# PERFORMANCE OF Nb/Cu CLAD SEAMLESS SC CAVITY MADE FROM A PIPE BY HOT&COLD ROLLING AND DEEP-DRAWING

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*Abstract*

Nippon Steel Co. has successfully developed Cu/Nb/Cu sandwiched seamless pipes for superconducting rf L-band cavities using deep-drawing and spinning of a Cu/Nb/Cu clad sheet which was fabricated by a hot rolling method. DESY formed single-cells with TESLA shape from the clad pipes using hydro-forming. KEK electron-beam welded Nb pipes on the cells and made surface treatments including barrel polishing, heat treatment and electropolishing. As a result of the vertical test, excellent performance : Eacc,max=39.0MV/m, $Q_0$,max= $1.67\times10^{10}$ at 1.5K and 1.3GHz was then achieved in the first test.

## 1 INTRODUCTION

So far sc cavities have been fabricated from Nb sheets by deep-drawing and EB welding. However this process looks to be too expensive for the future applications like TESLA, FEL and ERL projects. On the other hand, Nb/Cu clad seamless cavities have a lot of benefits for sc cavities: highly reliable performance and cost-effective fabrication[1]. This excellent idea was realized in our recent measurement. Here we present the measurement result and a new fabrication method of Cu/Nb/Cu sandwiched seamless pipes for sc cavities.

## 2 CU/NB/CU CLAD SEAMLESS PIPES

Nippon Steel Co. has unique original technology to fabricate NbTi/Nb/Cu multilayer composite sheets and seamless pipes for superconducting magnetic shielding[2] [3]. This technology was applied to produce Cu/Nb/Cu clad sheets and seamless pipes. Cu/Nb/Cu sandwiched sheets were fabricated by an airtight-cladding and hot&cold rolling method. Then clad seamless cups were formed by deep-drawing and spinning technology. After cutting the cups' bottoms, clad seamless pipes were made. The fabricating processes are shown in Fig.1.

### *2.1 Fabrication of Cu/Nb/Cu clad sheet*

After preparing a box and lid made of Cu sheets of 4-nine class, an Nb sheet with RRR = 250 was inserted into the Cu box, and a Cu/Nb/Cu sandwiched slab was assembled. The slab was EB welded at the seam between the box and lid, and vacuum-sealed (canning), then it was hot rolled and cold rolled to a 4.3mm thick clad sheet. At the time Nb thickness was about 0.75mm.

### *2.2 Fabrication of Cu/Nb/Cu clad seamless pipes*

Prior to deep-drawing, the clad sheet was annealed in $N_2$ gas mainly for Cu softening, and deep-drawn by four steps to a cup. Spinning was then performed on it. After cutting its bottom, a clad seamless pipe was made. It was 250mm long and 133mm in inner diameter, and is shown in Fig.2. During the deep-drawing and spinning processes, intermediate and final annealings in $N_2$ gas were made on it for Cu softening. Fig.3 shows the wall thickness distribution of a Cu seamless test pipe after deep-drawing and after spinning. The Cu pipe was fabricated from a 4.0mm thick Cu sheet to make sure fabricating processes. It is clearly shown that the thickness at the pipe's flange

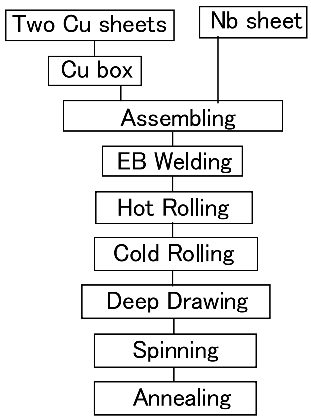



Figure 1: Fabricating processes of Cu/Nb/Cu sandwiched clad seamless pipes.

Figure 2: Cu/Nb/Cu clad seamless pipe made by cladding, hot&cold rolling, deep-drawing and spinning.

after deep-drawing is larger than that of the sheet by over 50%, and gradually decreases parallel to the axis to its bottom direction. But after spinning, very uniform thickness could be achieved. This tendency could also be observed with the Nb/Cu clad pipes. Their thickness increase at the flange was almost the same as 50%.

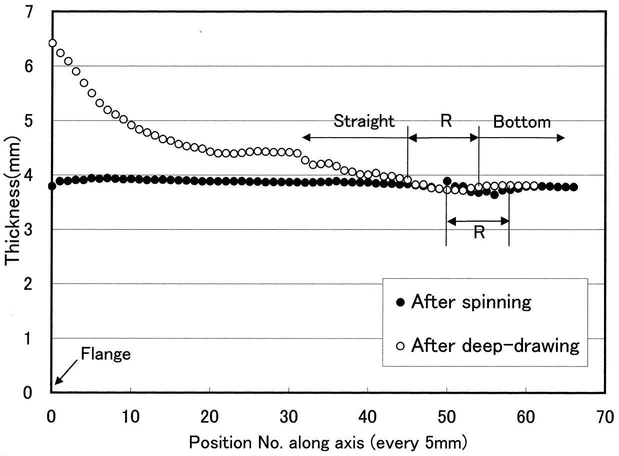
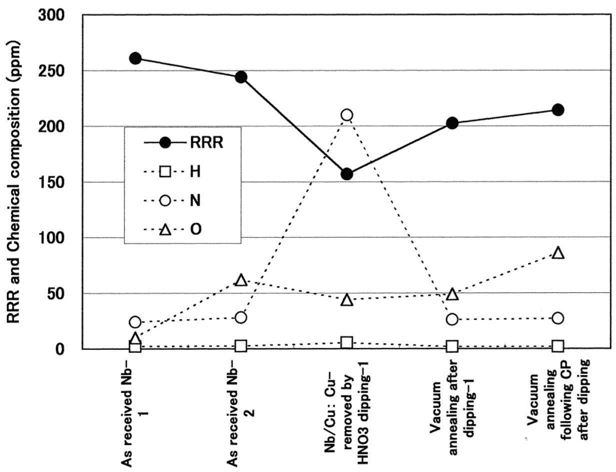



Figure 3: Wall thickness distribution along axis direction of Cu seamless test pipe.

### 2.3 *RRR and concentrations of H, N and O in Nb*

The clad sheets underwent high temperature heating in an air atmosphere before hot rolling, and the clad seamless pipes underwent a few intermediate annealings in $N_2$ gas. Therefore RRR degradation was investigated from the viewpoint of the effect of gas contaminations in Nb material on RRR. The results are shown in Fig.4. Measured RRR values of an as-received Nb sheet were 244 and 261. But RRR of a sample taken from a Cu/Nb/Cu clad seamless pipe decreased to 157 after Cu resolving by dipping in $HNO_3$. After resolving, its concentration of nitrogen increased from about 25ppm of as-received Nb sheet to 210ppm. But its RRR recovered to 202 by vacuum annealing at 750℃ for 3 hrs, and a

Figure 4: Effect of treating processes of Nb sample on




RRR and H, N and O concentrations in Nb material of Nb/Cu pipe.

better value of 214 could be achieved by the same vacuum annealing after etching the sample surface by CP, when nitrogen concentration decreased to around 25ppm in both cases. Nitrogen concentration aside, concentrations of H and O did not change so much. H was less than 6ppm and O was less than 90ppm in all samples. Therefore, for our fabricating method of Cu/Nb/Cu pipes, it was confirmed that their Nb was very resistant to gas contamination and degradation in RRR value during the processes.

## 3 NB/CU CLAD SEAMLESS SC CAVITIES

DESY has successfully developed hydro-forming technology for L-band Nb seamless cavities and Nb/Cu clad seamless cavities[4]. KEK possesses excellent technology for treating Nb inner surfaces including electropolishing successfully developed by itself[5].

### 3.1 *Fabrication of Nb/Cu single-cell cavities*

DESY formed the Cu/Nb/Cu clad seamless pipes to single-cells without beam pipes for L-band cavity shape by hydro-forming. Then KEK accomplished fabrication of single-cell cavities by removing their inner copper layers, EB welded Nb pipes on them and made a few inner surface treatments including barrel polishing, chemical polishing cleaning, vacuum annealing at 750℃ for 3 hrs, and electropolishing of about 70 $\mu$ m. Fig.5 shows the inner surface of Nb layer after resolving the inner Cu layer by nitric acid. After hydro-forming, a few small cracks, which were about 15mm long, were found on the surface of the inner Cu layer at the cell's equator. Their directions were perpendicular to its periphery. But after resolving the inner Cu layer, the cracks were confirmed by microscope inspection of the Nb inner surface to have been completely eliminated. Fig.6 shows the finished single-cell seamless sc cavity with Nb pipes.

### 3.2 *Performance of Nb/Cu clad seamless sc cavity*

The cold test was performed at 1.5K and 1.3GHz with one of the Nb/Cu clad seamless sc cavities. The measured

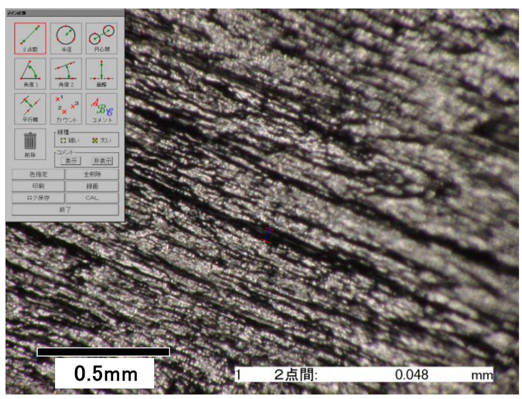



Figure 5:Inner surface of Nb layer of Nb/Cu clad seamless cell after resolving inner Cu layer by nitric acid.

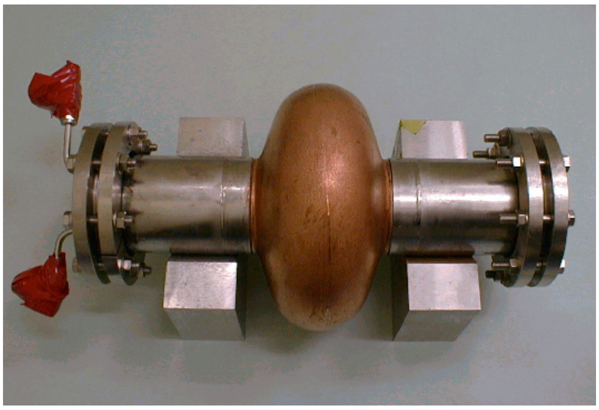


Figure 6: 1300MHz Nb/Cu clad seamless sc cavity.

result (●) is shown in Fig.7. Excellent performance of Eacc,max=39.0MV/m with $Q_0$ of $7.13\times10^9$ was achieved. And $Q_0$,max = $1.67\times10^{10}$ was achieved with Eacc = 4.01MV/m. However the Q value decreased somewhat after the first quench. In the second measurement, Eacc,max was not changed, and $Q_0$-value at that time dropped to $4.80\times10^9$. In addition, $Q_0$,max =$1.33\times10^{10}$ was obtained with the same Eacc of 4.02MV/m.

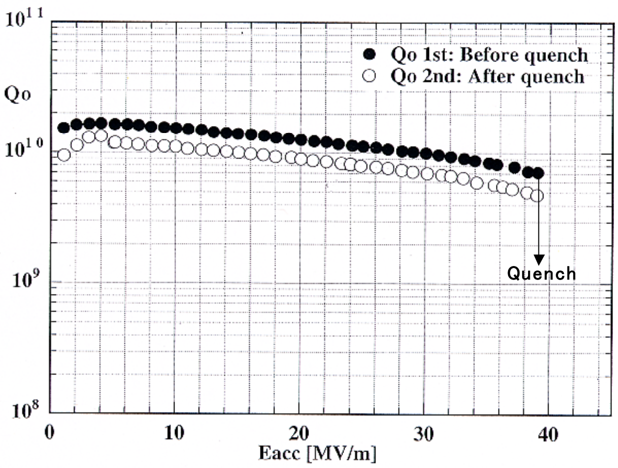



Figure 7: First result of high gradient performance of Nb/Cu clad seamless sc cavity.

## 4 DISCUSSIONS

The new fabrication method for Cu/Nb/Cu sandwiched seamless pipes for single-cell sc cavities was proved to have a high potential for excellent performance. The second cavity was also finished, and the measurement is uinderway. By these two cold test, we would like to confirm the excellent performance in statistics. There are a few issues in this method that still need to be solved. Since it is relatively hard to make a long pipe by our method, tube drawing will be needed afterward for a seamless clad cavity with larger cell numbers than single-cell including nine-cell. As the next step, we are planning to fabricate long pipes for multi-cell sc cavities. In addition, we consider jointing between clad pipes to increase productivity for future mass production of drawn pipes.

## 5 CONCLUSION

It was confirmed that our new approach to reliable clad seamless sc cavities has many advantages. (1)The deep-drawn and spun pipe had a good workability for hydro-forming. (2)Sandwiched structure has a resistance against cracking during the hydro-forming. (3)A good bonding can be achieved by hot rolling with large area reduction at high temperature. The first sc cavity made from the pipe showed an excellent performance. Therefore this new approach is very promising to yield a cost-effective and reliable fabrication technology for Nb/Cu clad seamless sc cavities.

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