DEVELOPMENT OF 1.3 GHz SINGLE-CELL SUPERCONDUCTING CAVITIES WITH NIOBIUM MATERIAL DEVELOPED BY ULBA METALLURGICAL PLANT

T. Ota†, M. Takasaki, M. Yamada, N. Kuroiwa, S. Nomura, T. Tosaka, Y. Otani,
Toshiba Corporation, Yokohama, Japan
Y. Shirota, BE International Corporation, Tokyo, Japan
A. Tsorayev, Y. Krygin, V. Kuznetsov, ULBA Metallurgical Plant, Ust-Kamenogorsk, Kazakhstan,
T. Saeki, H. Hayano, High Energy Accelerator Research Organization, Tsukuba, Japan

Abstract

TOSHIBA has been developing high purity niobium (Nb) material for superconducting cavities with ULBA Metallurgical Plant (UMP) since 2008. Recently, we have produced the high purity Nb plates. Two 1.3 GHz single-cell superconducting cavities using UMP's Nb plates have been fabricated by TOSHIBA and RF tested at High Energy Accelerator Research Organization (KEK). One of the cavities has achieved the accelerating gradient of E_{acc}=31.8 MV/m. The development of high purity Nb plates, details of the fabrication of the cavities and the RF test results are presented in this article.

INTRODUCTION

TOSHIBA has been continuing R&D on the fabrication of superconducting cavities for accelerators in collaboration with KEK since 2009. In order to ensure the quality of the superconducting cavities, the cooperation of the supplier of Nb material and the cavity fabricator is very important. In this sense, we are developing high purity Nb material of superconducting cavities for International Linear Collider (ILC) with UMP. Recently, UMP has produced the high purity Nb ingot in which Residual Resistance Ratio (RRR) value is higher than 300.

HIGH PURITY NB

UMP produces Nb ingots from Nb ore mined at a certain mine where is not Brazil. The impurities of Nb ingot are decreased by multi-melting. We have measured RRR of some samples of Nb ingots. Figure 1 shows RRR values depending on the number of multiple EB melting. RRR value is increasing with the number of melting. Multiple melting is effective for increase in RRR. RRR becomes higher than 300 by repeating of smelting Nb ingot more than six times. The chemical composition of UMP's Nb ingots and the mechanical properties of UMP's plates are shown in Table 1 and Table 2, respectively. UMP's Nb plates have reached to the performance equivalent to Nb plates of superconducting cavities for ILC.

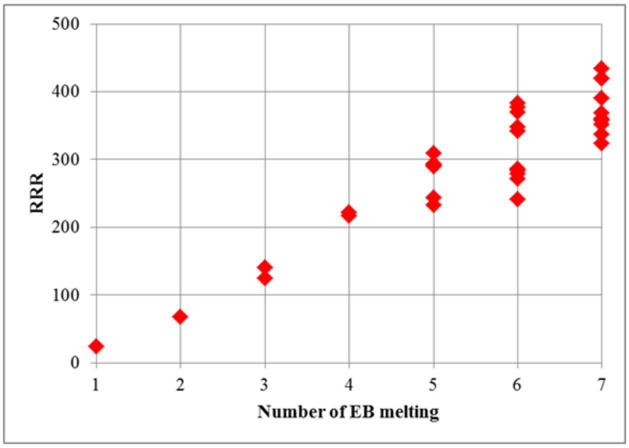

Figure 1: RRR values of multiple EB melting.

Table 1: Chemical Composition of Nb Ingot

	Element (< Wt.ppm)										
	Ta	W	Mo	Ti	Fe	Ni	Si	H_2	N_2	O_2	C
ILC specs	500	70	50	50	30	30	30	2	10	10	10
UMP's Nb	300	25	25	10	10	-	17	2	37	25	20

Table 2: Mechanical Properties Measurement of Nb Plates

	Tensile Strength (MPa)		Yield Strength (MPa)		Elongation (%)		Average Grain Size (μm)
	Longitudinal	Transverse	Longitudinal	Transverse	Longitudinal	Transverse	
ILC specs	140	140	39	39	> 30	> 30	40
UMP's Nb	167	167-172	53-56	55-56	53-56	59-60	23

---

† tomoko.ota@toshiba.co.jp

RF TEST OF SINGLE-CELL CAVITIES

Fabrication of Single-cell Cavities

To evaluate the performance of UMP's Nb plates, two single-cell superconducting cavities being made from them were fabricated based on the TESLA type cavity. Main specifications of the single-cell cavity are shown in Table 3. Half-cells were formed from Nb disks of thickness of 2.8 mm by deep drawing. Two flanges were made from niobium-titanium. Two half-cells were electron beam welded at equator. Equator welds were full penetration from the outside. Figure 2 shows a completed single-cell cavity without ports.

Table 3: Specifications of Single-cell Cavity

Frequency	1.3 GHz
Equator of cell diameter	205.6 mm
Geometry factor	277.6 Ω
Beam tube diameter	78 mm
Cavity length	368.2 mm

Figure 2: Single-cell superconducting cavity.

Surface Preparation

Two cavities were surface prepared at KEK. The inner surface of single-cell cavities were inspected using the Kyoto camera system [1]. After the inspection, the standard surface preparation of KEK was carried out to single-cell cavities, as shown below;

1. Initial electro-polishing to remove about 100 μm.
2. Annealing in vacuum for about three hours at 800 °C, with a titanium box around the cavity to degas hydrogen out of the Nb material.
3. Final electro-polishing to remove about 10 μm.
4. Hot water rinsing in the ultrasonic bath for about 30 minutes at 50 °C with detergent FM_20 of 2 %.
5. High pressure pure water rinsing with 8 MPa for about 7 hours.
6. Baking out for about 2 days at 120 °C, with vacuum inside the cavity.

Many defects were exposed on the inner surface of both the cavities after initial electro-polishing. Figure 3 shows defects on the equator of the 1st cavity. Many small defects of the size around 0.2 mm were gathering. Figure 4 shows defects on the equator of the 2nd cavity. A large defect and many very small defects were observed on the whole inner surface not on the equator bead. One of the causes of these defects may be the exotic material involved in Nb plates during roll processing.

Since it was thought that these defects might cause heating and field emissions, some comparatively large defects were removed by mechanical polishing. After that, electro-polishing to remove 50 μm and processing from No.2 to No.6 of the standard surface preparation of KEK was carried out.

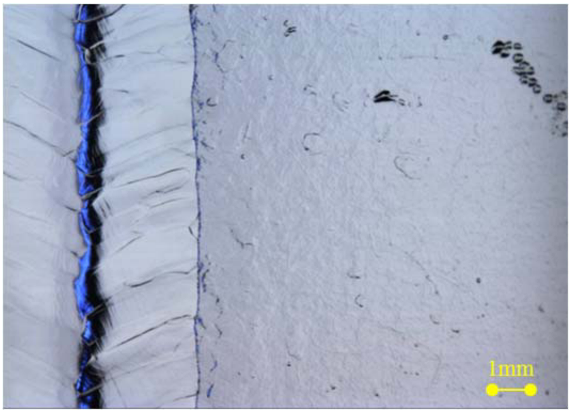

Figure 3: Defects on the equator of the 1st cavity.

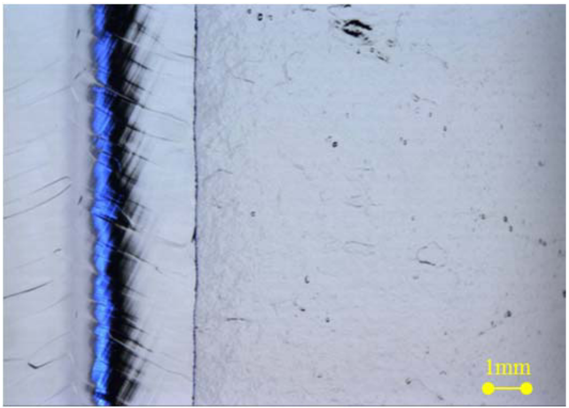

Figure 4: Defects on the equator of the 2nd cavity.

1st RF Test Results

After the surface preparation, the 2nd cavity was assembled for the RF test in a clean room. The cavity was cooled with superfluid helium and RF tested at 1.8 K. Dark blue marks in figure 5 shows the result of 1st RF test. When the accelerating gradient (E_{acc}) exceeded 16 MV/m, radiation began to occur. Finally, the E_{acc} was limited at 18 MV/m with Q_o=6.1x10^9 by quench. The residual surface resistance of the cavity was 9.8 nΩ.

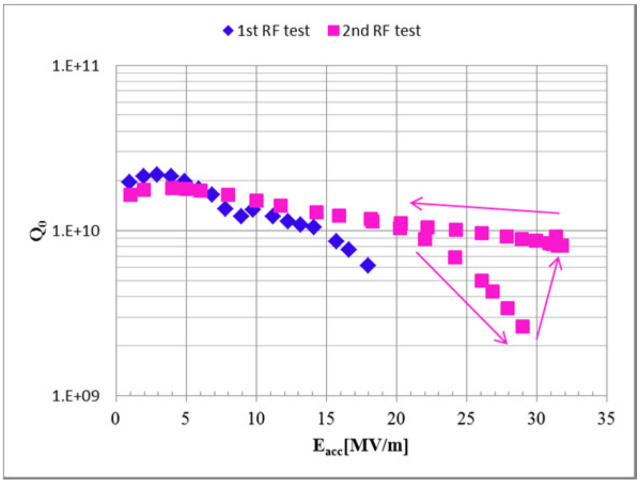

Figure 5: RF test results of the 2nd cavity.

Inner Surface Inspection and Surface Preparation after the 1st RF Test

After the 1st RF test, the inner surface of the cavity was inspected thoroughly. Although almost all large defects were removed, some small defects of 0.1 mm or less remained as shown in figure 6. Some of these defects were removed by mechanical polishing. After that, electro-polishing to remove 100 µm and annealing in vacuum for about three hours at 800 °C was carried out. The inner surface of the cavity was inspected again. Since some traces of mechanical polishing were rough, they were flattened by polishing. After that, final electro-polishing to remove 20 µm and ultrasonic rinsing was carried out, as shown below;

1. Setting the oscillator inside the SUS304 vessel to the bottom of a beam tube.
2. Filling with detergent FM_20 of 2 % inside the cavity.
3. Ultrasonic rinsing for about 15 minutes at 28 °C.

Next, the processing from No.5 and No.6 of the standard surface preparation of KEK was carried out.

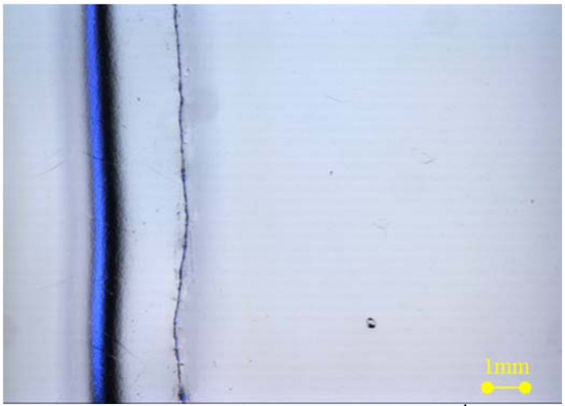

Figure 6: Defects on the equator of the 2nd cavity observed after the 1st RF test.

2nd RF Test Results

2nd RF test of the 2nd cavity was carried out at 1.9 K after the surface preparation. Pink marks in figure 5 shows the result of 2nd RF test. At first, radiation began to occur when E_{acc} exceeded 18 MV/m. Though the dose of radiation became very large at E_{acc}=29 MV/m, field emission was processed out by inputting large RF power to the cavity. Finally, the E_{acc} was limited at 31.8 MV/m with Q_o=8.1x10^9 because RF power was not able to be inputted into the cavity any more. The residual surface resistance of the cavity was 10.3 nΩ.

After the 2nd RF test, the inspection of the RF parts used for the RF test was carried out to investigate the cause of the limitation of the input RF power. As the result, there was no problem in the RF input antenna, the feedthrough and the adapter of N-type connector attached to the feedthrough atmosphere side. Discoloration was observed at the central conductor of L-type adapter attached to the adapter of N type connector. And there was no problem in the cable connector. So the loose connection of the central conductor of the L-type adapter may be one of causes which limited the input RF power and E_{acc}. The chemical composition analysis of the waste fluid of the ultrasonic rinsing was carried out. SUS304 may be the cause of the field emission since Fe, Cr and Ni were detected.

CONCLUSION

TOSHIBA and UMP have produced the high purity Nb plates. UMP's Nb plates have reached to the performance equivalent to Nb plates of superconducting cavities for ILC. Two 1.3 GHz single-cell superconducting cavities using UMP's Nb plates were fabricated. Many defects were exposed on the inner surface of both the cavities after initial electro-polishing. One of cavities was RF tested and achieved the accelerating gradient of E_{acc}=31.8 MV/m after removing these defects. We have to clarify the cause of these defects inside Nb plates. Our following target is establishing the technique of producing Nb plates which have no defects inside.

REFERENCES

[1] Y. Iwashita *et al.*, Phys. Rev. ST Accel. Beams 11, 093501 (2008).