical properties were verified. Most results are satisfied with RISP Nb specification but the results show different pattern from ATI certificate data.

RRR (Residual Resistance Ratio) Value RRR value is represented the property of superconducting material. We were set RRR value up as minimum 300 for RISP cavities. RRR value was verified by PPMS (Physical Properties Measurement System) using the sampling. All of the results were satisfied with the Nb specification. But it shows different value from ATI certificate data. ATI takes sample for RRR test from ingot and product but ingot does not have the same RRR value all over the part. ATI assume that ingot has RRR value going up and down from top to bottom.

Table 2: RRR Value Comparison between ATI ATI and RISP Data

No.	ATI	RISP
1	363	413
2	434	471
3	500	444
4	584	491
5	640	368

Chemical Composition Metal impurities in Nb sheet were verified by ICP-MS (Inductively Coupled Plasma Mass Spectrometry) using the sampling. Most

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results were satisfied with Nb specification but the results of two metal impurities, Ta and W, shows greater value than ATI certificate data. However we concluded that there is no big difference between the results and RISP Nb specification.

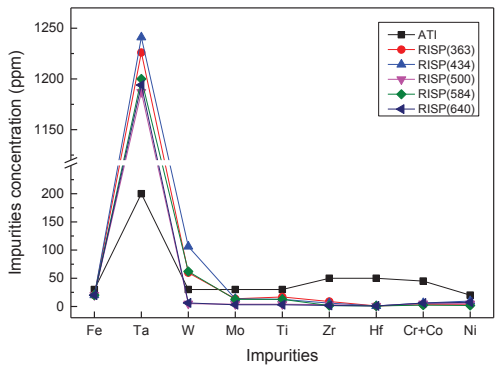

Figure 1: The results of impurity concentration.

Mechanical Properties Mechanical properties: Tensile strength (Mpa), Yield strength (Mpa) and Elongation (%) were verified by tensile test using the sampling. Figure 2 shows that what does degree means. The degrees such as 0°, 45°, 90° are represented sample angle to rolling direction of Nb sheet.

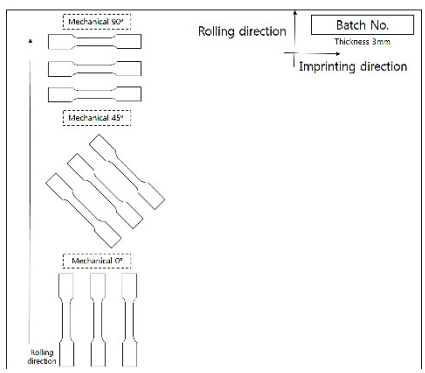

Figure 2: Sample angle to rolling direction of Nb sheet.

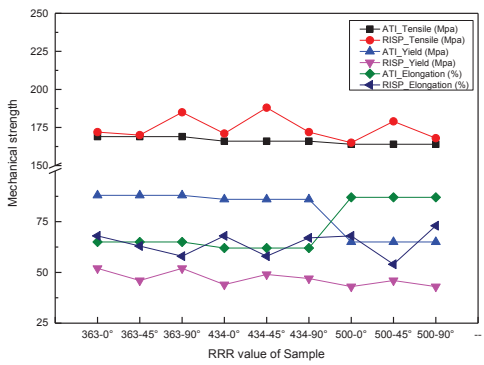

Figure 3: The mechanical property results comparison between ATI and RISP data.

In case of tensile strength and elongation, ATI and RISP data show similar result and it is satisfied with RISP Nb specification. However, yield strength results show a big difference gap, though ATI data narrowly are satisfied with RISP Nb specification. We think this difference from different strain rate. We have a plan doing tensile test with exactly same strain rate of ATI test.

Measurement

We inspected and measured surface condition, size, thickness, roughness and flatness of Nb sheet as part of Nb Q•C. Only parts that be seriously affected by RF field, such as around beam port parts, also upper and lower parts were inspected and measured. The parts are named as RF surface. All of the RF surfaces that were inspected and measured are RRR 300 grade. RRR 50 grade that need to build support structure on the outside of the cavity does not need inspection and measurement.

Surface Inspection & Size Check The surface and size of around five hundred Nb sheets were inspected and measured. The criteria of surface inspection to pass or fail is that no contamination and no scratch or dent which is larger than 50 μm depth. There is no Nb sheet that has serious scratch or larger than 50μm depth but it still have to check to decide which part is going to be inner part of the cavity.

The criteria of size to pass or fail is the tolerance of size, ± 3.175 mm. We found only two sheets are not satisfied this criteria among around five hundred Nb sheets.

Thickness Measurement We measured thickness of the Nb sheet of four corner and center. The criteria of thickness measurement to pass or fail is the tolerance of thickness, ±0.254 mm. Figure 3 shows the result of thickness measurement of one of the corner. Every four corner and center thickness measurement results show similar results. The average range of thickness is 2.85 mm to 3.10 mm. All sheets are satisfied with the criteria and we got new range of proper thickness of Nb sheet.

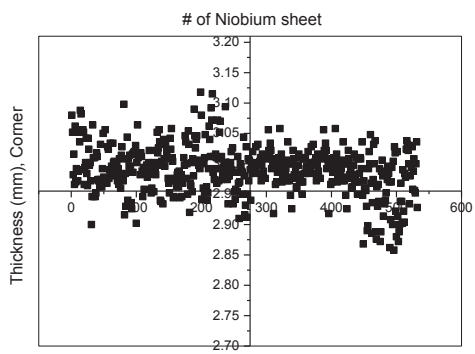

Figure 4: The result of thickness measurements.

Roughness Measurement We measured roughness only one point in Nb sheet. We does not have certain criteria when we decide to buy RRR 300 grade Nb sheet. The average range of Nb sheet as raw material is 0.2 μm to 0.45 μm. The roughness of Nb sheet for SRF cavity shall not be exceed 1 μm empirically.

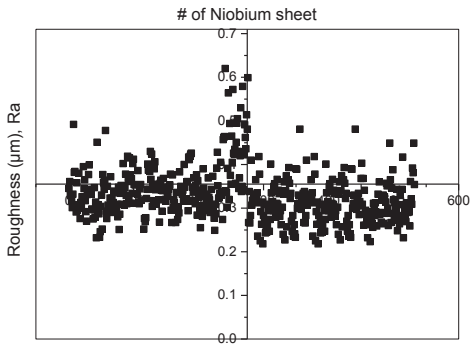

Figure 5: The result of roughness measurements.

Flatness Measurement We also measured flatness of Nb sheets. There was no certain criteria when we decide to buy RRR 300 grade Nb sheet also. The average range of peak to peak of Nb sheet is 0.1 mm to 1 mm. DESY was set up the criteria of Nb sheet flatness for SRF cavity in European XFEL (X-ray Free Electron Laser) project as maximum 1mm [1,2]. We confirmed this criteria is proper value for flatness of RRR 300 grade Nb sheet as SRF cavity material.

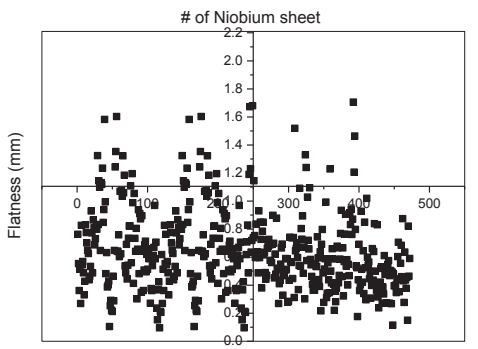

Figure 6: The result of flatness measurements.

CONCLUSION

The procedure of Nb Q•C for RISP cavities was set up and only RRR 300 grade Nb be controlled by Nb Q•C. All of certificates from ATI were satisfied with RISP Nb specification up to date. The test of RRR value, chemical composition and mechanical properties were carried out using the sampling and most of results were satisfied with RISP Nb specification. RF (Radio Frequency) parts which are named by RF surface are the parts that strongly effected by RF field among part of the cavity. All of RF surface were inspected and measured: size, thickness, roughness and flatness of Nb sheet. In case of size measurement, only two pieces were not satisfied with the tolerance that ATI guaranty. The average range of thickness, roughness and flatness of the Nb sheet as raw material were obtained respectively: in case of thickness; 2.85 mm to 3.10 mm, in case of roughness; 0.2 μm to 0.45 μm Ra, in case of flatness; 0.1 mm to 1 mm. All of data will use for SRF cavity fabrication process as reference data.

ACKNOWLEDGEMENT

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