STUDY OF FLUX TRAPPING VARIABILITY BETWEEN BATCHES OF TOKYO DENKAI NIOBIUM USED FOR THE LCLS-II PROJECT AND SUBSEQUENT 9-CELL RF LOSS DISTRIBUTION BETWEEN THE BATCHES

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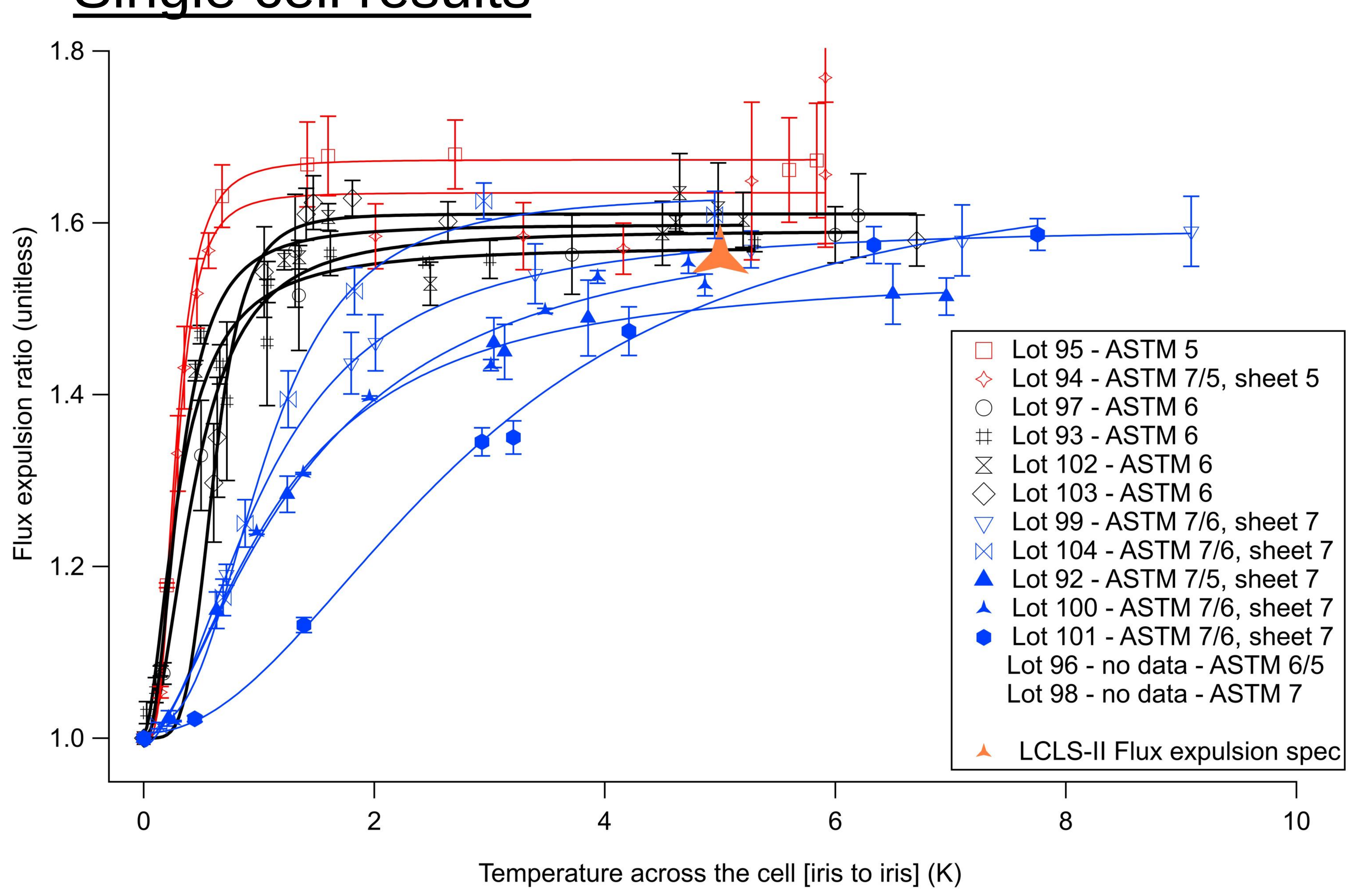
Abstract

During the LCLS-II project, a new batch of niobium was procured from Tokyo Denkai Co Ltd to make additional cavities. The original production material came from two vendors, Tokyo Denkai Co., Ltd. (TD) and Ningxia Orient Tantalum Industry Co., Ltd. (OTIC/NX)). It was found TD niobium required a lower annealing temperature (900°C) to obtain satisfactory flux expulsion characteristics compared to NX, which required a slightly higher annealing temperature (950°-975°C). To ensure the new TD material performed equivalent to the niobium produced three years ago after 900°C annealing; each heat lot of niobium had its flux expulsion characteristics parametrized using single cell cavities and custom thermal treatments developed for each lot. Subsequent pure heat lot 9-cell cavities were made and tested. We will look at the flux expulsion characteristics of each lot through single cell cryogenic cycling, and RF loss of the 9-cell cavities produced using the individual heat lots.

Flux expulsion results

Single cell results



- 11 single cell heat treated at 900°C and tested.
- Strong scaling with grain size observed.
- 9 cell cavities made from the niobium of the solid blued symbolled batch received heat treatment temperatures above 900°C.
    - Lot 101 did not change (not shown) after addition 925°C heat treatment – batch heated to 975°C.
    - Lot 100 – batch heated to 925°C.
    - Lot 92 see - 9 cell production data.

9 cell RF results

	Q0 @ 16MV/m 5mG field	Q0 @ 16MV/m 20mG field	change in RS (nΩ)	% field trapped
Lot 96	3.70E+10	2.75E+10	2.53E-09	17%
Lot 98	2.9E+10*	2.45E+10	NA	NA

* Stalled cool down created almost zero thermal gradient for the bottom third of the cavity - trapped all fields. Production pressure forced no retest. The 20mG RF was barley below Q0 specification so lot passed by proxy without trapped field %

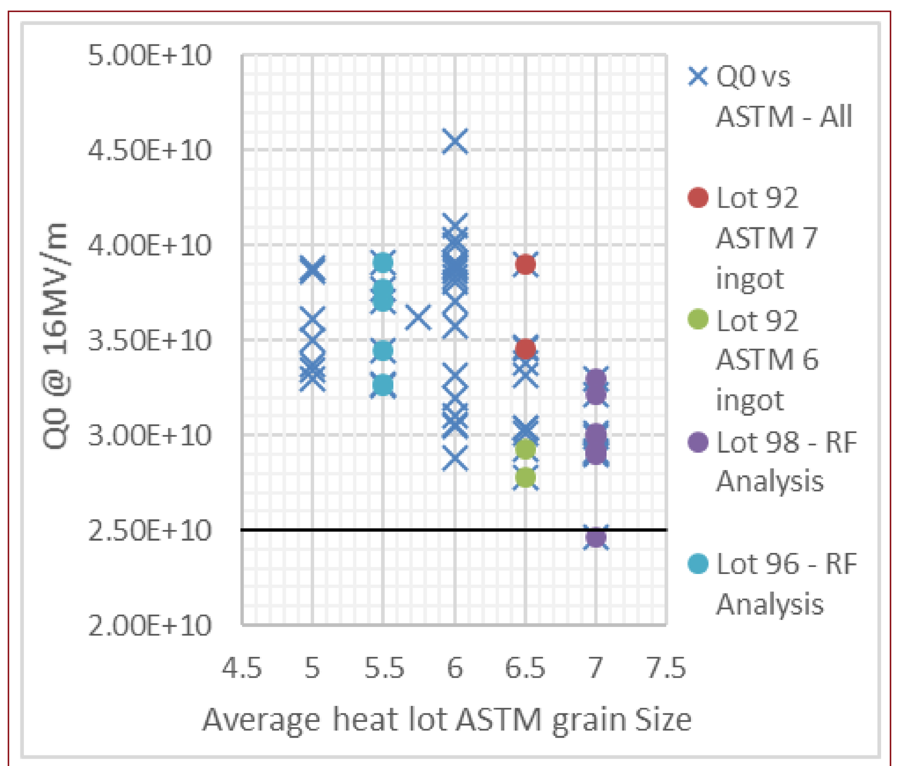
- 2 of the 13 lots required 9-cell undressed cavity qualification instead of single cell flux expulsion analysis.
- Cavity RF tested in a ~5mG field and ~20mG field.
- Trapped field % extrapolated using 1nΩ/mG RF loss - for LCLS-II 2/6 recipe.
- Lot 98 passed with 20mG field cool only – almost at spec of 2.5e10.

Niobium summary

heat lot	Heat run	ASTM sheet	ASTM lot average	Lowest ingot RRR	Highest ingot RRR	Flux expulsion ratio after 900°C @ 5K delta	Flux expulsion % after 900°C @ 5K delta	9 cell heat treatment
92	HT9-773	7	6	379	398	1.5	75	950/900°C
93	HT9-982	7	6.5	433	515	1.57	85	900°C
94	HT9-1002	7	6	356	395	1.6	90	900°C
95	HT9-1012	5	5	349	347	1.67	100	900°C
96	HT9-1013	NA	5.5	322	368	NA	NA	900°C
97	HT9-1025	6	6	344	367	1.57	85	900°C
98	HT9-1046	NA	7	402	415	NA	NA	900°C
99	HT9-1052	7	6.5	409	415	1.57	85	900°C
100	HT9-1065	7	6.5	395	399	1.55	82	925°C
101	HT9-1074	7	6.5	373	446	1.5	75	975°C
102	HT9-1081	6	6	339	340	1.595	89	900°C
103	HT9-1093	6	6	336	364	1.61	91	900°C
104	HT9-1101	7	6.5	410	433	1.62	93	900°C

9-cell production cavity analysis

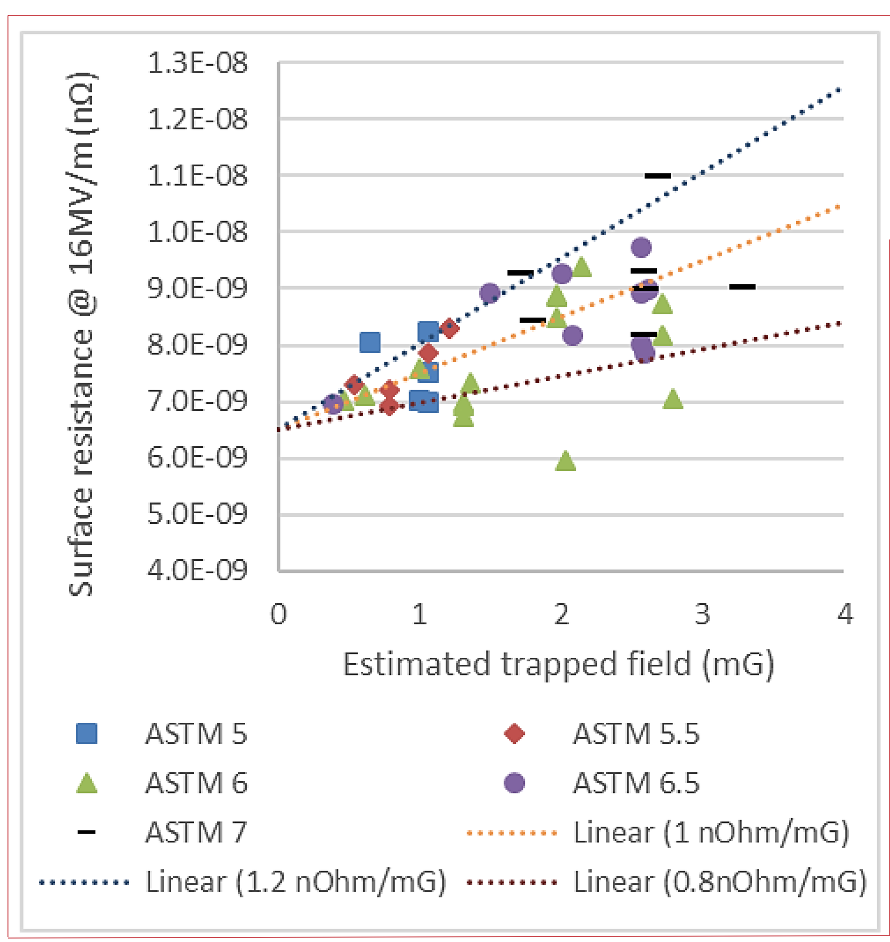
Grain size effects



Q0 @ 16MV/m vs Average heat lot ASTM grain size. The light blue "x" is all data available, with other subsets of data overlapped in closed circles.

- Clear scaling of ASTM grain size and Q0 after a 900°C heat treatment.
- Optimal performance for ASTM 6.5/7 should be heat treated above 900°C.
- Lot 98 in hindsight should have been heat-treated at 950°C to guarantee 100% pass rate – single cell flux expulsion is a superior to RF loss analysis.
- Lot 92's ASTM 6 ingot cavities should have been heat-treated at 950°C like the ASTM 7 cavities to maximize performance.
    - Stronger correlation between heat lots than ingot lot - processing is the larger driver of flux expulsion performance.

Trapped magnetic field effects



Surface resistance @ 16MV/m vs. estimated trapped field by grain size. The three linear curves are the trapped magnetic field losses for 2N6 doping (centroid and error).

- 43 of the 50 9-cells tested as of June 1, 2019 had axial magnetic field monitoring during cooldown.
- Estimated trapped field scaled with known magnetic field and flux expulsion ratio of the niobium (% trapped field).
- The surface resistance scales with trapped flux, and not grain size, as expected.

Summary

The use of single-cell cavities to analysis the flux trapping properties of a heat lot of high RRR niobium is an excellent way to extrapolate the added RF losses on High Q0 9-cell cavities. Careful analysis of the test setup for the 9-cell RF results yield the expected trapped flux losses for most of the cavities. This technique can be used for all application where flux expulsion analysis is required. Other techniques are under development to replace single cell analysis as the cost to manufacture and test in this way is quite significant.

Acknowledgements

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