ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-MOPCAV012

FABRICATION OF 1.3GHz SRF CAVITIES USING MEDIUM GRAIN NIOBIUM DISCS DIRECTLY SLICED FROM FORGED INGOT*

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Abstract

Medium grain (MG) niobium disc which is directly sliced from forged ingot is newly investigated for the cavity material. An effective cost reduction can be achieved using MG niobium since rolling process which is necessary for typical niobium sheet can be skipped during MG niobium production. An average grain size of MG niobium is 200-300 μm with occasional grains as large as 1-2 mm which is much smaller than large grain (LG) niobium directly sliced from melted niobium ingot. Hence, the formability of MG niobium is expected to be much better than LG niobium. KEK has fabricated two single cell cavities using MG niobium and RF tested one of them. In this study, the characteristics of MG niobium during fabrication and RF test result are discussed here.

INTRODUCTION

In a large accelerator experiment which uses large amount of SRF cavities such as international linear collider (ILC), reducing material cost for cavity is one of the big issues. Typical SRF cavities were made by forged and rolled niobium sheets called fine grain (FG) niobium. KEK has been trying to reduce material cost using several materials such as LG niobium [1]. Using LG niobium discs for cavity can reduce the material cost since it is directly sliced from melted niobium ingot and enables to skip forge and rolling process. The risk of contamination of foreign material on the niobium surface which occur during rolling step can be also reduced using LG niobium. On the other hand, LG niobium has large anisotropy since it has large crystals. This large anisotropy leads shape distortion of formed disc which makes fabrication process more difficult. Moreover, LG discs have different mechanical properties even in the same disc. Hence it is difficult to guarantee certain mechanical strength of cavity made by LG discs against high pressure air or helium.

MG niobium discs are directly sliced from forged niobium ingot called “billet”. Using MG niobium discs as cavity material is suggested in [2, 3]. The MG niobium discs have much smaller grain size than LG discs. Hence MG niobium discs are expected to have more uniform mechanical properties and better formability. Furthermore, an effective cost reduction and reduced chance of contamination can be expected because the rolling process is not used.

MATERIAL

In the MG niobium production process, a melted ingot was forged into columnar shape billet. This billet is then sliced into 2.8 mm thickness discs by multi-wire saw for the cavity material. Figure 1 shows one of the sliced MG discs which diameter is 260 mm. Several patterns which consist of small grains can be seen in the disc. Figure 2 shows the zoomed view of MG disc. Measured average

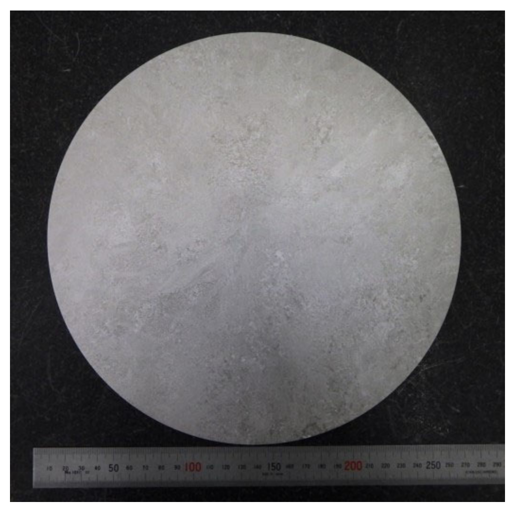

Figure 1: Sliced MG disc.

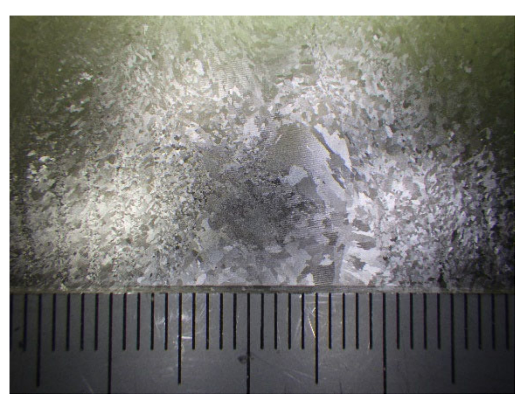

Figure 2: Zoomed view of MG disc.

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Table 1: Chemical Compositions of MG Niobium Billet [wt ppm]

C	Fe	H	Hf	Mo	N	Ni	O	Si	Ta	Ti	W	Zr
< 20	< 30	< 3	< 50	< 30	< 20	< 20	< 40	< 30	< 100	< 30	< 30	< 50

Figure 3: Fabricated cavity (R18 and R18b).

grain size is 200-300 μm with occasional grains as large as 1-2mm. Crystalline arrangement differs between top and bottom of billet. Surface roughness of the discs measured at KEK is about 0.7 μm Ra. The MG niobium billet used in this study was produced by ATI. Residual resistive ratio (ratio of resistance at 295 K and T_c) of billet used in this study is 494. Table 1 shows the chemical compositions of this billet.

Mechanical strengths of MG niobium were measured at KEK in both room temperature and cryogenic temperature. Tensile strengths of as received sample at room temperature were around 150 MPa which is similar to FG niobium. Discs from both top and bottom of billet were chosen for this test. Several specimens were then cut out from different regions of a disc. Tensile strength vary within 10 % for samples with same conditions. More details are described in [4].

FABRICATION

In this study, two single cell cavities named "R18" and "R18b" were fabricated which are shown in Fig. 3. The basic fabrication process follows;

1. Making a hole at the centre of the disc by punching
2. Press forming into half-cell shape
3. Shaping of iris and equator edges by lathe
4. Buffered chemical polishing (BCP) of half-cells
5. Annealing of half-cells for internal stress relief
6. BCP of each part
7. Electron beam welding (EBW) beam tubes and iris
8. BCP of each part
9. Equator welding.

Cell shape of these single cell cavities are TESLA shape [5] and beam tube length is 139 mm.

Formability

During the forming process, iris region cracked with some half-cells. An example of this crack is shown in Fig. 4. Cracks on each half-cell appeared at the same position on each disc. This crack also happens when LG disc is press formed. Even though the ingot was forged into niobium billet during MG niobium production, there are still effects of original crystalline arrangement. The diameter of the centre hole before press forming was increased, and discs were annealed (800 °C × 3 hours) before forming to avoid this crack. Figure 4 (right) shows the iris which is successfully formed after increasing the inner diameter acceptable for further shaping process. Thickness variation at iris can be observed even in half cells without cracks. Forming results are summarised at Table 2.

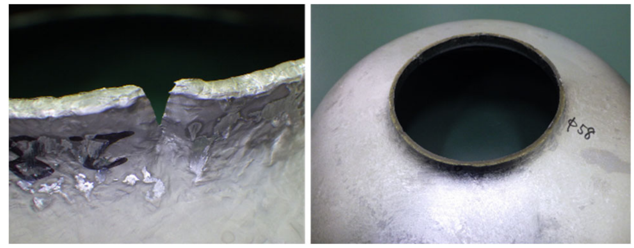

Figure 4: Cracked iris (left) and successfully formed iris (right).

Table 2: Summary of Press Forming

Disc #	Hole Diameter [mm]	Annealing	Forming Results	Purpose
#6	56	No	Light crack	R18
#7	56	No	Light crack	R18
#8	56	Yes	Deep crack	Test
#9	59	Yes	No crack	Test
#10	58	Yes	No crack	Test
#57	60	Yes	No crack	R18b
#58	58	No	Light crack	R18b
#59	56	No	Deep crack	Test
#60	58	No	Deep crack	Test

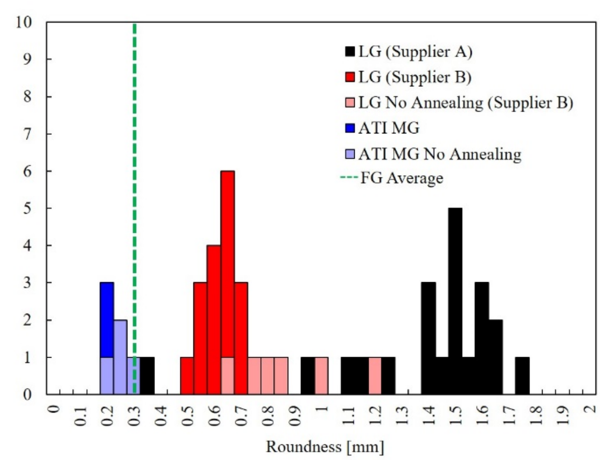

Figure 5: Histogram of measured roundness.

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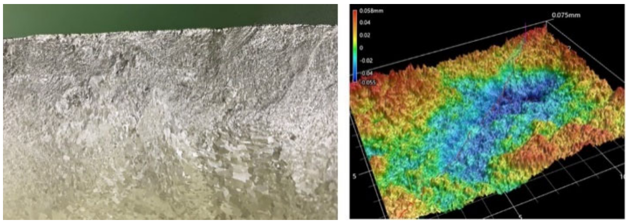

Figure 6: Photo of inner surface of half-cell equator (left) and 3D-data measured by laser microscope (right). 3D measured area is different from left photo.

Figure 7: Inner surface of each cavity.

The distortion of the MG half-cells after forming were much smaller than that of LG discs. Cross-section shape of MG half-cells measured by CMM matched design shape within ±0.5 mm. Roundness at equator of MG half-cells were also measured by CMM. Roundness is defined as difference between two diameters of inscribed circle and circumscribed circle. Roundness of MG half-cells and roundness of LG half-cells which were measured in the past study are shown at Fig. 5. Roundness of LG half-cells are more than 0.5mm. On the other hand, roundness of MG half-cells are less 0.3mm which is similar to average value of FG half-cells calculated from past data.

Surface Roughness

Surface of half-cell was rough especially at a curvature region after forming as shown in Fig. 6. This surface roughness caused by undulating of grain boundary. Measured roughness near the equator is about 2.6-5.7 μm Ra and 11-28 μm Rz where Rz is defined as average value of 1st to 5th highest hills and deepest valley respectively. Inner surface around equator of R18 is then mechanically polished before equator welding. Surface roughness became 2.6-3.7 μm Ra and 2.6-11 μm Rz. R18b was fabricated with original (not polished) surface.

Cavity is electropolished after completed toward RF testing as described below. Inner surface roughnesses near equator of R18 were measured again after 100 μm electropolishing. Its values were 1.1-1.5 μm Ra and 3.4-6.7 μm Rz. Figure 7 shows inner surface of each cavity.

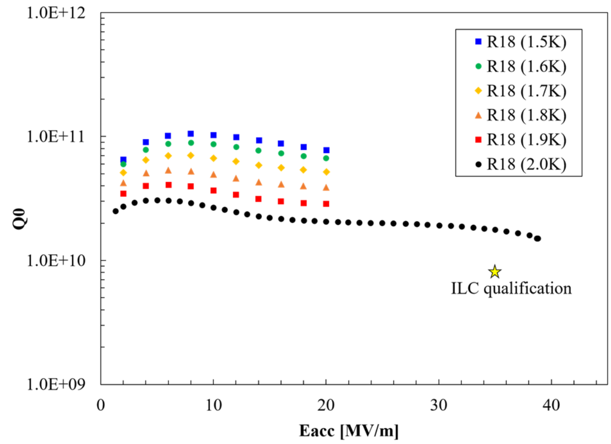

Figure 8: RF test results of R18. A star in the plot represents ILC qualification value.

PERFORMANCE TEST

Completed cavity was RF tested at cryogenic temperature. The following surface treatments were applied to completed cavity before RF testing at KEK;

1. Initial electropolishing of 100 μm
2. Annealing at 800 °C × 3 hours in a vacuum furnace
3. Second electropolishing of 20 μm
4. High pressure rinsing with ultra-pure water
5. Baking at 120 °C × 48 hours.

Cavity is then cooled down to 2 K in a vertical cryostat filled with liquid helium. Environmental magnetic field is canceled by coil set around cavity during RF testing. Remaining magnetic field around cavity was less 0.5mG when the cavity was tested.

In this study RF testing of R18 caivty was performed. Figure 8 shows the results of RF testing. Measurements at 1.5 K, 1.6 K, 1.7 K, 1.8 K and 1.9 K were performed prior to 2K measurement and stopped at 20 MV/m to avoid quench which may traps magnetic field and lowers Q_0 value. Finally, cavity reached 38 MV/m at 2K measurement and quenched. Q_0 value was 1.5×10^{10} at 38 MV/m. This result satisfied ILC qualification.

SUMMARY

In this study two single cell cavities were fabricated using MG niobium discs at KEK. The distortion after forming is much less than that of LG niobium disc, which is rather similar to FG niobium. On the other hand, the iris cracked on some discs after forming which also happens with LG niobium discs. This means that MG niobium still has characteristics of LG niobium. Surface of half-cell was rough after forming especially at curvature region. Hence, the equator of one cavity was mechanically polished. The other cavity was fabricated with original surface.

One of fabricated MG niobium cavity with polished equators was RF tested in cryogenic temperature. It reached 38 MV/m at 2 K measurement with Q_0 value of 1.5×10^{10}.

The other cavity with original surface is now under surface treatment process and RF tested soon.

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