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IMPROVEMENT OF CAVITY PERFORMANCE BY ELECTRO-POLISHING IN THE 1.3 GHZ NB SUPERCONDUCTING CAVITIES

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Abstract

A steep drop of the cavity quality factor (Qo) at high electric field has been observed frequently in chemically-polished and high-pressure-rinsed Saclay cavities, even in the absence of field emission. Three single-cell cavities from Saclay were tested at KEK following electro-polishing and high pressure rinsing. This treatment eliminated the steep Qo drop, and the quench field increased to an accelerating gradient of more than 30 MV/m with a quality factor above $2x10^{10}$. No dependence of the quench field on the niobium RRR was observed between RRR = 200 and 320 in electropolished cavities.

1 INTRODUCTION

In superconducting cavities, the cavity performance strongly depends on surface preparation techniques. To obtain a smooth and clean surface, the cavity interior is finished by chemical polishing (CP) or electropolishing (EP). The high pressure rinsing (HPR) that follows has been proven effective to remove dust particles and chemical residues. A clean environment during assembly and careful handling are essential for suppression of field emission. By following these preparation steps, high accelerating gradients (Eacc) of 30~40 MV/m has been achieved without field emission in many cavities at KEK. In the latest investigation at KEK, it was noted that the cavities prepared by EP performed better than CP cavities [1]. To confirm this observation, extensive tests of both CP and EP cavities has been carried out in collaboration between KEK and CEA-Saclay. Baseline tests were carried out at Saclay, making use of various diagnostic systems developed at Saclay. Then, the cavities were sent to KEK for further tests to study systematically the effect of surface treatment on cavity behavior. The following treatments were carried out: 1) only HPR, 2) CP and HPR, 3) EP and HPR. The effect of "parking" the cavity at 100K for two hours was also investigated to check for the hydrogen Qo-disease.

2 EXPERIMENTS AT SACLAY

Three 1.3 GHz Saclay cavities (listed in Table 1) were chosen for this study. These cavities were manufactured at Cerca (France). The initial CP was performed with a 20°C acid mixture of $HF:HNO_3:H_3PO_4$ = 1:1:2 in volume for a total removal of about 150μm at a rate of about 1 μm per minute. After HPR at 90 bar for 40 minutes, the cavities were dried in a dust-free air flow for three hours. These cavities were initially tested with no heat-treatment (HT). The location of a quench and the residual resistivity ratio (RRR) of the cavity were measured with a rotating temperature and RRR mapping system [2]. The obtained quench field and average RRR are shown in Table 1. One method to push up the quench field is purification of the niobium by Ti-gettering during HT to improve the thermal conductivity [3]. High temperature HT [4] was carried out on the cavities S-1 and S-2. The RRR was improved after HT, and the quench field increased to 25 MV/m. However, a steep drop of the Qo was observed above 18 MV/m, as seen in Figure 1. The same phenomenon had also been observed in KEK cavities tested at Saclay [5]. Neither x-rays nor field-emission electrons were observed at these higher fields. Similarly, thermometry measurement at 25 MV/m could not detect any field-emission sites. Each cavity in Figure 1 was limited by a quench around the equator seam of electron beam welding (EBW).

Table 1: Properties of the Saclay cavities

	niobium sheets		no HT, CP150μm	
cavity	supplier	RRR*	Eacc,max	ave.RRR
S-1	T-Denkai	200	20.9 MV/m	190
S-2	Heraeus	260	20.9 MV/m	160
S-3	Heraeus	280	15.1 MV/m	230

RRR* ; specification by the company.

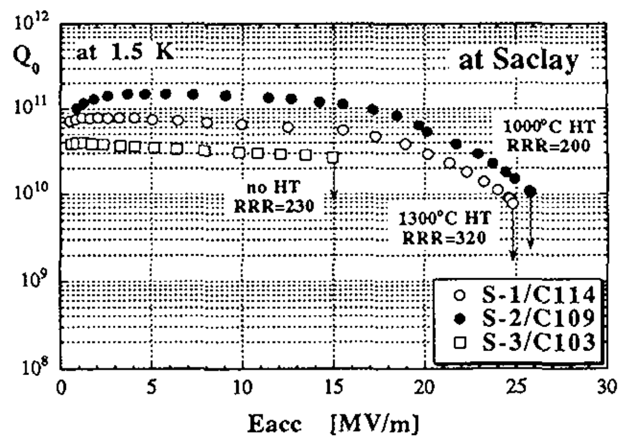

Figure 1: Test results at Saclay

3 EXPERIMENTS AT KEK

The same cavities were tested three times each at KEK. For the initial test, only HPR at 85 bar for 60 minutes was performed. A second test was preceded by CP with a 25°C acid mixture of $HF:HNO_3:H_3PO_4 = 1:1:1$, yielding a removal rate of 12 µm per minute (about ten times faster than that at Saclay). Finally, prior to the third test, EP was carried out with a horizontal, rotating electropolishing device [6]. An acid mixture of $H_2SO_4 : HF = 10:1$ was used, and the removal rate was 0.5 µm per minute at 30°C. In each case, HPR preceded the final cavity assembly. The wet cavity was pumped out and baked at 85°C for twenty hours. Then, the cavity was installed in the test stand, and no active pumping was performed during the cavity test. Figure 2 shows the KEK test results. In all cases, a quench (without field emission) was the ultimate field limitation, similar to the Saclay results. However, the quench field clearly increased after EP. The effect of 50µm EP with cavity S-3 was especially pronounced, pushing the quench field up from 17 MV/m to 33 MV/m. Moreover, in each test after EP, a steep Qo drop at high field was not observed, and changed to a standard slope. The quench field and the residual surface resistance (Rres) after each treatment are summarized in Figure 3. Both the quench field and the Rres had deteriorated in the first test at KEK (after HPR), presumably due to surface contamination during transport (*e.g.*, exposure to the air). However, the cavity performance was recovered by CP. EP then augmented the quench field to above 30 MV/m. On the other hand, the Rres remained unchanged by EP. The relatively high surface resistance of the S-3 cavity may be due to the small grain size (this cavity was never heat-treated).

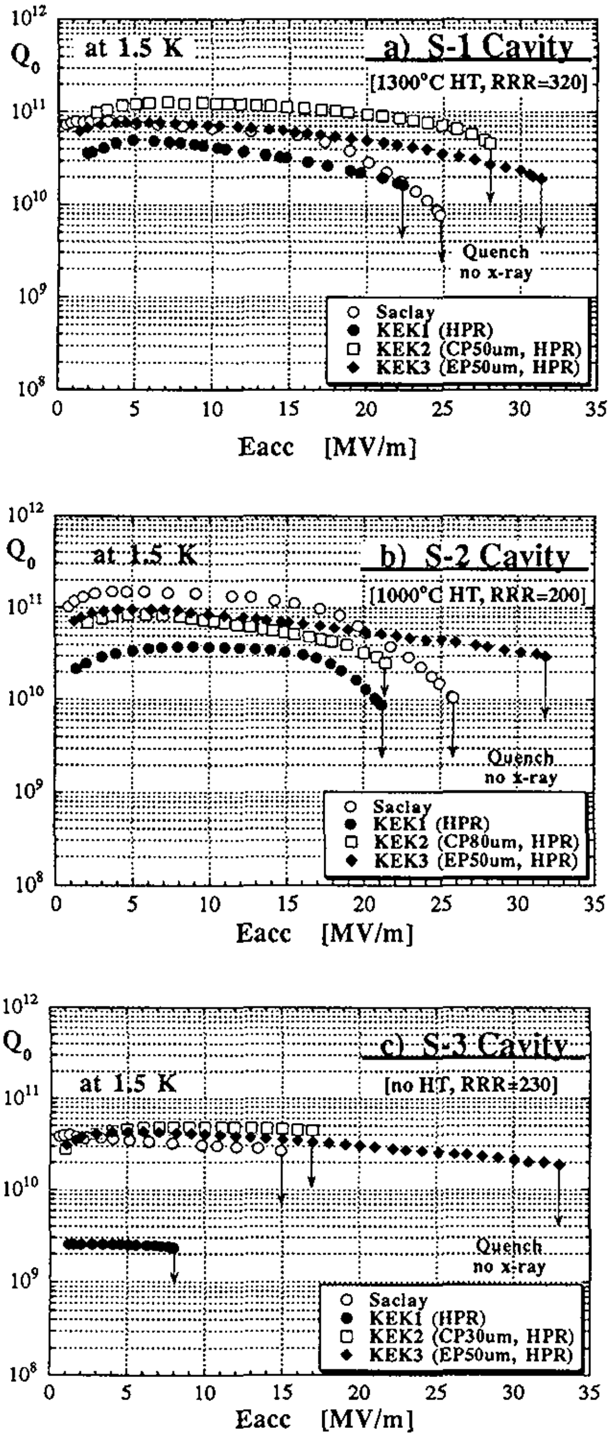

Figure 2: Test results at KEK

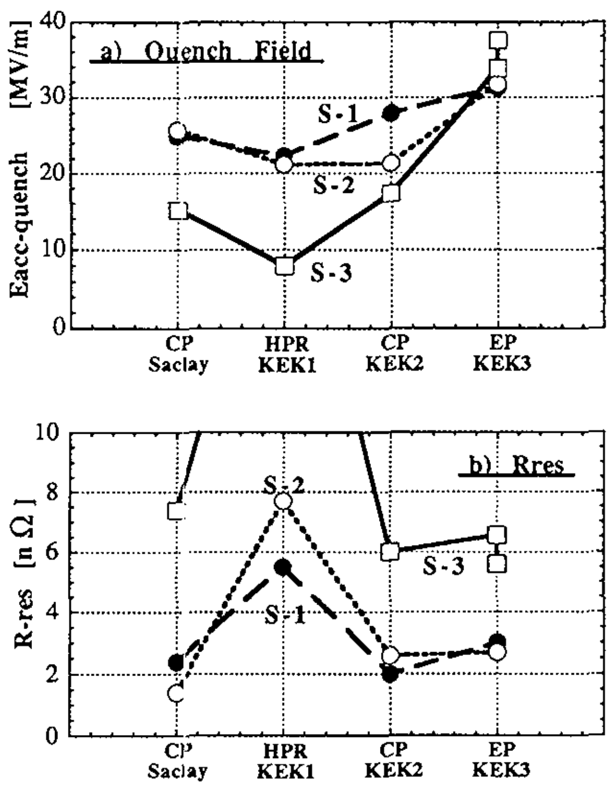

Figure 3: Summary of the quench field and the Rres

4 DISCUSSIONS

4.1 Degradation due to CP after EP

Additional EP of 70 μm was performed on cavity S-3, improving the quench field to 37 MV/m. A subsequent surface removal by CP clearly degraded the cavity performance again, as shown in Figure 4. A similar effect has been reported in reference [7]. Additional CP lowered the quench field even more and the steep decline of the Qo at high field appeared again. It is assumed that a chemical reaction between niobium and the acid during CP produces a bad superconductor, especially at the grain boundaries around the equator seam, where many impurities might concentrate due to recrystalization by EBW.

4.2 Quench field

High RRR niobium with its large thermal conductivity is needed to thermally stabilize surface defects that might otherwise cause a quench at a high gradient. The correlation between the quench field and the average RRR in eight cavities tested at Saclay is plotted in Figure 5. The results with the CP cavities in Figure 5 are consistent with above mention. After EP, however, no dependence of quench field on RRR was observed. This demonstrates that the origin of a quench may differ in CP and EP cavities.

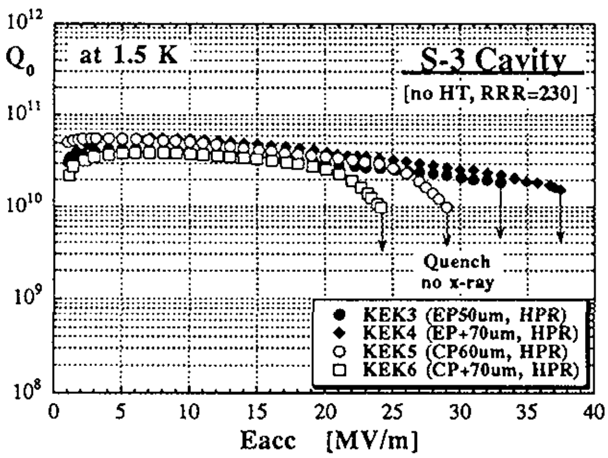

Figure 4: Cavity degradation due to CP after EP

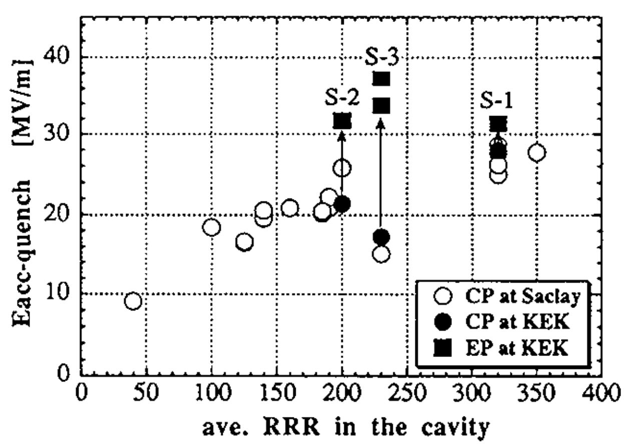

Figure 5: Quench field vs. RRR

4.3 Qo-disease

The cavities were parked at 100K for two hours to investigate possible hydrogen problem of the niobium (Qo-disease). The obtained Rres results in three cavities are listed in Table 2. It is well-known that HT above 700°C for hydrogen degassing is effective to avoid the Qo-disease. It is noteworthy that no Qo-disease was observed in the S-3 cavity (no HT), even after 120μm EP. This result shows an omission of 700°C HT after EP.

Table 2: The Rres following a 100K "park" for two hours

cavity	surface treatment	initial*	100K,2h	ΔRres
S-1	1300°C HT, CP140 μm	5.5	10.5	+5.0 nΩ
S-2	1000°C HT, CP130 μm	7.7	8.0	+0.3 nΩ
S-3	no HT, CP200 μm	6.1	5.9	-0.2 nΩ
	, +EP120 μm	5.6	5.3	-0.3 nΩ

initial*; fast cool-down within 1 hour from 300K to 4.2K

5 SUMMARY

a. The 50 μm EP eliminated the steep Qo drop at high field in CP cavities and pushed up the quench field to more than 30 MV/m.

b. No dependence of the quench field on RRR was seen between RRR = 200 and 320 in cavities that were electropolished.

c. There was no difference in the Rres between CP and EP cavities.

d. CP after EP gradually reduced the quench field and caused the Qo drop at high field to appear again.

e. No Qo-disease was observed after parking the cavity at 100K for two hours, even in the no HT cavity after EP.

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