FABRICATION AND EVALUATION OF LOW RRR LARGE GRAIN 1-CELL CAVITY

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Abstract

Successive R&D studies of SRF cavities are ongoing at KEK by using existing facilities of Cavity Fabrication Facility (CFF) and other equipment of Superconducting Test facility (STF). Recently, there are studies on the low RRR of niobium material with high and uniform concentration of tantalum which could be used for the fabrication of high performance SRF cavity, and hence it could reduce the fabrication cost of cavities [1]. In order to confirm the advantage of the material, a large-grain single-cell cavity was fabricated at CFF/KEK with sheets sliced from a low RRR niobium ingot with high and uniform concentration of tantalum. The resistivity measurement of sample from sliced sheet showed the RRR value of 100, whereas it is about 400 for the nominal qualification of fine-grain sheets at KEK. The low RRR large-grain single-cell cavity was already fabricated at CFF/KEK. The quality control of the fabrication processes are well under control. Then several vertical tests of the cavity were done at STF/KEK. In this presentation, the results of the vertical tests are shown. The potential of the low RRR niobium material for SRF cavity are discussed.

INTRODUCTION

To accelerate charged particles with superconducting RF (SRF) system is a widely used scheme. Especially, for International Linear Collider (ILC), more than 17000 SRF cavities are required. According to a technical design report of the ILC, those cavities would be fabricated from high RRR (>300) niobium material by using of press forming and electron beam welding processes [2]. Improving fabrication methods and researching other types of material for the SRF cavity could reduce construction costs of the accelerator. Focusing on this point, successive R&D studies of SRF cavities are ongoing by using cavity fabrication facilities of Mechanical Engineering Center and other equipment of Superconducting Test facility in KEK [3].

Usually, SRF cavity fabrication starts from fine grain (50~150um) niobium materials. Those materials pass through electron beam melting process several times to guarantee own high purity. Instead of using the pureness, RRR of the niobium material is used as an index of quality. Niobium grain fineness of the material originates in a production process. Ordinary procedures include forging and rolling steps. During those processes, metal crystal was crushed into rather fine structures. From a workability viewpoint, this transformation sustains suitable properties of metals. So, using fine grain high RRR niobium is the world standard recipe to fabricate the SRF cavity, nowadays. But iterative electron beam melting and following forging/rolling processes push up the fabrication costs. One idea to escape from this problem is using large grain niobium material. A main difference between the large grain and the fine grain niobium material is attributed from skipping the final forging/rolling processes. During the electron beam melting, melted niobium gradually becomes colder in a melting pot, and recrystallization occurs. An aligned crystal structure in a grain boundary becomes visible size. If there's no cursing procedures like forging are followed, those aligned structures are kept and become large grain niobium materials. Usual grain size is about several centimetres. To compare with the fine grain case, skipping several processes could lead to cost reduction. A striking drawback is difficulties of fabrication originate in the large grain size. Beside the peculiar difficulties, the large grain niobium materials are studied as an alternative material of the fine grain for SRF cavity fabrications [1].

Whichever grain size is used for the cavity fabrication, the RRR value still remains as a free parameter. And naively thinking, it is thought that niobium materials with higher RRR value (>300) is preferable for the SRF cavity use. A well-known explanation about this is shown as a relationship between thermal conductivity of the cavity and the RRR value around 4.2K [4]. With this relation, the thermal conductivity of the cavity proportionally increases when the RRR of the used material increases. As a result, heat exhausting property of the cavity depends directly on the residual resistance ratio of the material. To achieve high RRR value, the electron beam melting must applied several times for one batch. In other words, cost-determining step is the electron beam melting process. From the cost reduction view point, then, the key issue is to reconsider how high the necessary RRR level is. On the other hand, there are proposals to use commercial basis niobium materials for SRF cavity use [5]. Niobium is belonging to the same family with tantalum in the periodic table. Thus, those two show quite similar physical and chemical properties. And both materials are mined the same lode. Tantalum is a typical valuable rare-metal. And during refining procedures, niobium as an impurity of tantalum would be concentrated. After all, niobium which includes high and

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	H	C	O	N	Fe	Si	Ta	RRR
LG (high RRR)	< 5	< 10	< 10	< 10	< 10	< 10	80	390
LG (CBMM)	< 10	< 30	< 30	10	3	20	1034	100

Figure 1: Chemical compositions and RRR. (unit : ppm except RRR).

uniform concentration of tantalum is obtained as a by-product of highly purified tantalum. A specific supplier of such niobium material is CBMM Brazil [6]. Collaboration with JLab, CBMM provided a low RRR large grain niobium ingot to KEK. Using the material, R&D 1-cell cavity fabrication was started. In Figure 1, chemical compositions of usual high RRR large grain sheet and niobium delivered from CBMM are shown. Each component shows quite similar values except for tantalum.

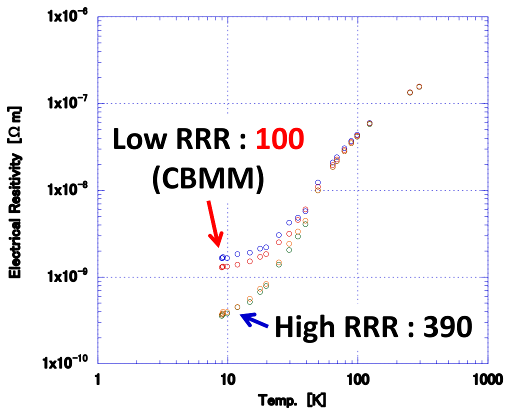

Figure 2: Electrical resistivity measurement.

For RRR, we prepared thin niobium samples with special care not to give any stress to the sample peace. (t = 1.0mm, w = 2.0mm, distance between electrode = 100mm) Using those, RRR value of CBMM one and usual high RRR large grain Nb was measured by standard 4-terminal method. Obtained results are shown in Figure 2. This measurement said that delivered Nb from CBMM shows certainly low value of RRR in comparison with usual use Nb sample. So far, background of this R&D is described. In following sections, 1-cell R&D cavity fabrication with this low RRR material and vertical test results are reported.

CAVITY FABRICATION

Actual R&D cavity fabrications were held at Cavity Fabrication Facility (CFF) in KEK. A niobium ingot of φ260×L 500 which provided by CBMM was cut by using sawing machine. But this tool was not delicate enough to make sheets for stamping. To obtain appropriate thickness sheets, multi-wire saw must be used. After cutting, several saw marks were on the sheet surface. But those marks were expected to be erase by tune the wire saw parameters. To adjust the sheets thickness finely, and clean up the remaining saw marks, mechanical polishing was applied before BCP. In Figure 3, Nb plate surface of each steps are shown.

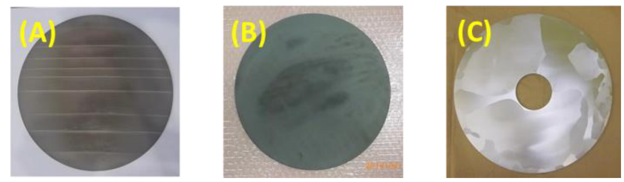

Figure 3: Sliced Nb plates. (A)Just after multi-wire sawing. On the surface, saw marks as horizontal lines still remain. (B)After mechanical polishing process. The saw marks are cleared. (C)After BCP. All abrasive grains are cleared.

Press forming and EBW processes were also held in CFF. After press forming, a few cracks along grain boundary were found. Those crack appearances were the first experience of KEK cavity fabrication, and confirmed that no one penetrating the sheet completely (keep leak tight). Just before EBW process, additional lathing to avoid thickness fluctuations caused of grain boundaries around the equator part were also applied. During welding around the equator area, we found fervent spattering several times. After welding process, remaining spatter marks outside of the cavity were clearly there. But corresponding area of inside, there's no remnant. This is another peculiarity of this cavity.

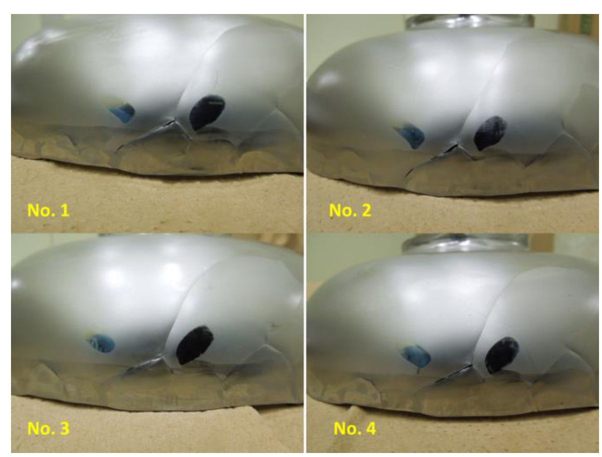

Figure 4: Found cracks along with grain boundary. All plates were sliced from the same ingot. So, the boundary marks were almost the same for each other. Once, after press forming procedure, the crack was found, then, all following plates also had on the corresponding grain boundary mark point.

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Figure 5: 1-cell cavity made by low RRR large grain Nb (left). On the equator part, several spatter marks are remained (right).

EVALUATION

To evaluate the fabricated cavity, vertical test was applied. In Figure 6, cold test results are shown. In 2.0K, reached maximum accelerating gradient was 28.1MV/m.

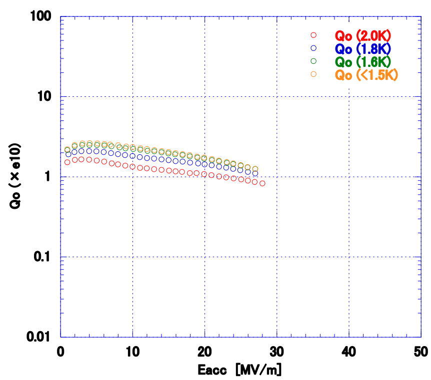

Figure 6: Vertical test results for the first time.

For comparison, not only the vertical test results of the low RRR cavity, but also those of the usual high RRR large grain cavity are shown in Figure 7(B). From Q-E plot (2.0K), reached Eacc of the low RRR cavity was 67% of high RRR large grain one. Using surface resistance measurement data, fitting with well-known representation of the surface resistance, residual resistance part of the low RRR cavity is almost twice than that of the high RRR large grain cavity (see Figure 7(A)).

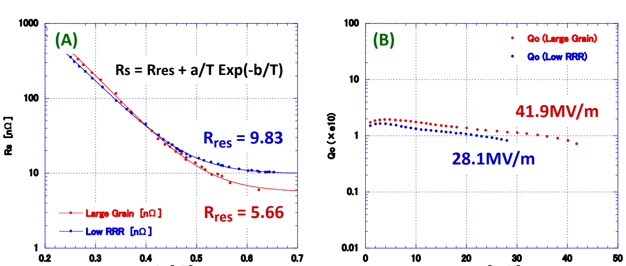

Figure 7: Comparison between the low RRR cavity and usual high RRR cavity performances. (A) Surface resistance measurement results. (B) Qo-E curves.

During the high power test, several thermometer attached on the cavity cell part showed generation of heat. After the test, we checked those areas by using Kyoto camera, and might detect a quench source. On the equator bead, unexpected ripple mark were found. Taking replica, and measured by using form tracer, the ripple has about 40um structures. This size structure might be enough to disturb cavity surface flow of magnetic field.

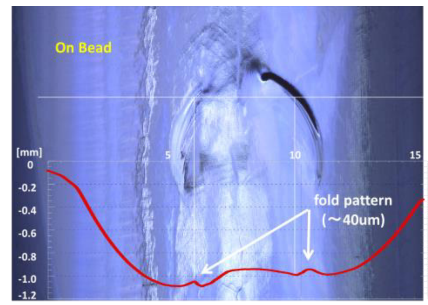

Figure 8: Found ripple taken by Kyoto camera. Red line shows surface measurement output of form tracer.

CONCLUSION

We fabricated a 1.3GHz single cell SRF cavity by using a low RRR (~100) large grain niobium. The niobium material is commercial basis product provided from CBMM Brazil and includes a lot of tantalum comparing with usual high RRR niobium. By applying vertical test, obtained accelerating gradient is 28 MV/m in 2.0K. In this first cold test, the maximum accelerating gradient did not attain to a value described in TDR of ILC. However, there may be other applications, so we conclude that this niobium material is applicable for the SRF cavity use.

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