QUENCH STUDIES IN LARGE AND FINE GRAIN Nb CAVITIES*

S. Posen†, N. R. A. Valles, M. Liepe, CLASSE, Ithaca, NY, USA

Abstract

Quenches without radiation are sometimes observed at accelerating fields between 25 and 40 MV/m in niobium SRF cavities. The cause for this limitation is not well understood. This work presents results from vertical tests of seven 1.3 GHz single-cell cavities performing above 25 MV/m. Studies were carried out on both fine grain and large grain cavities in ILC and Cornell Reentrant shape geometries. The quenches were located by triangulation using Cornell oscillating superleak transducers and then cavities were optically inspected to determine the surface conditions of the cavity at the quench location. Optical inspection images are presented as well as 3D recreations of quench spots generated using a surface mold and a confocal microscope.

INTRODUCTION

Over the years of SRF development, several different limitations of accelerating gradient in niobium cavities have been encountered, studied, explained, and mitigated. However, the cause of quenches without radiation at fields between 25 and 40 MV/m is not known, and finding a way to avoid such quenches would be highly beneficial to routinely achieving high gradients. This paper presents preliminary results of an investigation into these types of quenches.

CAVITY TESTS

Vertical tests were performed on seven different 1.3 GHz single-cell cavities. The properties of the cavities, their preparation, and their test results are summarized in Table 1.

The Q vs E curves of the cavity tests are shown in Figure 1 for the tests at 1.4 K and in Figure 2 for the test at 1.6 and 1.8 K. NR1-3 experienced some conditioning at low and mid fields. It still showed radiation above background near the quench field, but the quality factor remained above 1×10^{10} without strong Q-drop, indicating that the quench was likely not caused by field emission.

OPTICAL INSPECTION PHOTOS

Optical inspections were performed over the entire heat affected zones of the cavities, not just the quench spots. Any defects—especially near the equator—were noted.

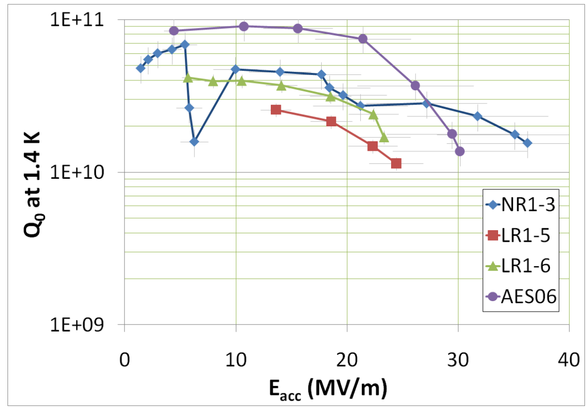

Figure 1: Q vs E curves of cavities tested at 1.4 K.

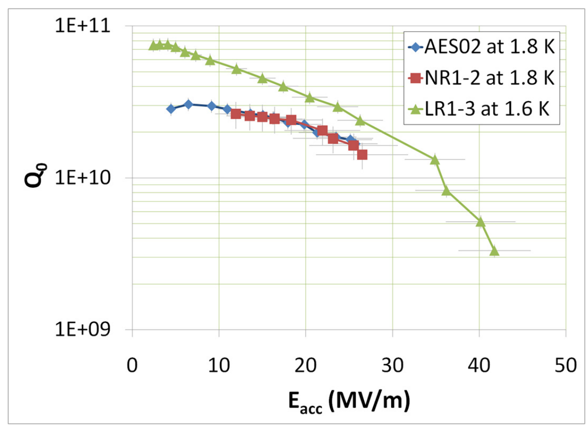

Figure 2: Q vs E curves of cavities tested at 1.6 and 1.8 K.

The optical inspection system consists of a camera connected to a telescope, which is focused on a mirror with LED lights around it, tilted at 45 to the vertical, suspended inside the cavity. The cavity is rotated and translated by hand, and pictures are taken using a computer remotely controlling the camera. The setup is shown in Figure 3.

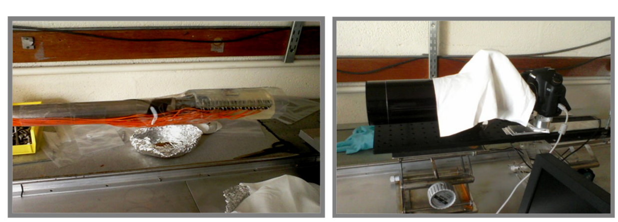

Figure 3: Optical inspection system light and mirror (left) and camera and telescope (right).

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† sep93@cornell.edu

Table 1: Summary of the seven cavity tests performed in this study.

cavity name	AES02	AES06	NR1-2	NR1-3	LR1-3	LR1-5	LR1-6
shape	ILC	ILC	ILC	ILC	reentrant	reentrant	reentrant
grain	fine	fine	fine	fine	fine	large	large
Manufacturer	AES	AES	Niowave	Niowave	Cornell	Cornell	Cornell
last main chemistry	~300 um VEP	~300 um VEP	~200 um VEP	~300 um VEP	VEP (C. barrel polish prior)	BCP	BCP
800 C bake	2h	2h	2h	2h	2h	n/a	n/a
final chemistry	micro-VEP	micro-VEP	micro-VEP	micro-VEP	micro-VEP	n/a	n/a
120 C bake	20 h	48h	48h	48h	48h	48h	48h
max acc. field	27 MV/m	30 MV/m	27 MV/m	36 MV/m	42 MV/m	24 MV/m	23 MV/m
limitation	quench, no radiation	quench, no radiation	quench, no radiation	quench, small radiation	quench, no radiation	quench, no radiation	quench, no radiation
OST results	quench at 1 location	quench at 2 locations	quench at 1 location	large quench region	Global quench	quench at 1 location	quench at 1 location
highest Q0 at low fields	3×10^{10} at 1.8K	9×10^{10} at 1.4K	3×10^{10} at 1.8K	7×10^{10} at 1.4K	8×10^{10} at 1.6K	3×10^{10} at 1.4K	6×10^{10} at 1.4K
optical inspection result	No defects observed	No defects near quench locations, but pits and bumps at other locations	No defects near quench locations, but pits and bumps at other locations	No defects observed	Some discolored spots observed	Rough area near weld and grain boundaries. Mold taken.	Rough area near weld and grain boundaries.

AES02

The quench location is shown in Figure 4. The rest of the cavity surface looked similar.

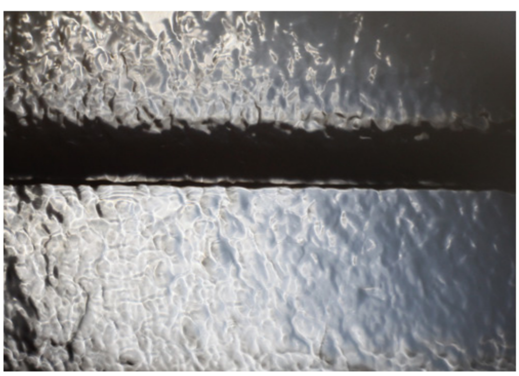

Figure 4: Quench location in AES02.

AES06

The two quench locations are shown in Figure 5. A pit or bump and a scratch, both located far from the quench spots, are shown in Figure 6.

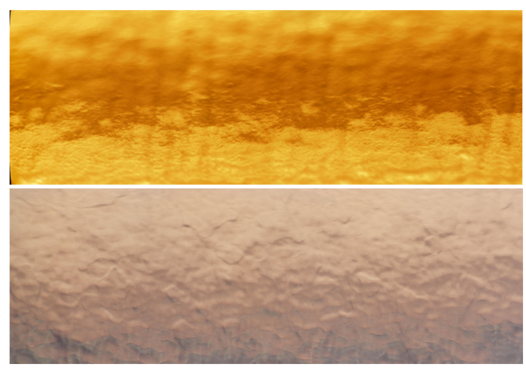

Figure 5: Quench locations in AES06.

Figure 6: Defects observed in AES06 not causing quench below 30 MV/m.

NR1-2

The quench location is shown in Figure 7. Two pits or bumps located far from the quench spot, one on the equator and one 3 cm from the quench location, are shown in Figure 8.

NR1-3

The quench location is shown in Figure 9. The rest of the cavity surface looked similar.

Figure 7: Quench location in NR1-2.

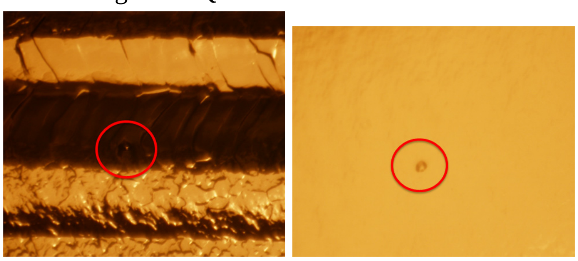

Figure 8: Defects observed in NR1-2 not causing quench below 27 MV/m.

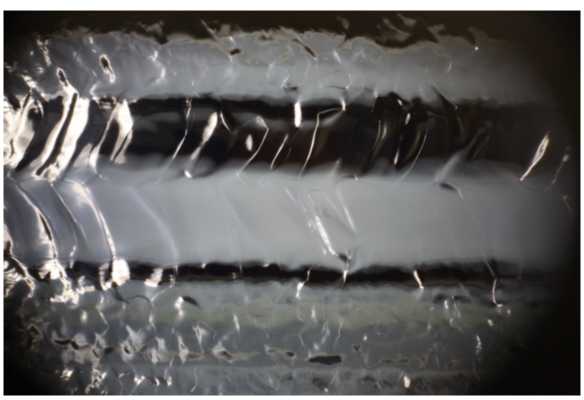

Figure 9: Quench location in NR1-3.

LR1-3

The OST signals from LR1-3 indicated a global quench. A typical area on the surface of the cavity is shown in Figure 10. During the inspection, a discolored area was noticed, shown in Figure 11.

LR1-5

The quench location is shown in Figure 12. Notice the sharp features near the equator weld and the boundaries of the large grains. A surface mold was created of the quench region. A 3D recreation of a sharp step in the mold was generated by a Keyence laser microscope [1] and is presented in Figure 13.

Figure 10: A typical area on the surface of LR1-3.

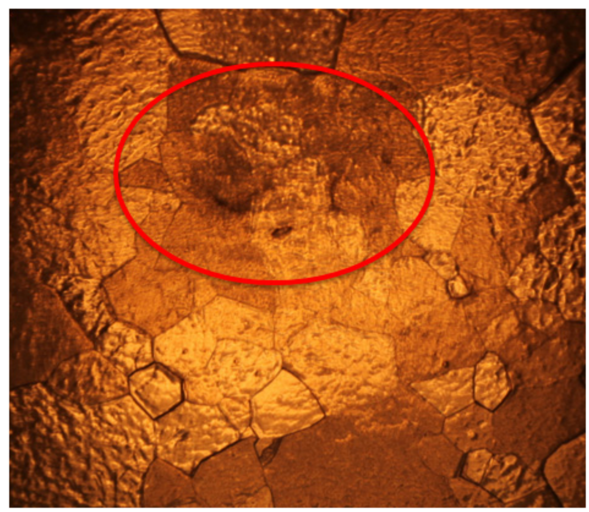

Figure 11: Discolored area observed on LR1-3. It did not cause quench.

LR1-6

The quench location is shown in Figure 14. A typical area on the surface of LR1-6 is shown in Figure 15.

DISCUSSION

All of the fine grain cavities but one quenched without or with minimal field emmission between 25 and 40 MV/m, but none showed any defects observable under optical inspection at the quench locations. In fact, AES06 and NR1-2 showed topological defects far away from the quench locations. This shows that topological defects large enough to be observed under optical inspection are not the cause of quench in these four cavities.

The two NR cavities were manufactured by Niowave, and the other two ILC cavities were manufactured by AES.

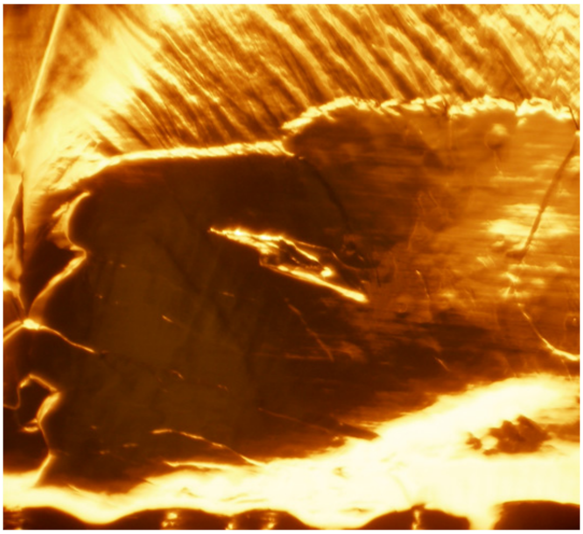

Figure 12: Quench location in LR1-5.

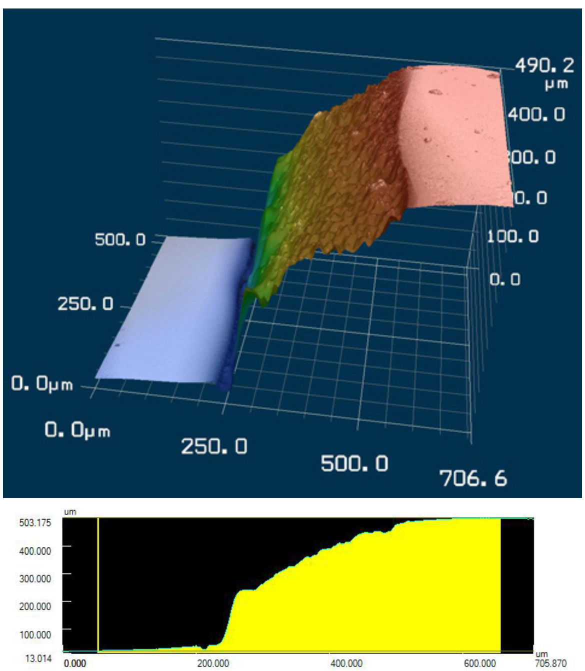

Figure 13: Confocal microscope rendering (above) and profile (below) of 500 um high step in surface mold of quench spot.

All the ILC cavities behaved similarly, showing that the occurrence of the type of quench under study does not depend on the manufacturer.

The fine grain cavities received bulk vertical EP for their main chemistry and micro-VEP after degassing. The low field Q_0 of these cavities exceeded $6x10^{10}$ at 1.4 K or $2x10^{10}$ at 1.6-1.8 K. This shows that VEP can reliably achieve high quality factors at low fields. The performance of LR1-3 shows that VEP'd cavities can reach fields >40 MV/m. However, from these tests, VEP cannot be ruled out as a cause of or contributor to quench without radiation between 25 and 40 MV/m.

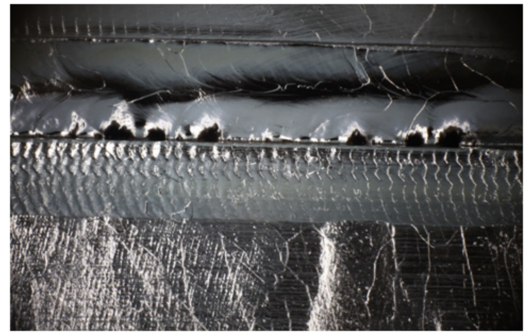

Figure 14: Quench location in LR1-6.

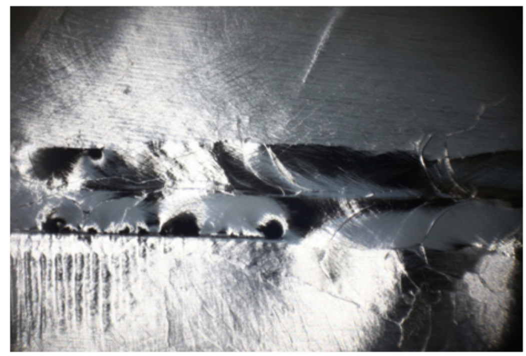

Figure 15: A typical area on the surface of LR1-6. Like the quench spot, it shows large, sharp topological features.

The quenches in the large grain cavities could have been caused by topological defects observed at the quench locations. The next step for these cavities will be centrifugal barrel polishing to smooth their surfaces.

CONCLUSIONS

Vertical tests were performed on seven single cell cavities, six of which quenched without or with minimal radiation between 25 and 40 MV/m. No defects were observed at the quench locations for many of these tests, and in some, topological defects were observed in locations that did not quench. This rules out visible defects as the only cause of this type of quench. VEP was shown to produce reliably high low-field Q_0s and accelerating fields up to 42 MV/m. It is not clear from these tests why many of the cavities are limited to accelerating fields <30 MV/m. To investigate further, a full-cavity single cell T-map is being commissioned that will fit both ILC and Cornell ERL shape cavities. Several cavities will be fabricated and tested with T-map. After testing, the cavities will be dissected, and surface studies will be performed on any quench spots.

REFERENCES

[1] www.keyence.com/