HOT ROLL BONDING METHOD FOR Nb/Cu CLAD SEAMLESS SC CAVITY

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Abstract

We have successfully developed Cu/Nb/Cu sandwiched seamless pipes for superconducting rf L-band single-cell cavities using deep-drawing and spinning of a Cu/Nb/Cu clad sheet which was fabricated by hot rolling technique. DESY formed single-cells with TESLA shape from the clad pipes using their hydro-forming technology. KEK electron-beam welded Nb beam tubes on the cells and made surface treatments including barrel polishing, annealing and electropolishing. As a result of the vertical test, an excellent performance : Eacc,max=39.0MV/m, Q_0,max= 1.67×10^{10} at 1.5K and 1.3GHz was achieved in the first test.

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.

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 sandwiched clad sheets and seamless pipes. The 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, the clad seamless pipes were made. The fabricating processes is shown in Fig.2.

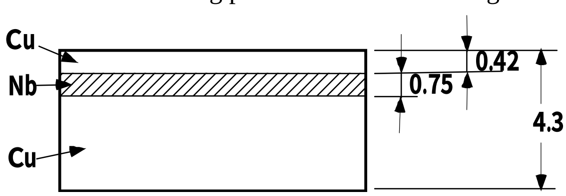

Figure 1: Designed cross sectional view of Cu/Nb/Cu sandwiched clad sheet.

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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. The designed cross sectional view of the clad sheet is shown in Fig.1. The hot rolling process of the Cu/Nb/Cu clad sheet is shown in Fig.3.

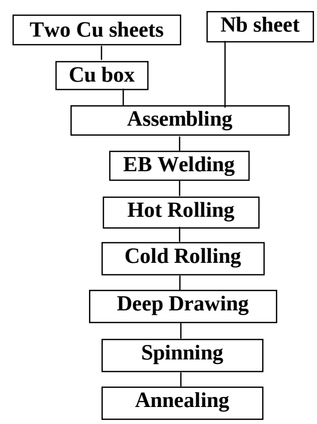

Figure 2: Fabricating processes for Cu/Nb/Cu sandwiched clad seamless pipes.

Figure 3: Hot rolling process of Cu/Nb/Cu clad sheet.

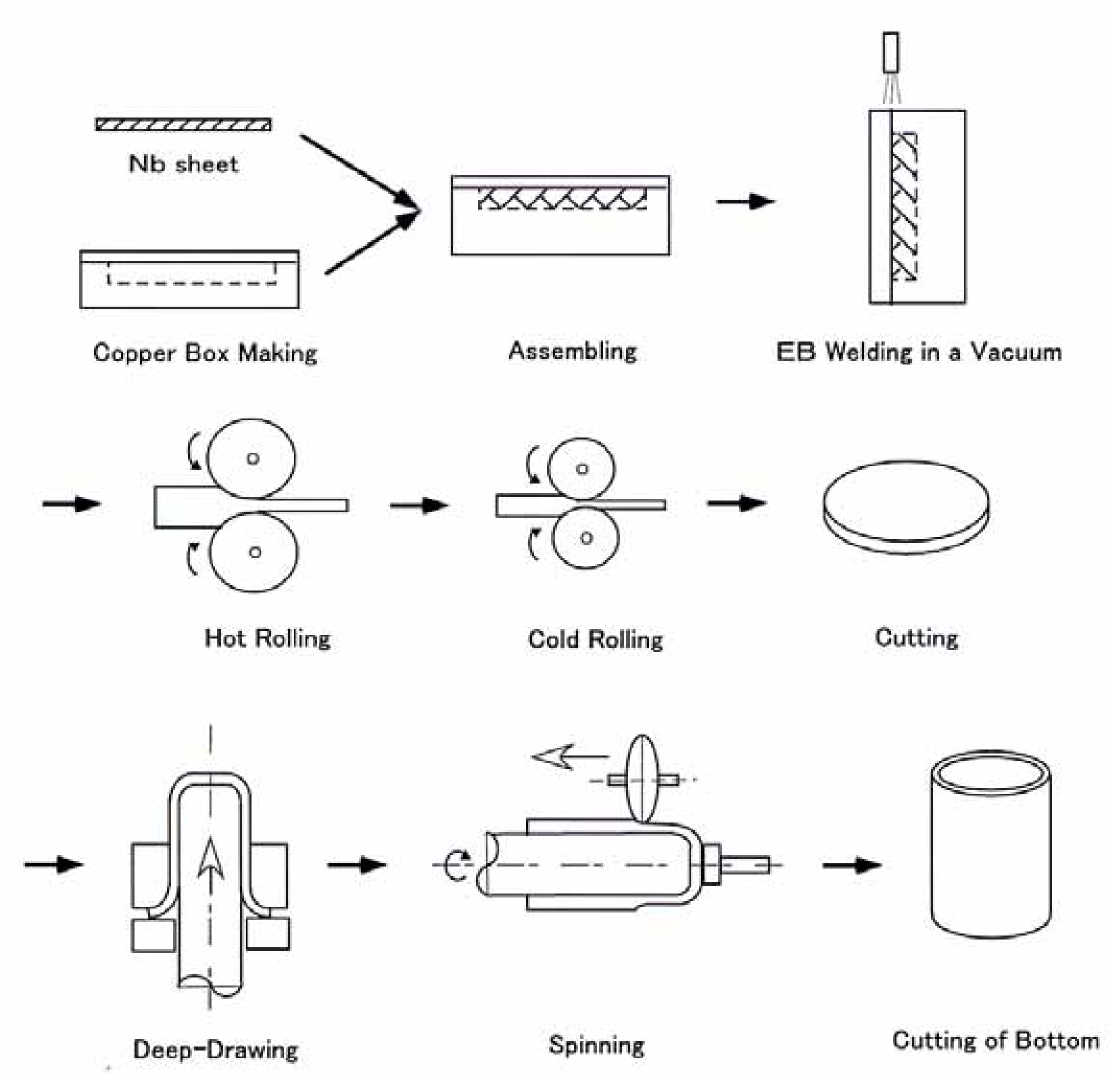

Figure 4: Schematic diagrams of fabricating processes for Cu/Nb/Cu sandwiched clad seamless pipes.

Fabrication of Cu/Nb/Cu Clad Seamless Pipes

Fig.4 shows schematic diagrams of fabricating processes of Cu/Nb/Cu sandwiched 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.5. During the deep-drawing and spinning processes, intermediate and final annealings in N_2 gas were made on it for Cu softening.

Characteristics of Cu/Nb/Cu Clad Seamless Pipes

Fig.6 shows the wall thickness distributions of a Cu seamless test pipe during the deep-drawing process. The Cu test pipe was fabricated from a 4.0mm thick Cu sheet to confirm fabricating processes. As the process goes on,

Figure 5: Cu/Nb/Cu clad seamless pipe made by cladding, hot&cold rolling, deep-drawing and spinning.

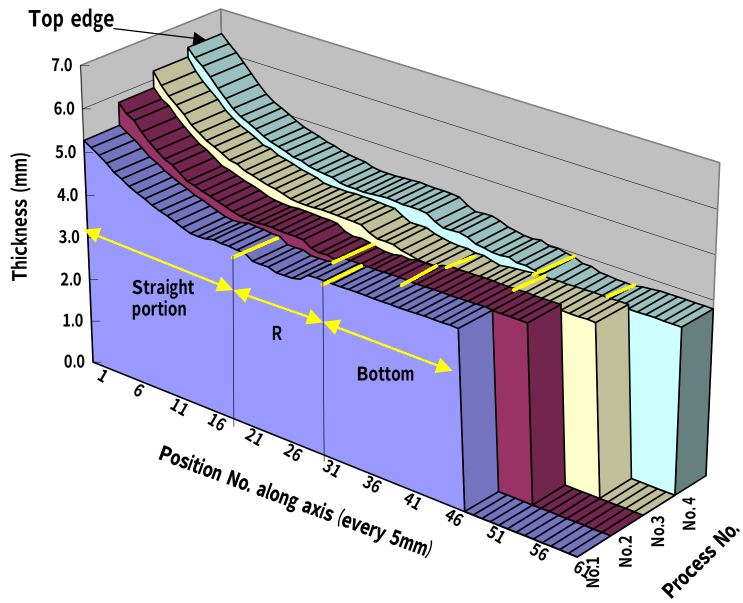

Figure 6: Wall thickness distributions of Cu seamless test pipe along the axis direction during deep-drawing processes.

it is clearly seen that the wall grows thicker toward its Top edge. The thicknesses of its bottom and bottom corner(R) portions does not deviate much from the original sheet's thickness of 4.0mm. Fig.7 shows the wall thickness distributions of the Cu seamless test pipe after deep-drawing and after spinning. It is clear that the thickness at the pipe's Top edge after deep-drawing is larger than that of the sheet by over 50%, and gradually decreases parallel to the axis to its bottom direction. After spinning, however, very uniform thickness could be achieved. This tendency could also be observed with the Cu/Nb/Cu clad pipes. Their thickness increase at the Top edge was almost 50%. The extent to which Cu hardness was affected by this cold reduction difference along the axis in spinning was evaluated. Vickers hardnesses atfter spinning and after final annealing are shown in Fig.8. "P" indicates that the evaluated plane is normal to the axis, and "Z" that it is parallel to the axis. Vickers hardnesses of the straight portion after spinning are over 100, and those of the bottom and bottom corner(R) portions are around 55. This 55 is the same level as those of annealed Cu sheet. After final annealing, vickers hardnesses of the straight portion dropped to around 50. Both the distributions after spinning and after final annealing are roughly flat in spite of cold reduction differences in spinning. This small fluctuation of vickers hardnesses after final annealing seems to meet the homogeneous deformation in the next hydro-forming process. Vickers hardnesses of both the bottom and bottom corner(R) portions did not deviate much from around 50 after final annealing. Therefore it is clear that the Cu test pipe has homogeneous hardness as a whole after final annealing. Fig.9 shows the peripheral distributions of outer and

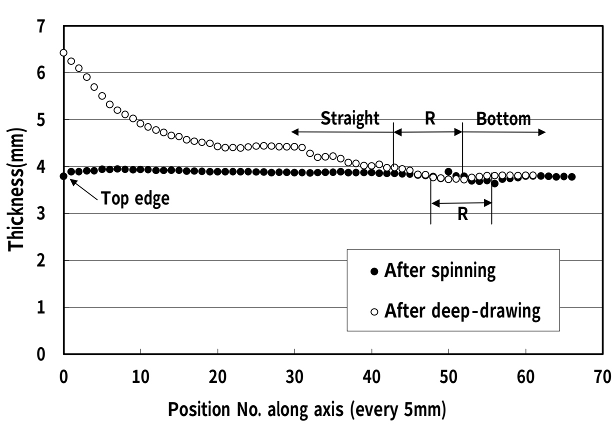

Figure 7: Wall thickness distributions of Cu seamless test pipe along the axis direction after deep-drawing and after spinning.

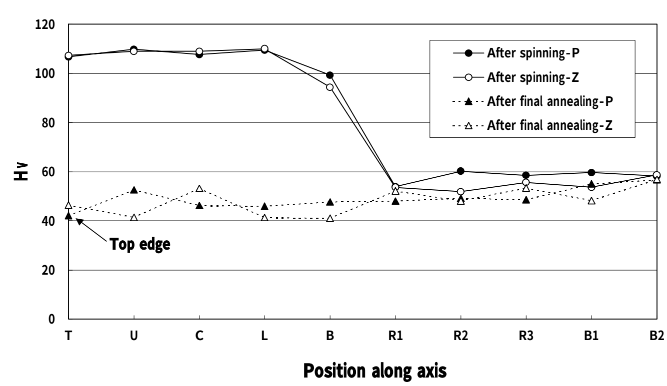

Figure 8: Vickers hardness distributions of Cu seamless test pipe along the axis direction after spinning and after final annealing.

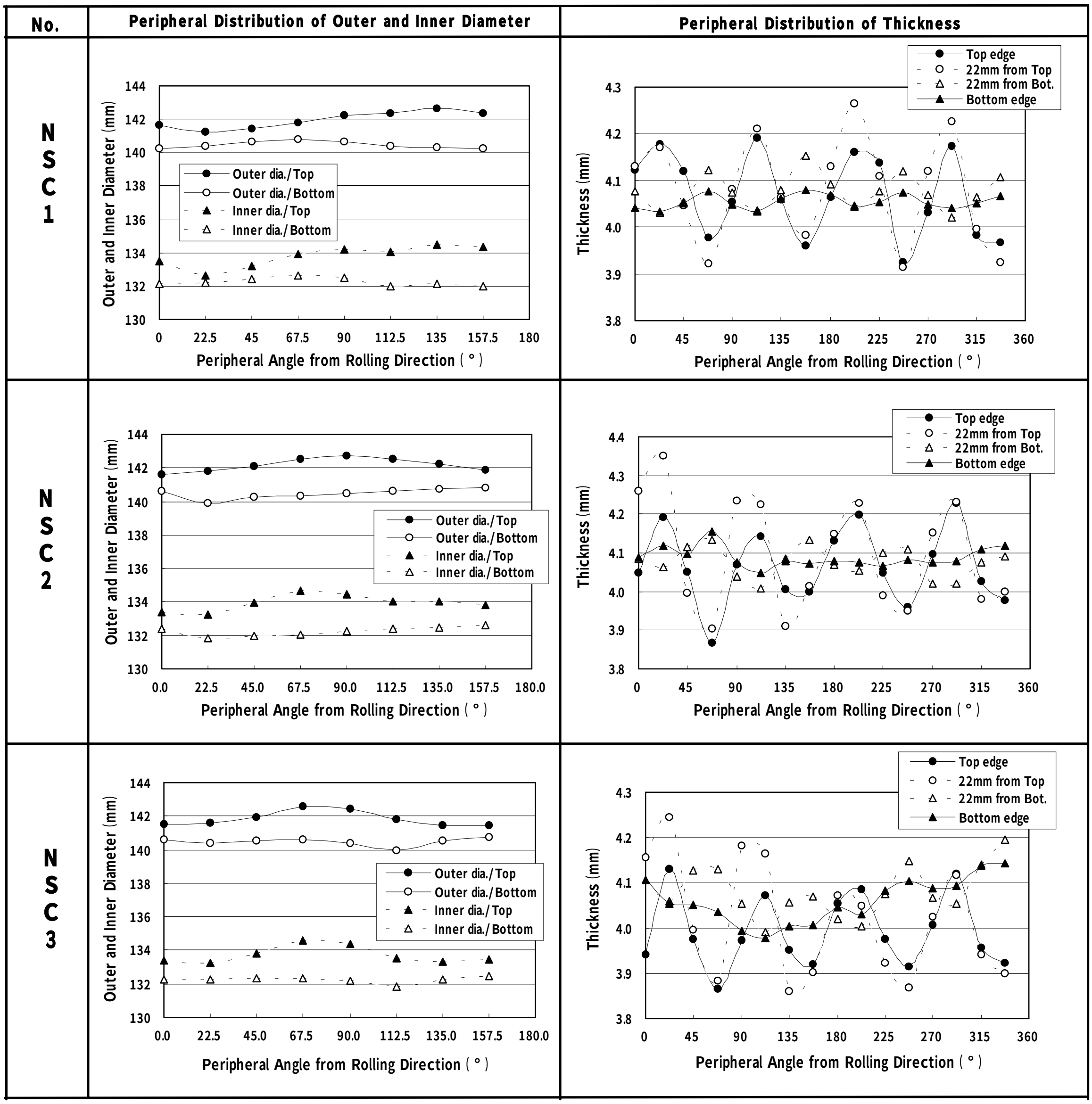

Figure 9: Peripheral distributions of outer and inner diameters and wall thickness at Top and Bottom edges of Cu/Nb/Cu seamless pipe after spinning. Peripheral angle starts from rolling direction of Cu/Nb/Cu clad sheet.

inner diameters and wall thickness at Top and Bottom edges of three Cu/Nb/Cu seamless pipes after spinning. The peripheral angle starts from the rolling direction of the Cu/Nb/Cu clad sheet. Both outer and inner diameters at Top are slightly larger than those at Bottom by 1 to 2mm. But all of them have small fluctuations of about 1.0 to 1.5mm. From the viewpoint of the peripheral distributions of wall thickness, four minima periodically appear in every direction of 45 degrees from the rolling direction. During deep-drawing, a small ear is always generated in each direction of 45 degrees. Therefore the four minima of wall thickness correspond to the formation of the four small ears. The maximum change of thickness at Top is not larger than 0.45mm, and that at Bottom is not larger than 0.2mm. Therefore it was comfirmed that fluctuations in dimensions of clad pipes were not particularly large, and that the three clad pipes had approximately the same dimensions.

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 N2 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.10. Measured RRR values of an as-received Nb sheet were 244 and 261. But RRR of a sample teken from a Cu/Nb/Cu clad seamless pipe decreasesd to 157 after Cu resolving by dipping in HNO3. After resolving, its

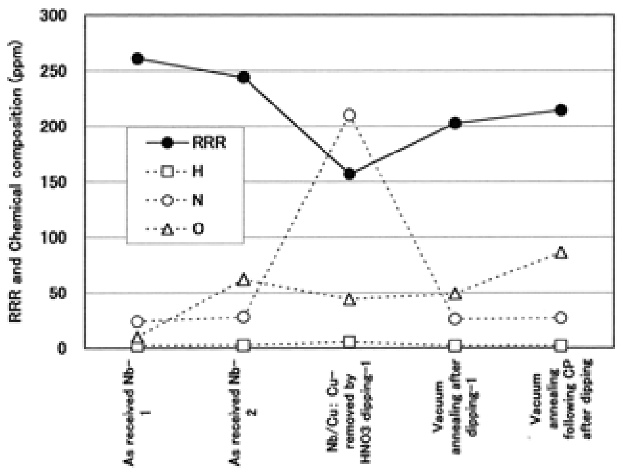

Figure 10: Effect of treating processes of Nb sample on RRR and H, N and O concentrations in Nb material of Nb/Cu pipe.

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 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.

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

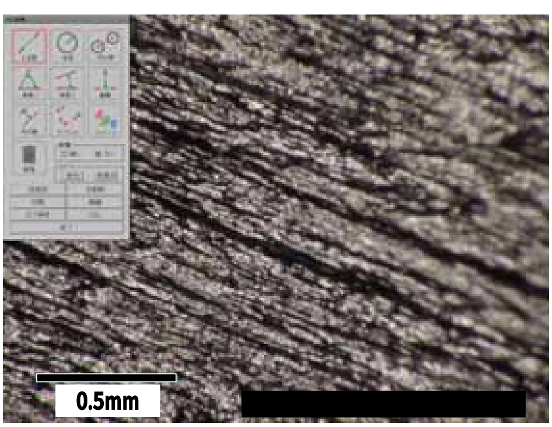

Figure 11:Inner surface of Nb layer of Nb/Cu clad seamless cell after resolving inner Cu layer by nitric acid.

electropolishing successfully developed by itself[5].

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 μm. Fig.11 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.12 shows the finished single-cell seamless sc cavity with Nb pipes.

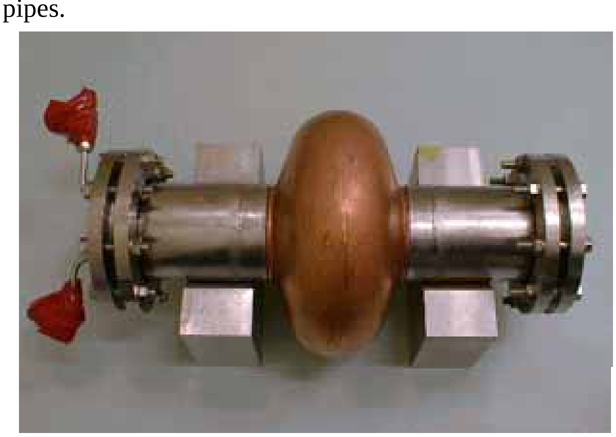

Figure 12: 1300MHz Nb/Cu clad seamless sc cavity.

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
result (●) is shown in Fig.13. Excellent performance of Eacc,max= 39.0MV/m with Q_0 of 7.13×10^9 was achieved. And Q_0,max = 1.67×10^{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 4.80×10^9. In addition, Q_0,max = 1.33×10^{10} was obtained with the same Eacc of 4.02MV/m.

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

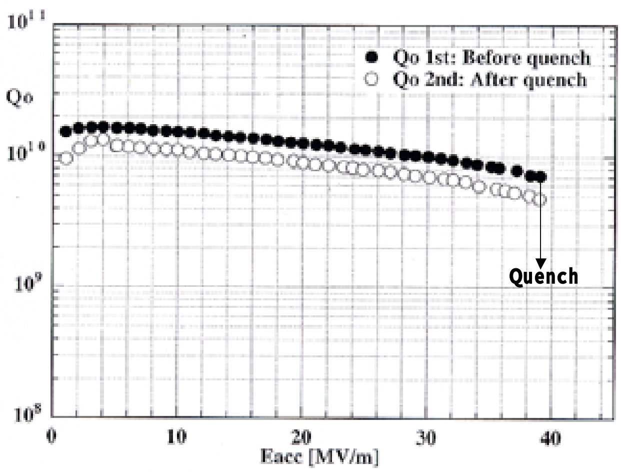

Figure 13: First result of high gradient performance of Nb/Cu clad seamless sc cavity.

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.

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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REFERENCES

[1] K.Saito, T.Fujino, H.Inoue, N.Hitomi, E.Kako, T.Shishido, S.Noguchi, M.Ono and Y.Yamazaki, “Feasibility Study of Nb/Cu Clad Superconducting RF Cavities.” IEEE Trans. Appl. Supercon., Vol.9, No.2, pp.877-880, June 1999.

[2] I.Itoh, T.Sasaki, S.Minamino and T.Shimizu, “NbTi/Nb/Cu Multilayer Composite Tubes for Superconducting Shielding”, IEEE Trans. Appl. Supercon., Vol.3, No.1, pp.177-180, March 1993.

[3] I.Itoh, K.Fujisawa and H.Otsuka, “NbTi/Nb/Cu Multilayer Composite Materials for Superconducting Magnetic Shielding --Superconducting Performances and Microstructure of NbTi Layers--”, Nippon Steel Tech. Rpt. No.85, pp.118-124, January 2002.

[4] W.Singer, H.Kaiser, X.Singer, G.Weichert, I.Jelezov, T.Khabibuline, A.Skasyrskaia, P.Kneisel, T.Fujino and K.Saito, “Hydroforming of Superconducting TESLA Cavities”, Proc. in the 10th Workshop on RF Superconductivity, Tsukuba, Japan, September 06-11, 2001. http://conference.kek.jp/SRF2001, FA009.

[5] K.Saito, T.Fujino, N.Hitomi, H.Inoue, Y. Yamazaki, V.Palmieri, W.Singer, P.Kneisel, K.Ohara and S.Tsukada, “R&D of Nb/Cu Clad Seamless Cavities at KEK”, Proc. in the 10th Workshop on RF Superconductivity, Tsukuba, Japan, September 06-11, 2001. http://conference.kek.jp/SRF2001, PT019.