QUALIFICATION OF THE SECOND BATCH PRODUCTION 9-CELL CAVITIES MANUFACTURED BY AES AND VALIDATION OF THE FIRST US INDUSTRIAL CAVITY VENDOR FOR ILC*

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Abstract

In the past several years, Jefferson Lab (JLab) in collaboration with Fermi National Accelerator Laboratory (FNAL) has processed and tested all the 9-cell cavities of the first batch (4 cavities) and second batch (6 cavities) production cavities manufactured by the Advanced Energy System Inc. (AES). Four out of the six 9-cell cavities of the second production bath achieved a gradient of 36-41 MV/m at a Q0 of more than 8E9 at 35 MV/m. This result validated AES as the first "ILC certified" industrial vendor in the US for ILC cavity manufacture.

INTRODUCTION

One of the major goals of ILC SRF cavity R&D is to develop industrial capabilities of cavity manufacture and processing in all three regions. In the past several years, JLab in collaboration with FNAL has processed and tested all the 9-cell cavities of the first batch (4 cavities) and second batch (6 cavities) production cavities manufactured by the Advanced Energy System Inc. (AES). These cavities are manufactured for FNAL. Over the course, close information feedback was maintained, resulting in changes in fabrication and processing procedures. Some mechanical features originally observable on the RF surface at the stiffening ring radius even after complete EP processing were successfully eliminated by improvement in forming and welding procedures. A light buffered chemical polishing is introduced, removing the weld splatters that cannot be effectively removed by heavy EP alone. An 800 Celsius 2 hour vacuum furnace heat treatment procedure replaced the original 600 Celsius 10 hour procedure. Four out of the six 9-cell cavities of the second production bath achieved a gradient of 36-41 MV/m at a Q0 of more than 8E9 at 35 MV/m. This result validated AES as the first "ILC certified" industrial vendor in the US for ILC cavity manufacture.

* Work supported by DOE. Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.
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Presently with Jefferson Lab

BRIEF REVIEW OF FIRST PRODUCTION BATCH CAVITIES

AES manufactured four 9-cell ILC cavities (AES1, AES2, AES3 and AES4) for FNAL in the first production batch. All of the four cavities are processed and RF tested at Jefferson Lab [1]. According to the then ILC S0 protocol, each of these cavities were repeatedly processed and tested. The gradient results achieved in all tests of these four cavities are shown in Fig. 1. No cavity passed the ILC vertical test specification (35 MV/m at Q_0 8E9). In contrast, two 9-cell ILC cavities (manufactured by an experienced European vendor) processed in parallel with these cavities both passed the ILC vertical test specification.

All these four cavities passed 15 MV/m during the first processing and testing cycle. One cavity ultimately passed 30 MV/m after four cycles of processing and testing.

Some cavities (AES1 and AES3) were quench-limited at a gradient < 20 MV/m by the same cell without detectable X-rays. The limitation is insensitive to repeated EP, suggesting that the quench-causing defects are of permanent nature. Further investigation located the responsible defects with geometrical features [2][3].

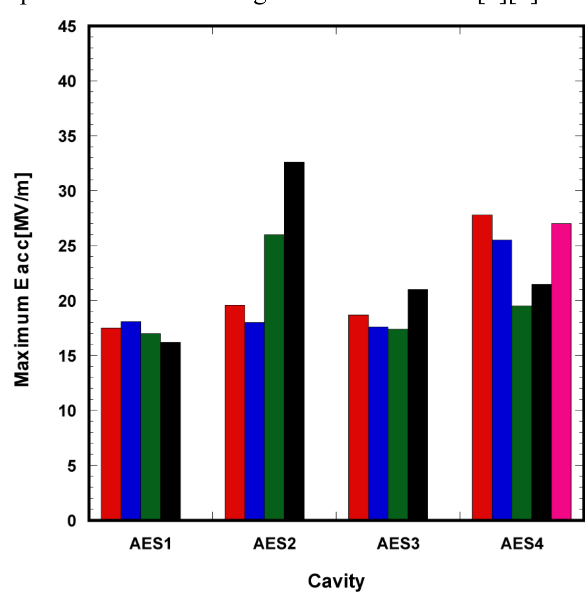


Figure 1: Gradient performance of 9-cell ILC cavities from the first AES production batch.

RESULTS OF SECOND PRODUCTION BATCH CAVITIES

Six 9-cell ILC cavities (AES5-10) were manufactured by AES for the second production batch. Processing and testing of these cavities started in February 2009 and ended in March 2010. During this period of time, a new ILC S0 protocol, “feedback loop”, replaced the old “tight loop” protocol. This change improved the understanding of different cavity failure mechanism and allowed effective information feedback from the laboratories to the vendors.

Summary of Performance of Second Production Batch Cavities

The gradient results of the second batch production cavities are shown in Fig. 2. Four out of the six cavities exceed 35 MV/m with the cavity AES8 reaching a maximum gradient of 41 MV/m. Three cavities exceed 35 MV/m during the first RF test following the ILC-style processing procedure.

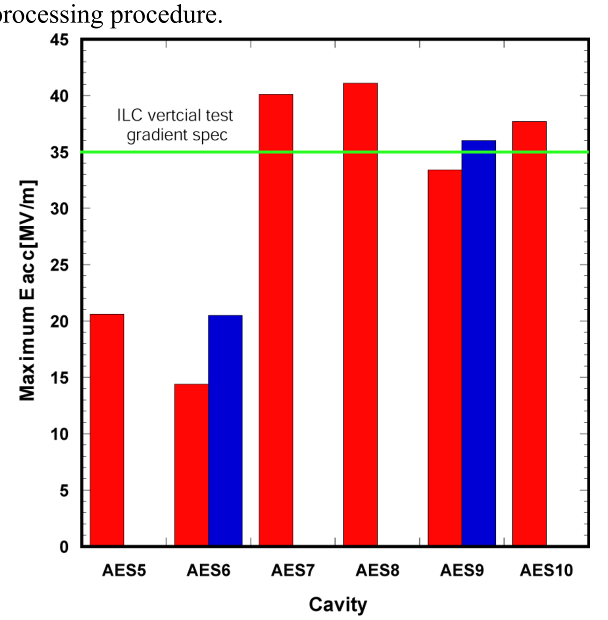


Figure 2: Gradient performance of 9-cell cavities from the second AES production batch.

As shown in Fig. 3, AES5 & AES6 were both quench limited by one defect in one cell [2] with other cells reaching a π-mode equivalent gradient of > 30-45 MV/m.

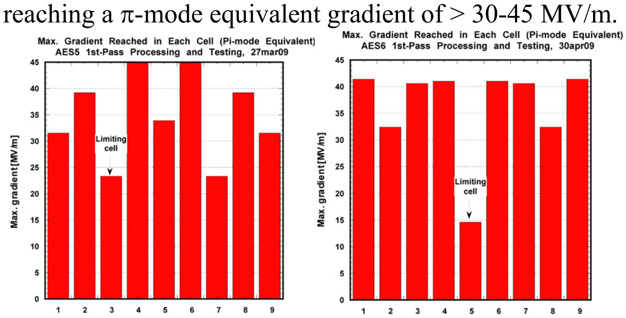


Figure 3: Gradient performance of each cell of cavity AES5 and AES6.

The Q(Eacc) curves of the second AES production batch cavities are shown in Fig. 4. As can be seen, the four cavities passing ILC gradient specification also pass the ILC vertical test Q_0 specification.

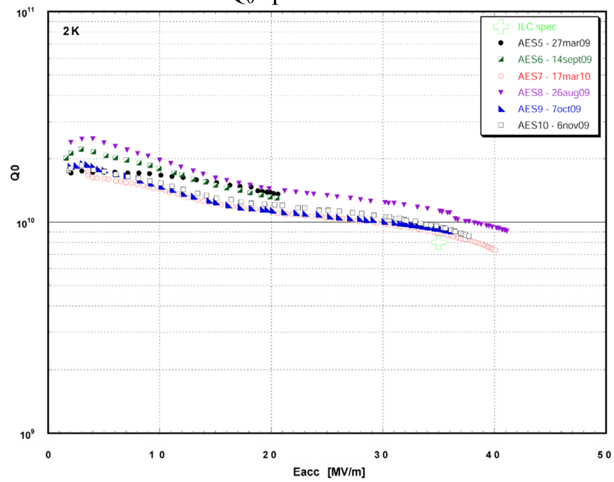
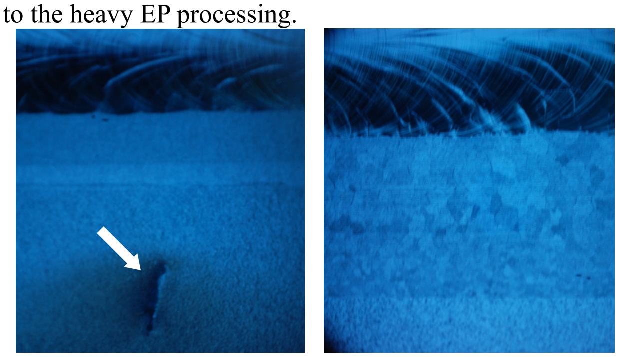


Figure 4: Q(Eacc) curves of 9-cell cavities from the second production batch by AES. 4 out of 6 exceed the ILC vertical test gradient and Q_0 specification.

Information Feedback between Lab and Vendor

Over the course of AES second production batch cavity processing and testing at JLab, a close information feedback was maintained between the lab and the company, allowing procedure changes both in processing steps in the lab and fabrication steps in the industry.

Through optical inspection of the inner surface of as-built cavities by using JLab’s high-resolution SRF cavity optical inspection machine [4], many weld splatters were observed near the electron beam weld of the equators (Fig. 5a). In the mean time, there was evidence to show that some quench-causing defects in earlier AES cavities might be related to the weld splatters. A joint JLab and AES study was started to find a solution for effective removal of weld splatter. A detailed JLab study of an AES welded double-dumb-bell ultimately resulted in the introduction of a light BCP etching (10 μm removal) prior to the heavy EP processing.

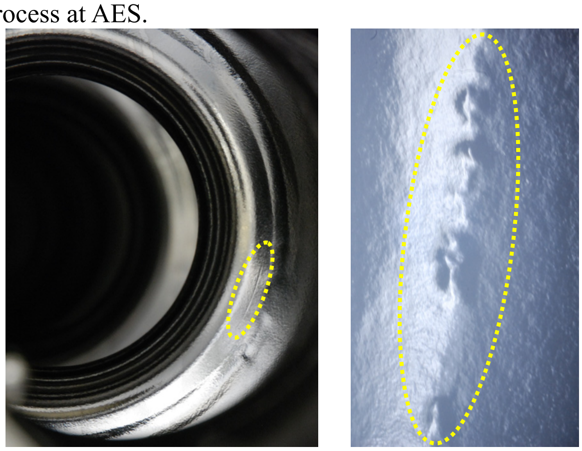


(a) (b)

Figure 5: (a) Weld splatter (arrow) observed on the inner cavity surface near the equator electron beam weld in an as-received cavity. (b) Clean surface with effective weld splatter removal by using a light BCP etching prior to the heavy EP processing.

Another change in processing is the temperature for vacuum furnace degassing. The original recipe of 600 °C for 10 hours was replaced by a new recipe of 800 °C for 2 hours. This change was originally made to mitigate the excessive stiffness of AES-built cavities. The new recipe has since then become standard at JLab for vacuum furnace degassing.

Close visual inspection of as-built cavities revealed arc segments of surface depression at a radius close to that of the stiffening ring (see Fig. 6a). This feature was still visible even after the heavy EP processing. But it was not of a concern until the discovery of surface damage in the depressed region after the surface was excited to a high field corresponding to a gradient of 30-40 MV/m, at which point a sudden field emission struck (see Fig. 6b). Since this depression feature was consistently observable on most cavities, it was traced back to a fixture used in the fabrication process. Ultimately, this feature was completely eliminated by improvement in fabrication process at AES.



(a) (b)

Figure 6: (a) Surface depression at a radius close to that of the stiffening ring (circled by ellipse). (b) Surface damage in the depressed region after the cavity was exited to a gradient of > 30 MV/m.

FURTHER EFFORTS TO ADDRESS REMAINING ISSUES

As shown previously, AES5 and AES6 were both quench-limited during the first test by only one defect in one cell, while most other cells already reaching a high field corresponding to a π-mode equivalent of 30-45 MV/m. These defects are sub-mm sized geometric imperfections (pits and bumps). The exact mechanism of formation of these defects is still not fully understood and is being actively studied. Our present understanding is that these defects are originated from the fabrication. As already shown in first batch production cavities, repeated EP has little or no effect in improving the performance of these genetically flawed cells. On the other hand, mechanical polishing has shown to be an effective means for removal of geometric defects. In fact, further effort at Cornell by tumbling cell #3 improved AES5 to a best gradient of 31 MV/m [5]. The latest joint FNAL/JLab effort on AES6 has improved its gradient performance to 36 MV/m by global mechanical polishing at FNAL and degassing, electropolishing and testing at JLab [6]. The best gradient performance of the second batch AES production cavities is summarized in Fig. 7.

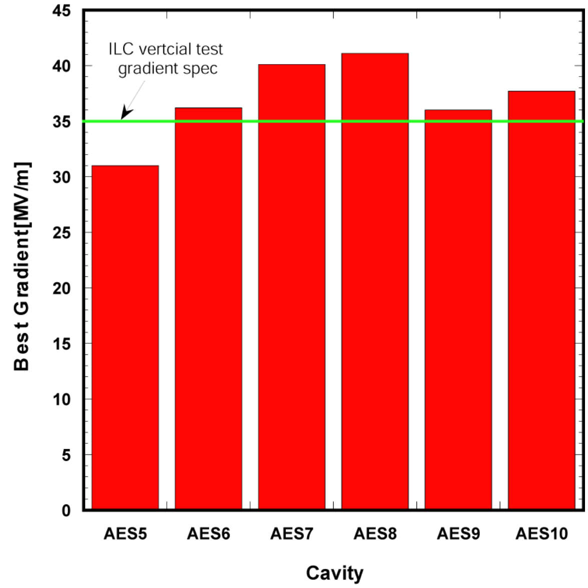


Figure 7: Best gradient performance of 9-cell cavities from the second AES production batch. AES5 and AES6 were improved by mechanical polishing for removal of known defects.

CONCLUSION

Four out of the six ILC 9-cell cavities from the second AES production batch reached a gradient in the range of 36-41 MV/m, passing the ILC vertical test specification of 35 MV/m with Q_0 > 8E9. Close feedback between the lab and the industry resulted in improved processing steps and fabrication steps. These test results validated AES to become the first “ILC certified” industrial vendor in the US for ILC cavity manufacture. Further effort is needed toward 90% gradient yield at 35 MV/m by eliminating genetic defects in particular cavity cells.

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