nel

R2R QC Discussion

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05/06/2021

Background

- R2R MEA fabrication is an area that we continue to explore for fit with current manufacturing volumes and scale
- Currently manufacture MEAs in-house using batch process
  - Process of inspection is a blend of instrumentation and visual review of single parts
  - R2R will not only eliminate tedious process with potential for operator error
  - Also removes some of the subjective nature from inspector to inspector
- Understanding of MEA defects associated with the R2R process is evolving
  - Using current manufacturing screening criteria for in-house process has informed R2R development

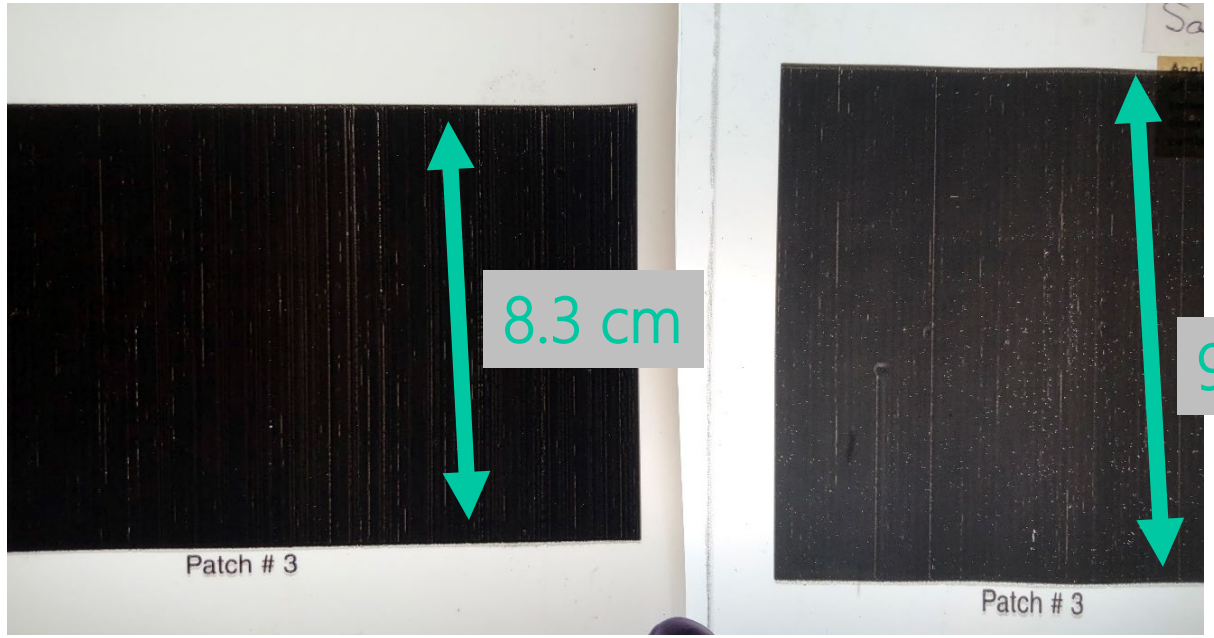
Measuring Dimensional Change

Depositions onto Teflon Substrate

- Printed directly onto material first for transfer process conducted later
- All patches had some streaks / missing pixels, but retained target dimension

Direct Membrane Deposition

- The inks were the same, but as deposited dimensions were changing
- Some patches elongated by ~20% when compared to Teflon coating
- Measuring deposition dimenesions seen as critical to keep electrodes in active area



Measuring for Non-Uniform Coatings

- Trials have shown some differences in quality occurring at various points in run
- QC capability to identify locations where process drifts would reduce scrap
  - Allows for rework of parts that don't meet loading targets
  - Significantly cheaper pathway to rework than to throw away

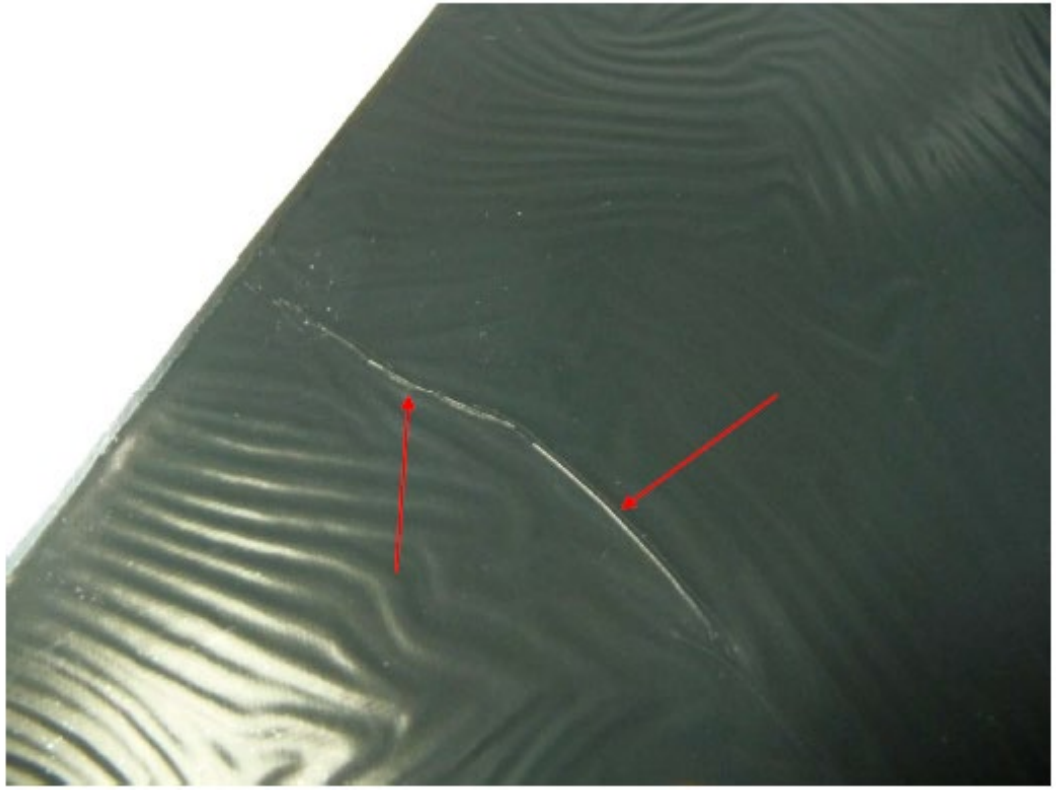
Single Pass Double Pass

- Applying a criteria of minimum percentage coverage allowable would flag incomplete part processing

Active Area Imperfections

Defect: Imprint within active area
Description of defect: Palpable deformation
Size limit of defect: None allowed
Inspection tool: Current inspection by naked eye and if necessary, with a magnifying glass

Defect: Wrinkle on CCM
Description of defect: Locally thicker CCM
Size limit of defect: No limits
Inspection tool: Current inspection by naked eye and if necessary, with a magnifying glass

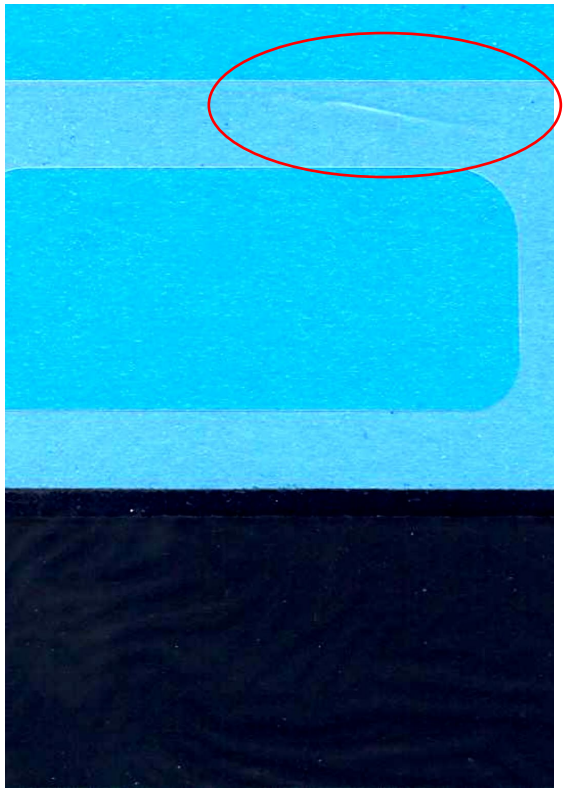


Measurement of Voids – Size and Occurrence

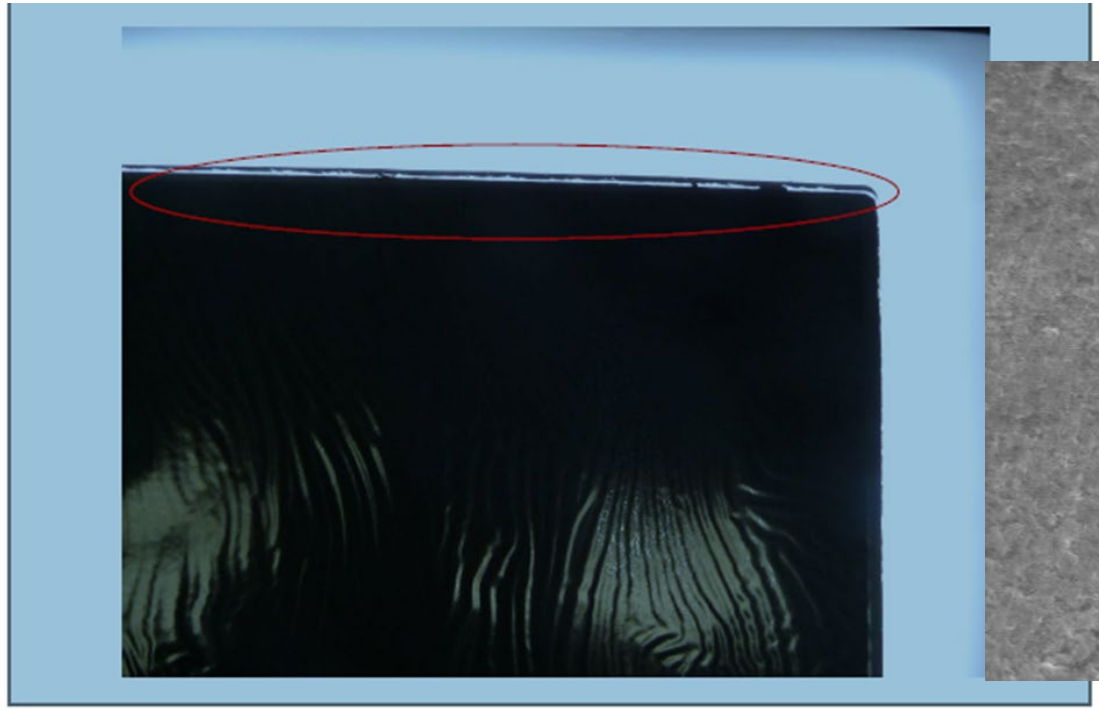
Defect: Uncoated spots in catalyst layer
Description of defect: Catalyst layer not completely transferred to membrane
Size-limit of defect: TBD
Appraisement: Unacceptable at high frequency
Inspection tool: Current inspection by optical inspector, single part process. Visual inspection also used by operators

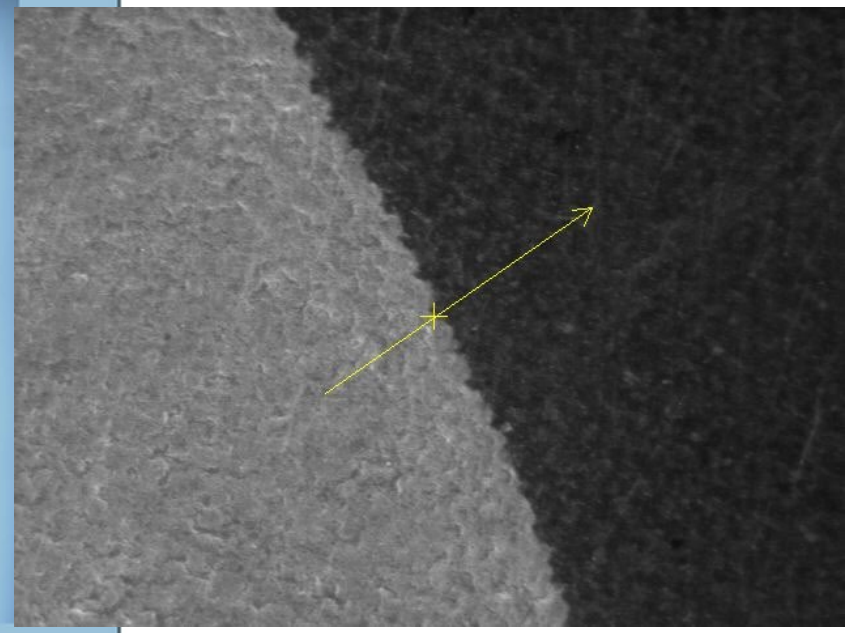
Seal Area Defects

Defect: Deformation in sealing area
Description of defect: Continuous elevation on one side
Size limit of defect: No minimum allowable
Inspection tool: Visual inspection and if necessary, with a magnifying glass



Defect: Misalignment of anode and cathode catalyst layer
Description of defect: Uncover active area/Catalyst into the seal area
Size limit of defect: TBD
Inspection tool: Visual inspection, supported by single part optical inspection





Summary

- Many of the defects encountered in early fabrication batch process techniques still apply in R2R
- Beyond loading, voids, and high spots in catalyst coated area, all areas of MEA must be considered to consolidate inspection
  - As long as some portion of manual or single part inspection exists, full cost reductions will be difficult to realize.
- Allowable limits for certain defects in R2R produced parts still being assessed internally
  - Establishing max/min for rejection criteria of parts will help to reduce scrap rates.
- Nel continues to build a catalogue of failure conditions observed in processing so specifications can be set for acceptance or rejection.
  - As these are identified, new automated inspection methods are being reviewed for high volume manufacture implementation.

number one by nature