OPTIMIZING CENTRIFUGAL BARREL POLISHING FOR MIRROR FINISH SRF CAVITY AND RF TESTS AT JEFFERSON LAB.*

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Abstract

We performed Centrifugal Barrel Polishing (CBP) on a 1.3 GHz fine grain TESLA shape single cell cavity and 1.5 GHz fine grain CEBAF high gradient superconducting radio frequency (SRF) single cell cavity following a modified recipe originally developed at Fermi National Accelerator Lab (FNAL). We were able to obtain a mirror like surface similar to that obtained at FNAL, while reducing the number of CBP steps and total processing time. This paper will discuss the change in surface and subsequent cavity performance post CBP, after a 800°C bake (no pre-bake chemistry) and minimal controlled electro-polishing (10 micron). In addition to Q vs. E_{ACC} thermometry mapping with preheating characteristics and optical inspection of the cavity after CBP will also be shown.

INTRODUCTION

Superconducting radio-frequency (SRF) cavity technologies is one of the key technology driving current and future particle accelerators. Modern SRF cavities are made out of high purity niobium sheets which are formed into cavities. To achieve state–of–the art performance, these cavities must go through a multi-step process which condition the inner surface to support a high Q and maximum acceleration gradient (E_{ACC}). One standard method to treat the inner surface of a high gradient cavity included initial bulk electropolishing (EP), followed by a high temperature bake (HTB) to remove hydrogen, followed by another light EP, high pressure rinse (HPR), and low temperature bake (LTB). This technique can achieve $Q_o > 2 \times 10^{11}$ and $E_{ACC} > 40\frac{MV}{m}$ for an ILC 1.3 GHz cavity at 2K [1].

One of the alternate techniques to reduce bulk and light chemistry is mechanical polishing, pioneered at KEK in Japan [2]. In addition to reducing chemistry, recent work at FNAL by Cooper *et. al* [3] has shown that centrifugal barrel polishing (CBP) can reduce the surface roughness by a order of magnitude lower than chemistry alone [4]; which in turn possibly raises the Q thereby improving the performance. Coupon studies done at Jefferson National Lab (JLab), suggested one of the polishing step (400 mesh) from the original recipe could be removed with hindering smoothness. [5]

We discuss the current status of mirror finish CBP at JLab on fine grain SRF cavities. The two cavities tested so far at Jefferson lab are single cell RDT-5 and D-II. Each cavity underwent a 4 step CBP, high temperature bake, and light chemistry (10 micron total). Details of the steps are show in Table 1. The only difference between the two cavities, was that RDT-5 was vertically electro-polished (VEP) on JLab's experimental VEP machine and D-II was horizontally EP'ed at Argonne National Lab.

Table 1: JLab prototype cavity processing with CBP

CBP – 9mm x 9mm triangles - 8hrs (not optimized)
CBP – RG-22 cones - 15hrs
CBP – 800 mesh alumina & wood block - 30hrs
CBP – colloidal silica & wood block - 40hrs
Ultrasonic degrease/rinse
one cycle HPR
HTB – 800°C bake for 2hrs
Chemistry – 10 micron EP
Ultrasonic degrease/rinse
1 hour HPR
Slow pump down
LTB – 120°C for 48Hrs

RDT-5

The first CBP candidate for JLab's mirror finish CBP is a brand new in-house built 1.3GHz ILC end cell cavity with indium flanges (RDT-5). After CBP to a mirror finish, it was found that the removal of about 130 microns did not smooth the weld region and media/pockets were left behind at the weld edge. The cavity was still EP'ed knowing the CBP processes was not optimized. Surprisingly, without VEP optimization as well as incomplete weld smoothing the cavity was still able to reach 35MV/m, albeit with a lower than expected Q (Figure 1). During both vertical tests there were multiple processing/quench events around 20MV/m and a Q drop during cleanup; there was no field

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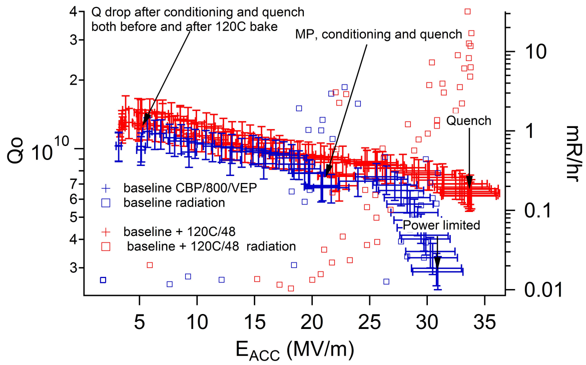
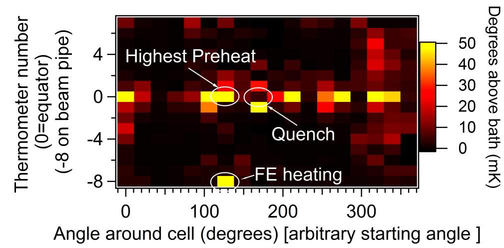


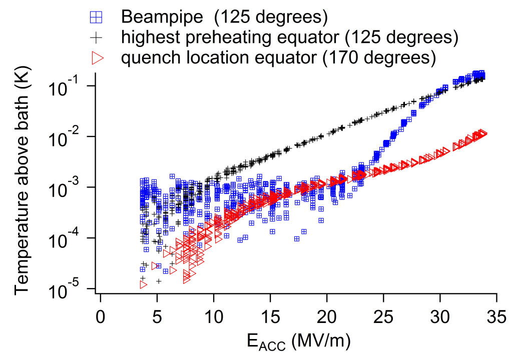
Figure 1: Test results for RDT-5 Q vs. E_{ACC} and radiation at 2K. The first test with 10 micron VEP after 800°C bake (Blue) and second test after an additional 120°C bake (Red).

emission after MP in the first test, and light FE in the second test.

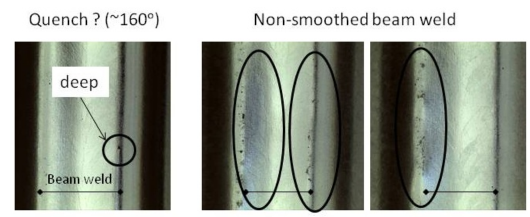
During the vertical test surface temperature maps were also performed using JLab's temperature mapping system. [6] The detailed heating of the quench location, highest preheating location and beam pipe FE heating on the unfolded map @ 34MV/m (post 120C bake) are displayed in Figure 2. The unfolded temperature map shows heating both on the equator as well as globally over most of the cavity. The preheating curves (Figure 2 (b) red triangles and black crosses) suggest the heating on the quench/defect is not from normally conducting material, and not purely geometric [7] The lower temperature at the quench (170 Degrees) was from a weak connection between the cavity and the sensor, so only the shape and not the magnitude should be compared between the curves. The possible quench defect (optically deep pit), as well as general e-beam weld edge defects are shown in Figure 2 (c) [left and right respectively].



(a) Unfolded temperature map take at 34MV/m.



(b) Preheating temperature curves vs field (E_{ACC}) at three location in marked in (a).



(c) Internal inspection at possible quench defect at 160 degrees (left) and general location representative on most of the weld region in the cavity (right).

Figure 2: Compiled temperature mapping and inspection from RDT-5 (during second test); (a) temperature map, (b) temperature vs. field (c) internal optical inspection.

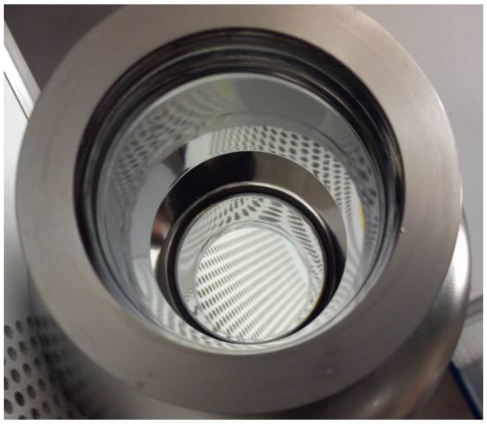
D-II

Our second mirror finish CBP R&D candidate cavity is a 1.5 GHz fine grain CEBAF 12 GeV upgrade high gradient prototype cavity with an alternative beam weld (D-II Figure 3). The cavity was found on the shelf with indefinite prior history. We know the cavity had been heavenly BCP'ed in the past as the wall thickness was 1.6 mm before CBP and therefor probably not a good cavity. The cavity was tested three times after CBP; once, before any chemistry but after a 800C bake, after a 10 μm EP at Argonne national lab, and finally after a 120C low temperature bake. The complied test data is show in Figure 3 (b).

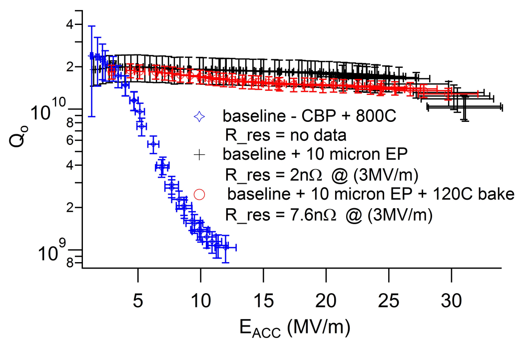
After the cavity quenched at 30MV/m an internal inspection was performed with JLab's internal inspection machine. [8] As one can see from Figure 3 (c), similar to RDT-5, the weld was not completely smoothed in all locations. About 30% of the cavity had a "perfect" removal while the rest did not, with almost all of the defects laying on the edge of the weld bead. Temperature maps were not avalible, so the exact quench location is not known.

GENERAL COMMENTS AND CONCLUSIONS

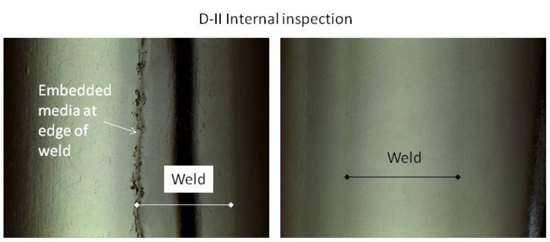
Our initial mirror finish cavity result show that our current recipe does not smooth out the welding beam location which allows embedded media/pits to remain within the valley. One question that still needs to be investigated, is if the pits were there from the beginning and only filled with the media (welding defect), or are then from the media itself. Once the first step is under



(a) Picture of D-II after EP.



(b) Three different cavity Q vs. E_{ACC} at 2K; HPR only, after 10 micron horizontal EP, and after 120C bake for 48 hours.



(c) Internal inspection pictures from 2 different location of D-II, one with the weld smoothed by CBP and the other with embedded media/pits left behind at the edge of the weld.

Figure 3: Compiled information from D-II; (a) cavity picture, (b) cavity test data, and (c) internal inspection.

control (weld smoothed) the rest of the recipe should be good (inferred from D-II Figure 3 (c) right).

Another item that is new with this study it that only a 10 micron EP is needed after CBP to regain crystal structure at the surface; if the EP as well as CBP(smooth weld completely) are both optimized. [9] Previously reported results had chemistry both before and after the high temperature bake. [10] There was one other reported cavity which went through a high temperature bake without chemistry, ILC 9 cell AES6 - mirror finish CBP at FNAL and bake/EP at JLab - quench limited at 36MV/m, but it was not specifically pointed out, as we do here. [13]

One result from previous mirror finish CBP study suggest the Q is higher on average from mirror finish CBP followed by light EP rather than the standard double EP procedure. [3, 11] D-II showed the same results, with a residual resistance (Rs) of $2n\Omega$ before low temperature bake. In addition, to our knowledge this is the first know publication of the CBP cavity without any chemistry but after a high temperature bake (required to removed hydrogen). At this time it is not clear if the lower Q in RDT-5 is from the embedded media alone or from CBP and VEP which has been seen to create a strong Q slope in cavities. [12]

We have reported on continuing progress of mirror finish CBP at Jefferson Lab. We were able show that $10\mu m$ of electropolishing is needed after mirror finish CBP to regain the RF surface. In addition, pre-HTB chemistry is not needed after mirror finish CBP. Work still remains to understand what is the optimal CBP recipe for new JLab cavities to ensure proper smoothing of the weld region, or if there is a fabrication problem with the current JLab welding procedure.

ACKNOWLEDGMENT

We would like to thank Allen M. Rowe, Michael P. Kelly, and Damon J. Bice from FNAL/Argonne for the EP of D-II and Jim Follkie at JLab for the VEP of RDT-5.

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