RESULTS FROM ANL/FNAL AND WELD ZONE QUENCHING*

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Abstract

A series of single cell and 9-cell cavities has been processed at ANL/FNAL facility. Those cavities represent major cavity and niobium material vendors. All cavity defects are characterized by temperature mapping and replica technique. Most of the defects are located in or next to the electron beam weld zone. Majority of the cavities reached high gradient despite of the defects located in high magnetic field region.

INTRODUCTION

To support Fermilab's ILC R&D effort and Project X development, a joint Superconducting Surface Processing Facility was established in collaboration between Fermilab and Argonne National Labs (ANL) at ANL campus. The facility includes a jointly developed state-of-the-art Electropolishing (EP) system [1], and an ultrasonic rinsing system, a high pressure water rinsing system (HPR) and cleanroom assembly area.

Work has been in progress to fully commission the facility and to develop the optimized cavity procedures both for single-cell and multi-cell cavities.

Since the beginning of the facility operation, 7 single-cell cavities, 3 nine-cell cavities and two dressed nine cell cavities have completed 22 complete or partial cycles. The majority of the single cells were being electropolished and achieved above 35 MV/m. Field emission (FE) of single cell cavities was completely under control. Electropolished nine-cell cavities achieved 24 MV/m in the very first attempt [2]. Nine-cell cavity rinsing and clean assembly was demonstrated on a cavity which reached 38 MV/m.

The single-cell cavities were thoroughly investigated through the camera inspection system [3] and T-map systems [4,5]. Identifiable geometric defects were investigated through a replica technique [6] and their computer modelling is in progress.

CAVITY PROCESSING AND TESTING

The electropolishing system at the joint ANL/FNAL facility is capable of electropolishing a single cell or 9-cell cavities in a simple setup. The acid/water temperatures, flow rates, current, voltage, air flow can be controlled remotely and individually to allow process optimization [1]. A 50°C or higher ultrasonic bath at 1% detergent concentration is available for cavity rinsing immediately after electropolishing.

Cavity handling has been designed to only allow clean parts to move inside the cleanroom. All activities after evacuation such as baking, active pumping and test stand mounting are conducted in separate clean environment. Cleanroom activities between HPR and final sealing off cavity ports have been kept to a minimum. The evacuation is controlled not only to minimize the turbulent flow near the vacuum joint, in the valve and also to keep the molecular flow in the main vacuum hose connected to the cavity valve.

Various cavity surface temperature monitoring tools are available to help diagnose the cavity performance limitation during vertical test. The diode based full body temperature mapping system [5] can find quench locations and hot spots on cavity surfaces. The fast thermometry system is simple to use, and the quench location can be identified through one or two RF tests. Second sound based detectors for quench location are being tested in collaboration with Cornell University [7].

All the cavities were inspected by an optical inspection system [3] before and after chemical processing to document the cavity defect history. For those cavities with visible geometrical defects, a replica technique [6] was used to obtain fine details for further computer simulations.

CAVITY PERFORMANCE AND LIMTATIONS

Cavity Performance Statistics

Six single-cell cavities representing three vendors and various histories are shown in table 1. All but one cavity reached above 35MV/m after first EP. Cavity NR-1, TE1AES004 and TE1AES005 had been buffer chemical polished (BCP) at Cornell University. Cavities TE1ACC001, 2 and 3 had no chemistry treatment after receipt from the vendor. The EP removal was set around 100 µm, except in cavity TE1AES004, for which the removal was substantially less. All but one cavity was limited by quench and had no detectable field emission. The results indicated the EP setup, HPR and clean assembly at the joint ANL/FNAL facility are performing as expected. The overall cavity performance is plotted in Figure 1.

After the performance of single-cell cavities demonstrated the facility's capability, two nine-cell cavities were used to further investigate the performance of the electropolishing and clean assembly of 9-cell cavities. ACCEL6 and TB9ACC014 were electropolished at Jlab and both achieved above 35 MV/m [2]. The first several attempts indicated that field emission was the major limitation. It is believed the main control valve for slow evacuation was failing, which caused a sudden pressure surge in main pumping line and also turbulence within cavity. In the sixth attempt, a limiting valve was used between the main control valve and cavity. So the cavity volume can be protected if main control valve fails. The sixth cavity test achieved 38 MV/m, clearly showing

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the importance of slow evacuation. All the test results are plotted in Figure 2 and also listed in Table 2.

Table 1: Recent 6 single cell cavities history and performance limitations

Cavity	BCP* [μm]	EP [μm]	E_{acc} [MV/m]	Limitation
NR-1	150	93	26.5	Quench
TE1AES004	107	65	39.2	Quench
TE1AES005	104	100	36.3	Quench
TE1ACC001		99	41.3	FE
TE1ACC002		112	37.1	Quench
TE1ACC003		119	42.1	Quench

* BCP conducted at Cornell University.

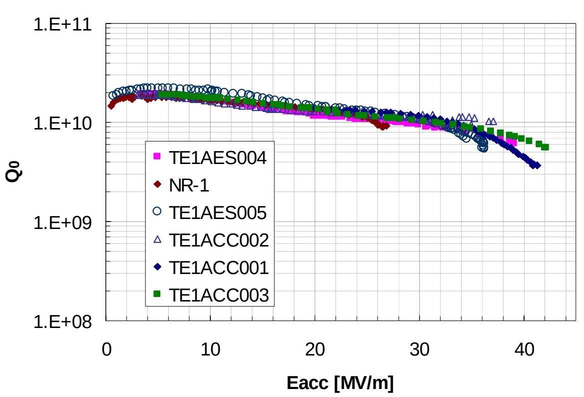


Figure 1: Q-E_{acc} of six single cell cavities.

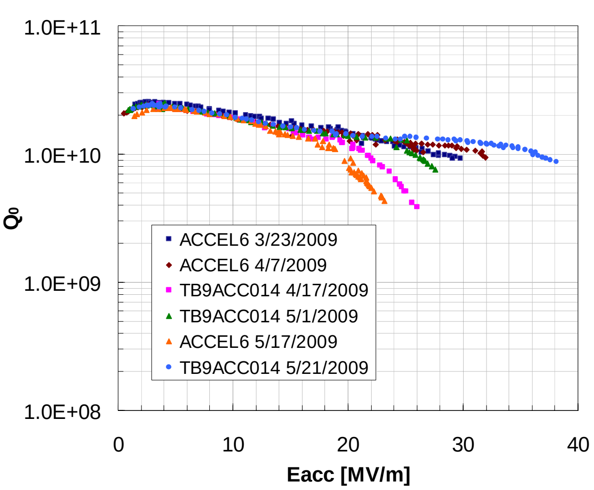


Figure 2: Q vs. E_{acc} of two nine cell cavities. (Data courtesy of J. Ozelis)

Table 2: Recent two 9-cell cavities cerformance limitations

Cavity	RF test	E_{acc} [MV/m]	Limitation
ACCEL6	1	30	FE and RF power
ACCEL6	2	32	FE and RF power
TB9ACC014	3	26	FE and RF power
TB9ACC014	4	26	FE and quench
ACCEL6	5	22.8	FE and RF power
TB9ACC014	6	38	RF power

Performance Limitations

Among the six single cell cavities listed in Table 1, TE1ACC001 showed strong field emission before reaching the quench field. Nevertheless, this cavity reached 41 MV/m. Post-EP optical inspections did not show any significant features. The cavity will be rinsed again to eliminate the field emission and to identify the performance limiting location.

NR-1 initially suffered heavy oxidation due to strong acidic water residue. The oxidation extends from beam line flange to the cavity equator as shown in Figure 3.

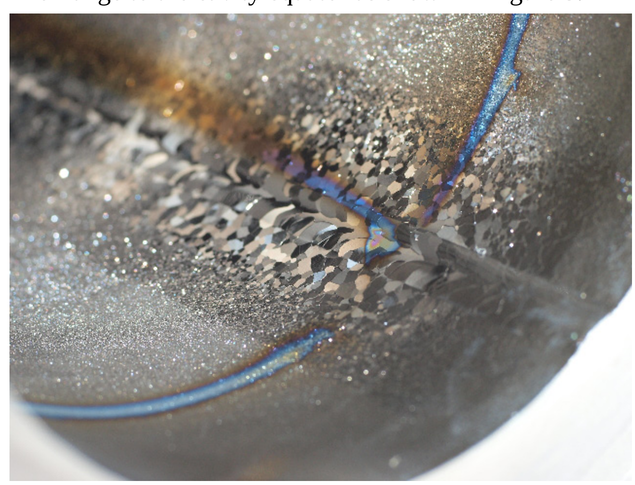
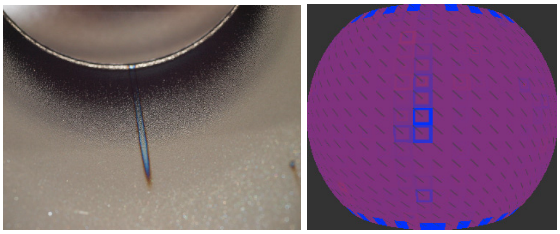


Figure 3: Oxidation mark in NR-1. (Courtesy of M. Ge)

However, the T-map data from Cornell University [8] and Fermilab both indicated a quench on the equator was not at oxidation location. Once the oxidation was removed at Cornell University, the cavity reached the same field level and was still limited by an equator quench. Optical inspections showed no distinguishing feature present throughout the cavity equator. A replica technique will be used to obtain detailed surface geometry before the cavity is electropolished again.

Cavity TE1AES005 has a similar oxidation spot caused when the high pressure nozzle stopped rotating while cavity was moving vertically during the HPR. The oxidation mark extends from beam pipe to a little over equator as shown in Figure 4. It will be rinsed using hydrofluoric acid to remove the oxidation before it is tested again.



(a) (b)

Figure 4: Oxidation caused by the high pressure water jet malfunction in TE1AES005. (a) The oxidation mark extends from the beam pipe through equator (Courtesy of M. Ge); (b) The temperature map shows heating at the oxidation location (Courtesy of A. Mukherjee).

TE1ACC002 was another cavity for which the quench location has no distinguished features.

Both TE1AES004 and TE1ACC003 have unique geometric features as shown in Figure 5 and Figure 7. While the TE1AES004 defect is large and has inner peak, the TE1ACC003 defect is a commonly observed “cat eye” shape. The locations of these defects are also unique. The TE1AES004 defect sits right at the edge of the electron beam path. The TE1ACC003 defect is clearly out of recrystalization area next to the electron beam path. The T-map data show the TE1AES004 defect is merely a hot spot instead of a quench, while TE1ACC003 defect was really causing the cavity quench. Despite of these distinguishing defects, these two cavities reached remarkably high surface field. A replica technique was used to extract the geometrical contour of the defects. The obtained 3D surface data includes important edge curvature and the defect depth information which was used to estimate the local magnetic field enhancement (Figure 6 and Figure 8). The calculation shows the magnetic field enhancement is consistent with the highest surface field reached in the cavity.

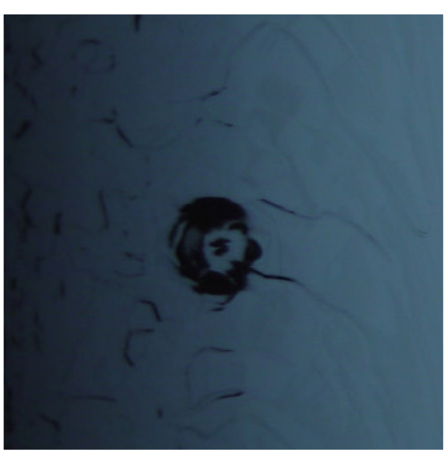


Figure 5: Picture of geometric defect on equator of TE1AES004.

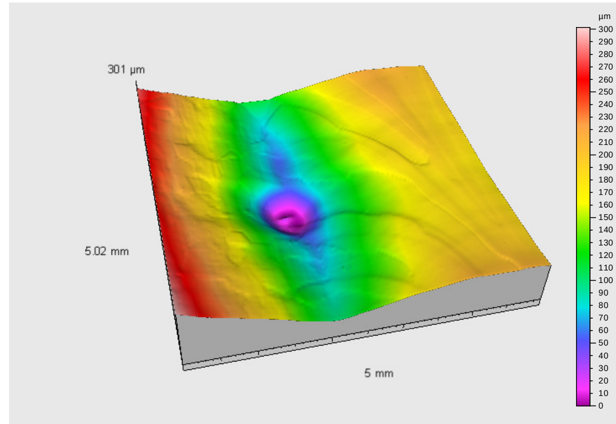


Figure 6: 3D surface profile of replica of TE1AES004 equator defect.

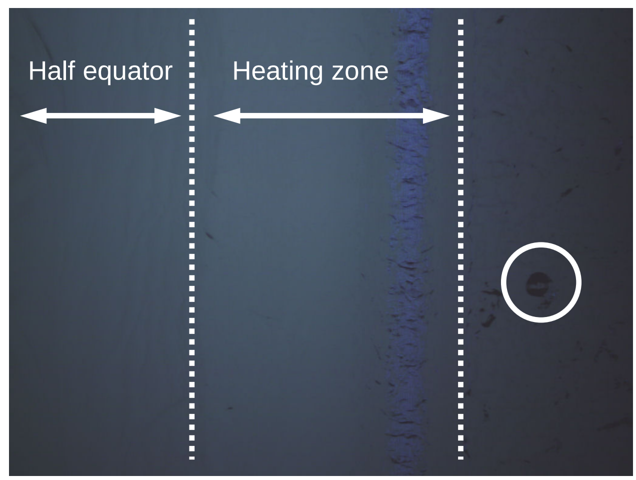


Figure 7: Picture of geometric defect near equator of TE1ACC003.

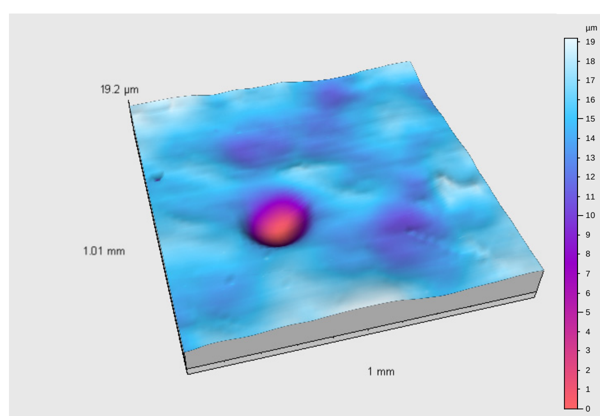


Figure 8: 3D surface profile of replica of TE1ACC003 near equator defect.

DISCUSSION

While the effort at the joint ANL/FNAL continues its progress, several interesting facts have been gathered.

While optical inspection tools remain popular and useful, their capability to identify the true defects is limited. This observation has been reported elsewhere [9]. The defects' shape and origin cannot be explained in a single theory. While the TE1ACC003 defect was present as received from vendor, it does not seem to be caused by electron beam welding since it is out of the heat affected zone. The number of potential causes can be overwhelming if the manufacturing details of the original material are considered. Even though we don't have the full history of TE1AES004 cavity defect before acid etching, the 3D shape suggests that it is caused by a crystal grain being dislodged during manufacturing or processing.

It is widely believed the BCP process roughs up the fine grain niobium surface, yet the subsequent EP in those single cell cavities shows it can polish the surface to achieve high gradient. Even in the case of pits, EP can smooth out the defect's edges so it will not cause significant magnetic field enhancement.

CONCLUSIONS

The test results from cavities processed and assembled at the joint ANL/FNAL facility proved is capable of providing high gradient cavities to meet ILC and other project goals. EP on single-cell cavities showed remarkably high gradients. Single-cell cavity field emission is completely under control. 9-cell HPR and clean assembly at ANL/FNAL facility also proved to be able to produce high gradients.

A replica technique proved to be very useful to understand the pit geometries.

Future work will focus on improving the 9-cell performance and yield. In parallel, single-cell cavities will continue to be indispensible tools for SRF R&D.

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