ACID FREE EXTENDED MECHANICAL POLISHING R&D*

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Abstract

Extended Mechanical Polishing (XMP), as described in this paper, may be a pathway to eliminate chemistry from the elliptical SRF cavity processing sequence. It would be beneficial to remove chemistry after the XMP process because it would be more environmental friendly, would require much less infrastructure and would be less technically involved, opening up avenues for cavity processing at more industrial partners and facilities in general. Also the XMP process would be cheaper without the post-XMP chemistry step. Recent results on cavities processed by the fine polishing of XMP and followed by no chemistry show that the fine polishing does not have much if any negative effect on cavity performance. Recent attempts to remove contamination introduced in the bulk material removal and rough polishing steps of the XMP process shows need for further improvement. This paper describes the XMP process, optimization experiments, and resulting cavity tests that that showed Q_0 close to $3x10^{10}$ and E_{ACC} over 30 MV/m.

INTRODUCTION

Niobium superconducting radio-frequency (SRF) cavities are a key component of accelerators using cold technology. Niobium has been the element of choice as it becomes superconducting at close to 10° K. Niobium has mechanical properties that are suitable, yet far from ideal, to fashion polycrystalline sheets of it into radio-frequency cavities. There are a wide variety of problems encountered when working with the niobium used for SRF cavities including: a high melting point that necessitates electron beam welding, poor tensile strength and hardness of ingot material, high chemical resistance, high purity of material required, and a high affinity for hydrogen and oxygen [1-4]. Much work has been done on the manufacturing of niobium SRF cavities to increase accelerator performance and decrease accelerator installed and operating costs [5- 9].

Extended mechanical polishing (XMP) has already demonstrated the ability to remove the damage layer from the cavity manufacturing process and has achieved mirror like finishes smoother than previously obtained through chemistry [10]. Using XMP, a cavity manufacturing process was also demonstrated that had the ability to successfully repair cavities with performance limiting defects that were unsuccessfully processed by EP [10]. However this work also showed that 20 microns of chemistry were required, after the cavity was processed by XMP, to produce a high performance cavity. At the time, it was theorized that this 20 microns of chemistry was needed because the tumbling process left contamination behind, although little to none was apparent from visual and chemical analysis on coupons.

The work in this paper details the attempt to remove the need for chemistry after XMP. This requires an understanding of the amount of contamination left by the process. It would be beneficial to remove chemistry after the XMP process for several reasons. The process would be more environmental friendly. The process would require much less infrastructure and would be less technically involved opening up avenues for cavity processing at more industrial partners and facilities in general. Also, the XMP process would be cheaper without the post-XMP chemistry step.

EXPERIMENTAL

The XMP process was thoroughly described in a previous publication [10]. XMP of single-cell, polycrystalline and large grain niobium, 1.3 GHz TESLA SRF cavities was done using a machine custom built for this purpose by Mass Finishing Inc. [11]. Cavities were secured in buckets, where each bucket rotated around the central shaft at up to 115 rpm at a 0.45 m (18 inch) moment arm. Simultaneously, each bucket counter-rotated around its own axis at the same rate. The machine accelerates media with approximately 6-7 g of force against the inner cavity surface.

Two coupon cavities were also utilized, as seen in Figure 1. The coupon cavity was made in the same manner as a standard single cell 1.3 GHz niobium cavity. But after the standard cavity was made, many small hubs were electron beam welded and holes cut into the cavities at the equator, beam tube and transition area from the cell to the beam tube. The coupons were initially flat and tumbled to match the geometry of the cavity before data was taken. The amount of force and hardness of the material being polished are two critical variables in studying mechanical polishing. The coupon cavity allows for a very close approximation to the actual tumbling process.

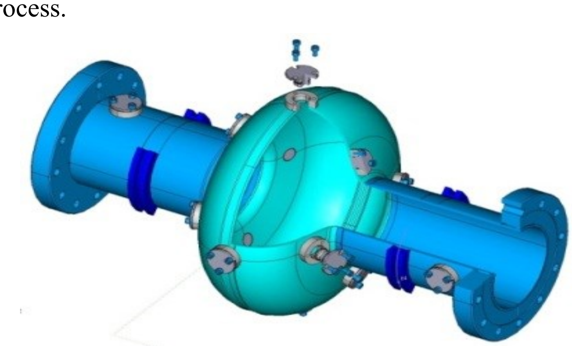

Figure 1: Model of niobium coupon cavity used to study the XMP process.

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The surface morphology of the coupons was measured using a KLA-Tencor P-16 Stylus-Type surface profilometer with a 0.1 micron diameter tip. A 5900 JEOL scanning electron microscope, with Oxford EDS model 7460, was also used to analyze the samples. Pictures of the equatorial welds were taken by a special camera system (Kyoto Camera System) designed to access the cavity interior [12]. This system has 20 micron resolution. In all pictures, the weld bead is approximately 10 mm wide and runs from top to bottom. Adjacent to the weld bead and running parallel to it on either side is a heat-affected zone, which is approximately 14 mm wide.

RESULTS

Initial tests on cavities cold tested after XMP and no post XMP chemistry yielded poor results with low quality factors and poor maximum accelerating gradients. This was originally thought to be caused by media left in the cavity after the XMP process. It was shown that 20 microns of chemistry after XMP and the 800 C hydrogen bake out was needed to produce a high performing cavity.

It was however recently found that titanium from the flanges was depositing in the cavity during heat treatment [13]. There was some question as to if this apparent surface contamination from heat treatment was causing the need for chemistry after the tumbling process. Because of this question, two new cavities were processed by XMP, 800° C heat treated and 2° K cold tested with no chemistry. The results are in Figure 2.

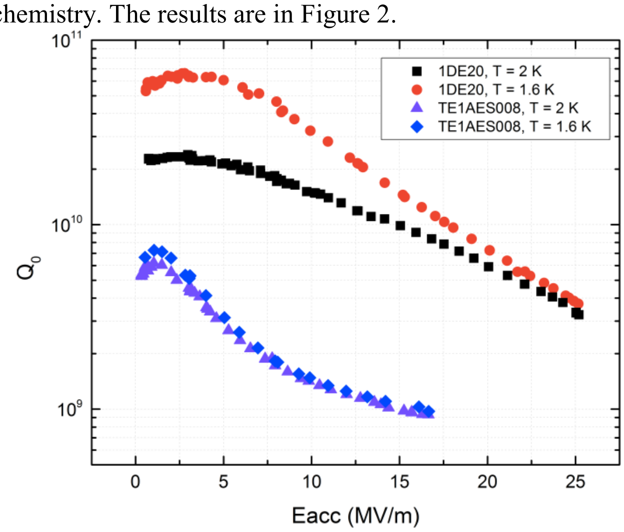

Figure 2: 2° K cold test results of 2 different single cell 1.3 GHz TESLA cavities after tumbling to a mirror finish and 800° C bake. Processing was done with no chemistry. The large grain cavity, 1DE20 performs much better than the polycrystalline cavity TE1AES008.

The bottom trend of Figure 2 is of a polycrystalline cavity, TE1AES008, and has very bad performance. This bottom trend very closely parallels the results from other tumbled cavities tested without chemistry. But the top trend of Figure 2, cavity 1DE20, performed much better than any previously tested cavity that had been tumbled and tested without post heat treatment chemistry. The main difference in the 2 cavities seen in Figure 2 is the number of grain boundaries. The difference in performance was attributed to titanium, from the cavity flanges, which vaporized and preferentially deposited in grain boundaries [13]. This realization that the limitation in cavity performance after XMP and the 800 C heat treatment was vaporization of titanium lead to an improvement in the furnace to eliminate it [13]. After this furnace work there has been a flurry work in minimizing the amount of contamination that has been found in the cavities after XMP [14].

Recent results on cavities processed by the fine polishing of XMP and followed by no chemistry show that the fine polishing does not have much if any negative effect on cavity performance. Recent attempts to remove contamination introduced in the bulk material removal and rough polishing steps of the XMP process shows need for further improvement, but have produced cavities with Q_0 close to $3x10^{10}$ and E_{ACC} over 30 MV/m.

The first wave of work on centrifugal barrel polishing and XMP at Fermi focused on repairing poor performing forming cavities with as short a processing time as possible and on obtaining as smooth surfaces as possible. A new approach was needed when focusing on acid free processing. To minimize amount of material imbedded in the surface of the cavity new media, new carriers and new process parameters we examined. The force of the media on the surface of the cavity was changed by varying the revolution rate of the tumbler. New more durable media have been examined. Low aspect ratio media that would be less likely to be driven into the polished surface were examined. The carriers for unsupported abrasive materials were examined. No suitable carriers were found, so we developed several of our own that are now under testing. These are high density carriers with little to no potential to scratch the soft niobium surface.

Some of the recent success in achieving higher quality factors and accelerating gradient in cavities that have gone through XMP without chemistry is likely due to a reduced amount of residual contamination left behind. SEM has demonstrated that some of the changes we have made to the process have reduced the amount and severity of the pitting. The EDS has shown much less contamination and smaller pieces of contamination. Figure 4 below shows an SEM picture from a coupon from the coupon cavity that was tumbled with the first step of the original XMP process. The niobium is very distressed with many apparently deep pits. There are also large pieces of contamination (the white areas) in some of the pits. As the niobium is soft this type of surface is hard to completely recover since the embedded media can get covered over during XMP.

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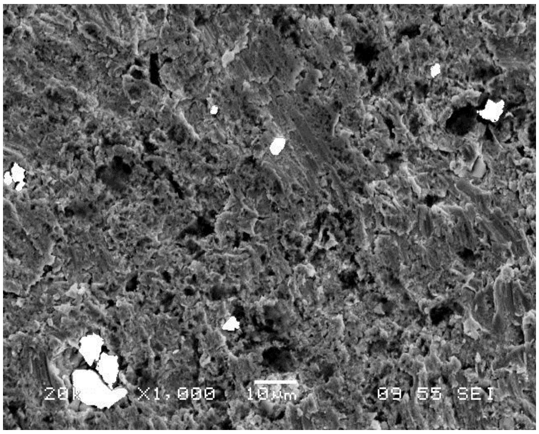

Figure 3: SEM picture after original XMP 1st step.

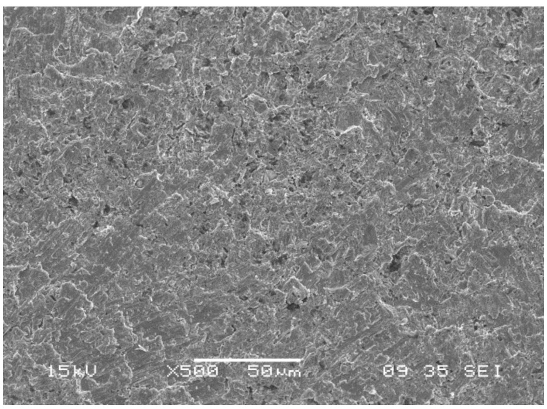

Figure 4: SEM picture after modified XMP 1st step.

Figure 4 above shows that the surface produced from this particular modification of the XMP process has less pitting on the surface. There is also much less media on and imbedded in the surface. Similar results are seen for subsequent steps that do not require a carrier.

Since the high temperature baking process was improved so that heat treatment does not introduce a contaminant, a new wave of work on acid free tumbling has commenced. Much encouraging progress has been made and record performing XMPed, no chemistry cavities have been processed. Current work shows promise for future further improvement in the performance of acid free XMPed cavities.

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