Improving Nb_3Sn Cavity Performance Using Mechanical Polishing

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Key Findings

- Centrifugal barrel polishing (CBP) is an effective method of polishing Nb_3Sn coated cavities.
- Nb_3Sn films polished using CBP can acheive less than 20 nm surface roughness with minimal material removal.
- CBP treatment of a Nb_3Sn cavity leads to a significant increase in the maximum accelerating gradient.
- However, a secondary re-coating procedure is required to achive this increase.

Background Information

Superconducting radiofrequency (SRF) cavities are essential components for providing the electric fields required to accelerate charged particles in particle accelerators. SRF cavities coated with a layer of Nb_3Sn can reach up to 100 MV/m of accelerating field in theory. However, in practice surface roughness and other defects limit Nb_3Sn SRF cavity performance. Centrifugal barrel polishing (CBP) is a proven technique for mechanically polishing Nb SRF cavities to nanometer scale smoothness. To show the evolution of the surface during CBP, we polish Nb_3Sn samples using a coupon cavity, which can simulate cavity polishing conditions.

- Centrifugal Barrel Polishing (CBP) is a technique used to polish niobium cavities without using toxic chemicals such as HF.
- CBP uses a custom built tumbling machine that can fit up to 9-cell size cavities, and can accelerate the polishing media against the cavity surface with up to 6g of force.
- An alumina nanoparticle suspension is used as the abrasive material. Felt cubes are added to push the abrasives against the cavity surface.

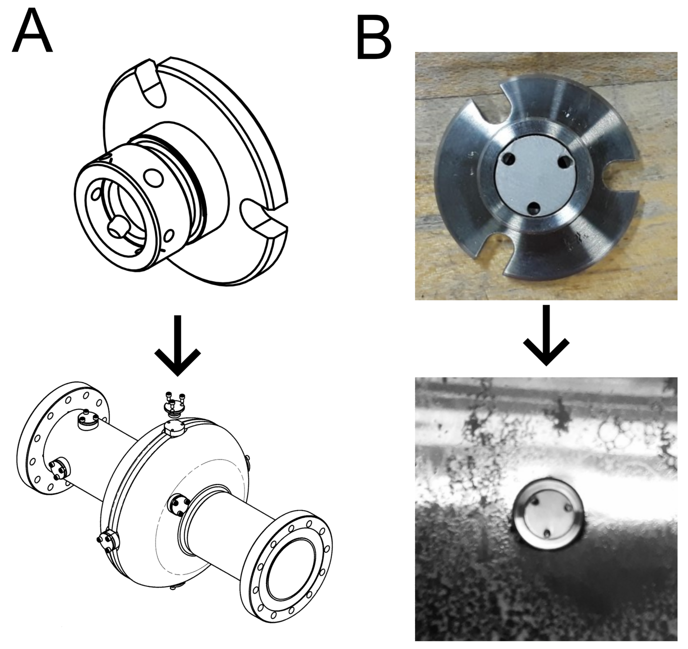

Figure 1. (A) A schematic of the coupon cavity and the sample holder used to polish the Nb_3Sn coated samples. The sample holder can hold 1 cm diameter disks by clamping the sides of the sample with set screws. (B) Pictures of the sample holder sitting outside the coupon cavity and with a sample mounted as seen from the inside of the coupon cavity.

Surface Analysis of Nb_3Sn Polished with CBP

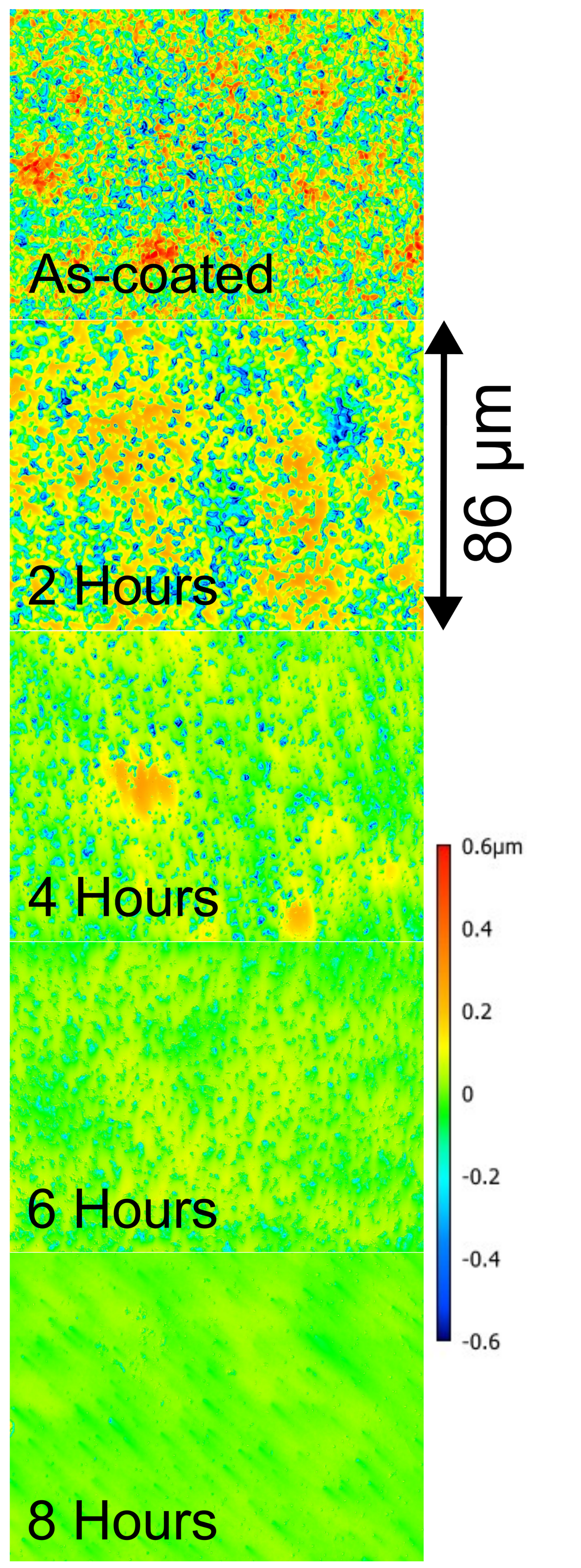

Figure 2. Surface height maps of Nb_3Sn polished between 0 to 8 hours.

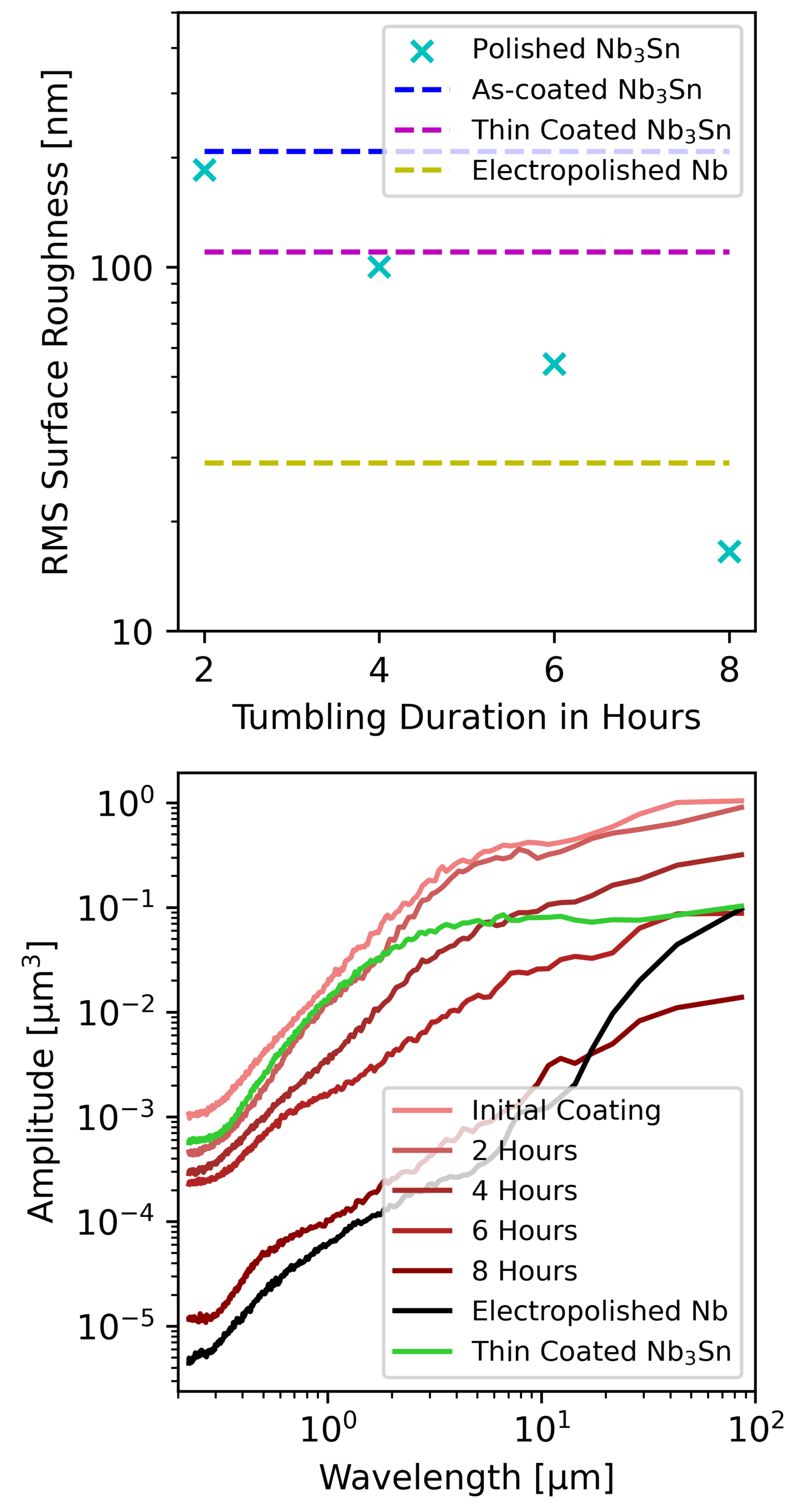

Figure 3. Surface roughness of Nb_3Sn over time (top). The power spectral density (PSD) of the surface profiles, electropolished Nb, and thinly coated Nb_3Sn[1].

To evaluate the performance of CBP, the surface roughness of the polished samples is measured using con-focal laser microscopy and the surface is analyzed using scanning and transmission electron microscopy (SEM and TEM). The material removal rate is measured using focused ion-beam tomography.

- Material is preferentially removed from the highest point on the surface.
- The material removal rate is measured to be 170 nm per hour.
- After 6 hours of polishing, the surface roughness is comparable to the surface roughness of the well-performing, thinly coated Nb_3Sn coatings created at Fermilab[1].
- After 8 hours of polishing, the surface roughness is comparable to a typical niobium surface after EP.

RF Performance Improvement from Polishing

A Nb_3Sn-coated single-cell 1.3 GHz cavity was polished for 4 hours followed by high-pressure water rinsing and ultrasonic cleaning for 30 minutes to remove any residual abrasive material. A conservative polishing time was used to minimize the possibility of removing the Nb_3Sn film while still providing a considerable improvement in surface roughness.

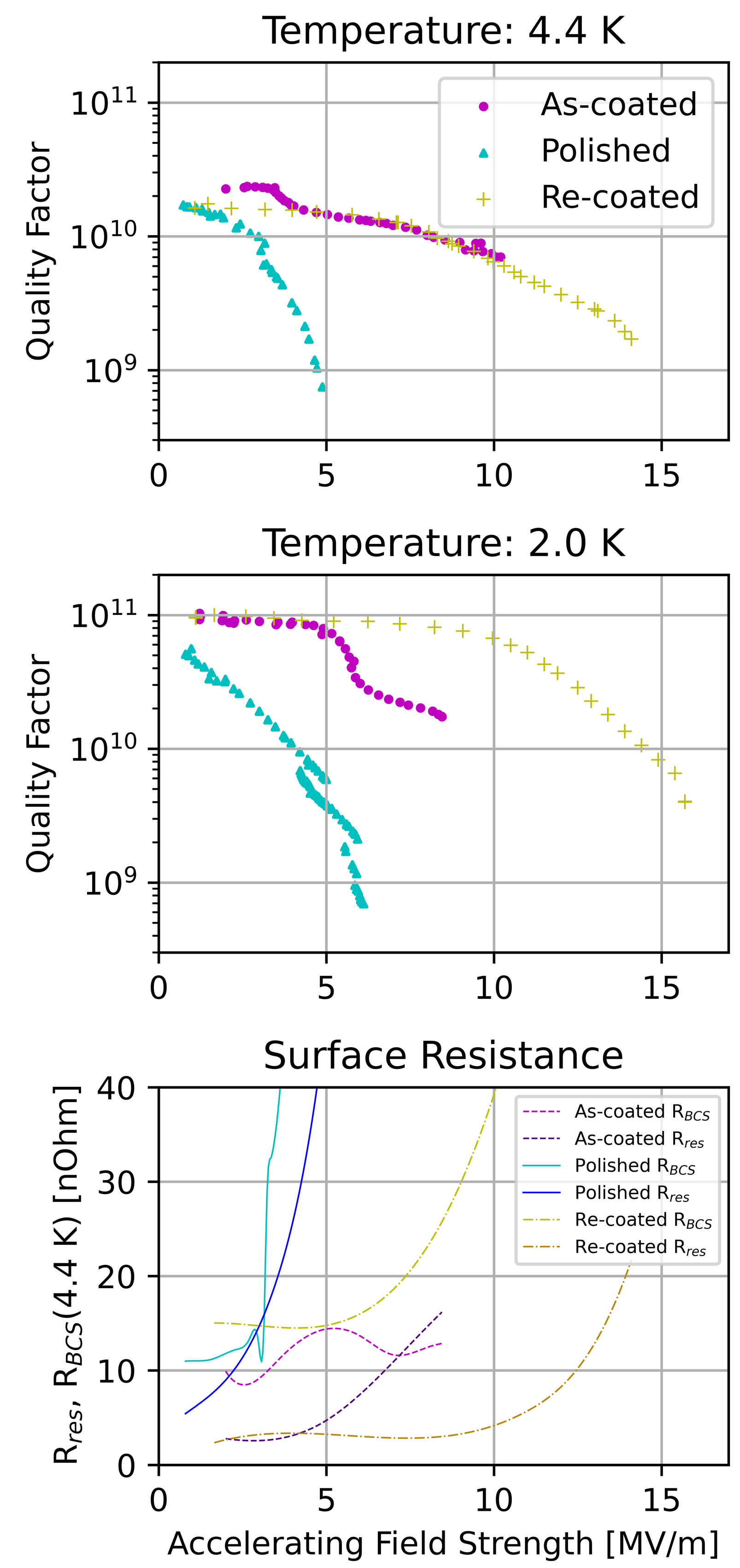

Figure 4. The RF performance of the Nb_3Sn-coated SRF cavity before and after mechanically polished and after a re-coating treatment.

- The resulting cavity surface had a mirror-like appearance.
- The as-coated performance was poor, with a maximum gradient of around 10 MV/m and Q of 10^{10} at 4.4 K.
- After polishing, the cavity exhibited Q-slope and the maximum gradient was only 5 MV/m.
- A re-coating procedure was applied to repair surface damage and subsurface defects at 1,000 °C, using one third of the normal amount of tin and no $SnCl_2$.
- After the re-coating procedure, the Q-slope was ameliorated, and the maximum accelerating gradient increased to 15 MV/m.
- The quality factor of the cavity was also improved over the as-coated state at 2.0 K, but not at 4.4 K.

Bibliography

[1] Sam Posen, Jaeyel Lee, David N Seidman, Alexander Romanenko, Brad Tennis, OS Melnychuk, and DA Sergatskov. Advances in nb3sn superconducting radiofrequency cavities towards first practical accelerator applications. *Superconductor Science and Technology*, 34(2):025007, 2021.