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EXPLORING INNOVATIVE PATHWAY FOR SRF CAVITY FABRICATION

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Abstract

This article shows a study on an alternative pathway for the fabrication of a complete 1.3 GHz SRF cavity, aiming at improving production reliability, reducing the use of chemical polishing (EP or BCP) which is a costly and safety-critical step, and preserving surface quality after forming. Unlike the conventional pathway, the fabrication process is performed after polishing. This point is crucial as the used polishing technology could be applied only to flat geometries. The performed investigation demonstrates that damages during the fabrication process can be considered minor, localized, and limited to the near-surface. Moreover, these studies confirm that the damaged layer (100-200 µm) is mainly caused by the rolling process, and not by the subsequent fabrication steps. A laser confocal microscope and SEM-EBSD technique were used to compare samples before and after forming. The preliminary results are discussed and presented in this paper.

INTRODUCTION

Extensive chemical treatment for material removal around 100-200 µm is required after cavity fabrication to meet the needs of the SRF surface [1]. This step is focused on eliminating/reducing crystalline defects (high residual strain, dislocations, grain boundaries...), and impurities/contamination release from the surface [2]. Furthermore, as some cavities are almost reaching the physical limit of Niobium [3, 4], new superconductors are required to achieve higher performance levels [5, 6]. These superconductors are obtained in the form of thin films via different deposition techniques [5, 7], so surface roughness has gained even greater significance, as the film quality closely related to the substrate quality [8, 9]. This goal is one of the reasons to push the R&D efforts to explore alternative surface processing for preparing improved substrates [9–11], but not only. Moreover, the use of dangerous acids in conventional polishing methods poses risks for both personnel and environment. In order to overcome such safety concerns and potentially reduce the costs of surface processing, by using a more robust, eco-friendly, and reproducible technique, metallographic polishing (MP) is used as an alternative. This technique might find an application for large-scale facilities production (ILC, FCC), as this method can be easily industrialized, and create smoother surfaces than conventional polishing, potentially improving the production yield, and preparing substrates for a thin-film deposition applicable not only to Nb, but to Cu also [12]. However, MP is performed only on flat geometries, so polishing has to be done before the cavity fabrication. Hence, the damages after fabrication have to be characterized and evaluated.

Recent studies by O. Hryhorenko et al. on Nb samples have highlighted that grain quality can be preserved after optimized deep-drawing and high residual strain regions are located only at the grain boundaries [13]. However, a systematic study that investigates the distribution and propagation of those damages into the bulk on the completed cavity has not yet been investigated.

In this article, we show the fabrication of a 1.3 GHz cavity using an alternative pathway (polishing before forming) and systematic studies of the internal surface quality to complete research.

NIOBIUM SURFACE PROCESSING

Metallographic Polishing

Mechanical polishing is a polishing technology, the principles of which are used in different fields [14, 15] to obtain a very smooth surface in a limited number of steps and time. However, additional requirements are necessary to consider for SRF applications, as the RF penetration into the bulk is of the order of 200 nm, where the material has to meet SRF requirements meaning a very low level of impurities and crystal damages. A specific 2 steps procedure was developed at IJCLAB and CEA-IRFU [12], to preserve the quality of the surface. Metallographic polishing (a subtype of mechanical polishing) was done on a standard lapping machine and performed at the company LAM PLAN (Gaillard, France) [16]. For this project, large Nb disks with a diameter of 260 mm were used and were polished with 2 steps MP.

The following recipe is applied:

- Diamonds 9 µm on the New Lam M'M' Green lapping disk (200 µm removal, approximately 2 hours).
- SiO_2 + H_2O_2 + a basic solution on the polyurethane cloth (2 hours cycle).

Figure 1 shows a final surface after the application of a 2 steps MP procedure. The resulting surface is considered

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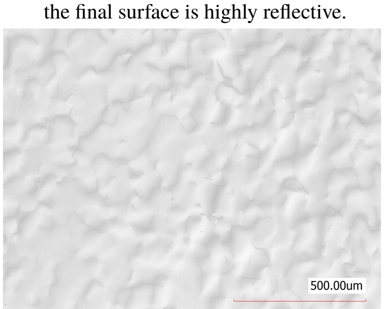
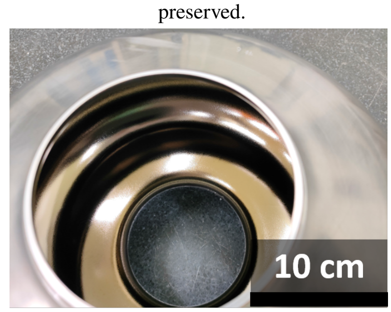
(a) Photography. Note: the image shows that the final surface is highly reflective.



(b) Laser confocal image. Note: image indicates the crystalline structure with smooth grain boundaries.

Figure 1: Surface quality of Niobium disk after 2 steps MP polishing.

(a) Half-cell after deep-drawing. Note: photography indicates that high reflectivity is preserved.



(b) Electron beam welded cavity. Note: photography shows that the 'whitish' color of the inner surface is changed by the 'yellowish'. Sign of strong oxidation.

Figure 2: Surface quality of Nb surface after different fabrication steps.

as a high reflective, mirror-finished, and pollution free. The average surface roughness is equal to Ra=170 nm, and measured over the scan area of 290 µm x 215 µm using a laser confocal microscope. In order to compare the roughness before/after fabrication the same scan area is considered.

Alternative Cavity Fabrication Process

The conventional pathway of SRF cavity fabrication follows a specific sequence of steps applied to Niobium disk, which are as follows: deep drawing, half-cell machining, electron beam welding, bulk chemical polishing (100-200 µm), heat treatment, and 'flash' polishing [17]. As was mentioned earlier, in the case of alternative processing, disks are polished by MP before actual half-cell production, while the remaining steps remain unchanged. However, several technological changes have to be done in order to protect the polished surfaces during half-cell production. The following changes are applied:

- Ultra-thin polyurethane sheet is placed as an intermediate layer between the disk and the die.
- Metal disk holders used for half cell-production were replaced with plastic ones.
- Cleaning concerns.

The one-cell 1.3 GHz test cavity was built using the alternative fabrication path at the KEK laboratory (Tsukuba, Japan), wherein a single disk was pre-polished with the conventional chemical treatment (BCP), while the second disk underwent metallographic polishing. The purpose of fabricating this cavity is to assess and characterize any associated damages resulting from the cavity fabrication process. As shown in Fig. 2a, the formed surface appears to stay mirror-looking, but after EBW of the half-cells, The appearance of the inner surface changes from white to yellow hues, see Fig. 2b, and can be considered as an effect of oxidation during EBW. Nb is known as a good getter with high affinity to O, N and H, so in addition to visual inspection, a dedicated analysis is required. The investigations of the material quality are presented in the following chapter.

EXPERIMENTAL RESULTS

Strips from the cavity were cut using the by wire EDM in order to get access to the surface. Six regions, ranging from the equator (cut-out N1) to the cavity iris (cut-out N6), were defined and evenly distributed, as shown in Fig. 3.

First, the analysis of the top face and evaluation of surface roughness changes and the appearance of damages were performed and recorded using the laser confocal microscope. Subsequently, cross-sections were prepared by ion milling, and damages within the bulk were described with a SEM-EBSD analysis.

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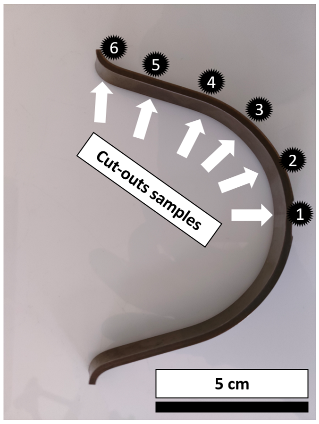

Figure 3: Photography of an Nb strip with schematically defined analyzed regions.

Internal Surface Analysis

The surface imaging of the inner surface was performed after the fabrication process of a single-cell cavity. As shown in Fig. 4, notable changes in the surface were observed after forming.

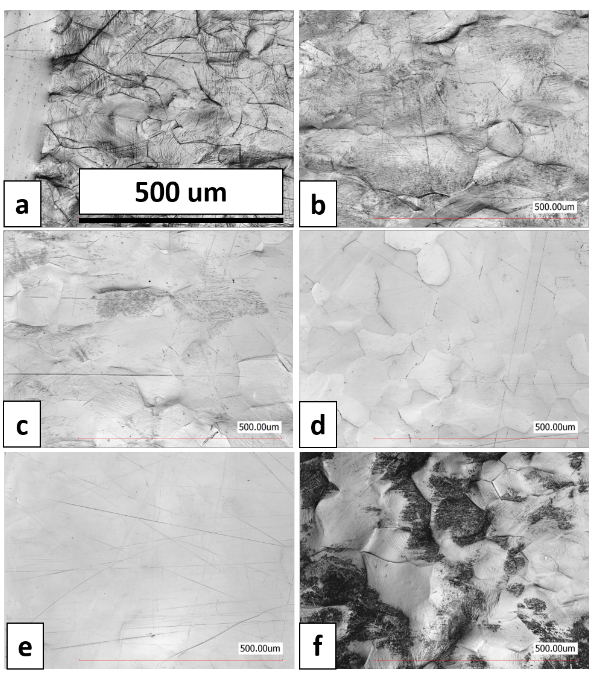

Figure 4: Laser confocal images of cut-outs samples from fabricated SRF cavity taken in the different locations: (a) Cut-out N°1, (b) cutout N°2, (c) cut-out N°3, (d) cut-out N°4, (e) cut-out N°5, and (f) cut-out N°6. Note: N°1 is located nearby the EBW area, N°6 is located at the iris region, and others are uniformly between those two areas.

Forming caused the reappearance of scratches, dislocations, and grain boundaries, which are the main sources of damages presented. Meanwhile, the grains which were in contact with the dies show the residual patterns presented on the surface. Figure 5 shows measured initial and after-

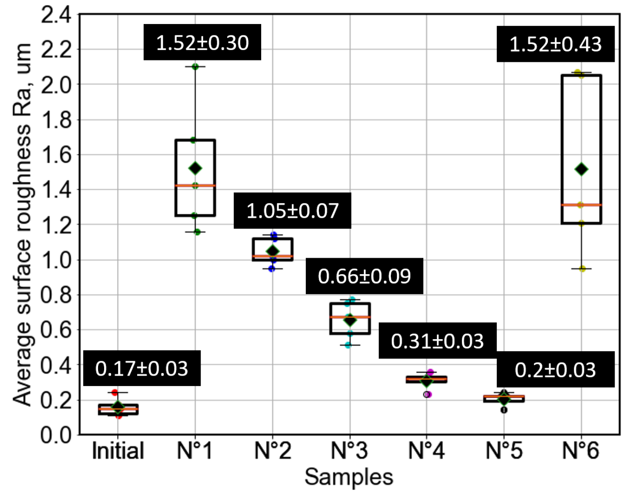

Figure 5: Evolution of the average surface roughness Ra before and after fabrication as a function of the analyzed region.

fabrication surface roughness as a function of an analyzed location. An increase in roughness was observed in the vicinity of the equator zone, and at the iris, where the deformations are maximum.

In the previous work, see the paper [13], the analysis of the inner face surface was conducted using an EBSD detector. The findings indicated that the main locations of high strain were new revealed grain boundaries. However, the measurement of the depth of the affected layer remained unperformed. The following section will address these studies. It is hypothesized that in this particular case, heat treatment at high temperatures (800 °C, 2 h) can potentially eliminate the high strain induced by deep drawing due to crystal growth based on the following studies, see papers [18]. The statement above will be verified in future work.

Cross-Sectional Analysis

For a comprehensive evaluation of damage penetration, cross-sections were prepared using an ion-beam milling machine at STFC laboratory (Daresbury, UK), followed by analysis using an EBSD technique at IJCLab with an accurate resolution with a scan step of 1 µm. This research aims to provide valuable insights into the damage evaluation of pre-polished disks after cavity fabrication. The measurements of the two main EBSD figures, namely the inverse pole figure (IPF) and the kernel average misorientation (KAM), were performed and compared.

The three cut-outs (N°1, N°5, and N°6) were chosen for the following analysis. Figure 6 depicts that the crystallinity is well-preserved, as all electrons were reflected from the surface, with a presence of minor strain at the grain boundaries (green color in the KAM map). An affected layer is evaluated to be less than 1 micron and this is determined only by the scan step, as the IPF maps show very good diffracted patterns, which are matching the KAM maps.

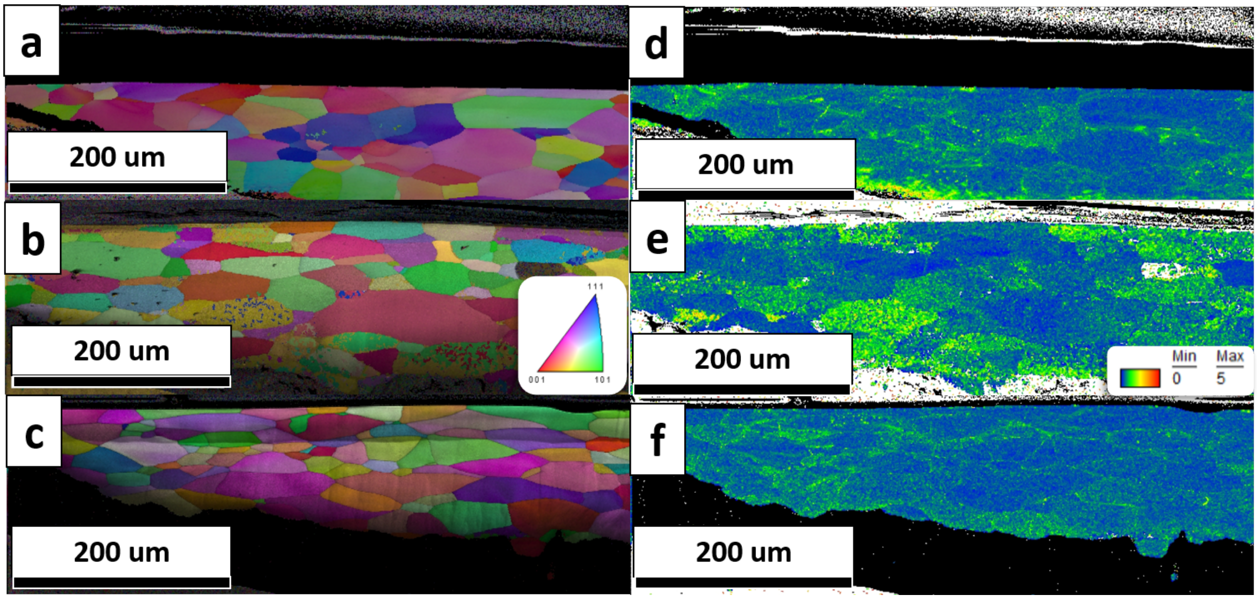

Figure 6: EBSD scans of the cross-sections after MP+alternative forming step investigated in relation to damage creation during half-cell production as a function of the analyzed region: (a, d) IPF and KAM maps for cut-out N°1, (b, e) IPF and KAM maps for cut-out N°5, and (c, f) IPF and KAM map for cut-out N°6.

Hence, the combined action of an intermediate layer at the interface between dies and disk, and improved final internal surface resulted that the load being better distributed during deep drawing, as well as the better-distributed and reduced friction, so it resulted in less localized damage compared to the conventional processing.

In order to define the more precisely affected layer the scans with better resolution are required. However, those results are inspiring for future investigations, as the processing shows evident advantages compared to conventional polishing techniques. The simplicity of this technology opens a possible pathway for future mass production with improved yield production, but in addition to material analysis, an RF test is required to give a final conclusion.

CONCLUSION

In this work, we fabricated a one-cell 1.3 GHz cavity with a novel approach, applying polishing before fabrication. Material investigations, such as laser confocal imaging and EBSD, were performed on the inner cavity surface, demonstrating that the damage after cavity fabrication is significantly less than typically has to be removed. Meanwhile, metallographic polishing of the flat surfaces shows a superior level of roughness and flatness compared to conventional polishing, so MP is already taken for the preparation of the QPR samples and RF disks used as an initial substrate for thin-film deposition. These results are encouraging us to fabricate the three cavities and evaluate RF performance after light EP. Six additional disks were polished so far, half-cells are prepared, and one cavity is welded. These studies will be continued in the framework of the FJPPL collaboration.

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