Welcome

to today's episode:

From Malfunction to Solution

Advanced Failure Analysis for Materials & Electronics

Audrey Chamoire, PhD
Director of Failure Analysis
Covalent Metrology

Cole Rademacher
Failure Analysis Engineer
Covalent Metrology

AUG 21, 2025
11 AM Pacific Time

COVALENT ACADEMY
Industrial Applications of Advanced Metrology
Episode 44

COVALENT METROLOGY

Covalent's Failure Analysis Lab, Capabilities, and Network

COVALENT METROLOGY

Failure Analysis Experts

Pralav Shetty, Ph.D., P.E.
Vice President and General Manager

Technical Background: Mechanical Engineering, Materials Science

Experience: OLED/LED Displays, Housing, Inks, Batteries, Battery Management Systems, PCBs, ICs, Adhesives

Audrey Chamoire, Ph.D.
Director

Technical Background: Materials Science and Engineering

Experience: Batteries, LEDs, PCBs, Components, ICs, Thermal and Electrical analysis, RCA

Cole Rademacher
FA Engineer

Technical Background: Metallurgy, Fractography

Experience: RCA,, biomedical, aerospace and infrastructure

\+ **Specialized Experts**

Specialized Experts support projects in additional application areas, including:
- Semiconductors and electronics
- Polymers, plastics, and adhesives
- Metallurgy and corrosion

\+ **FA Support Team**

Our broader FA Team members collect the best data possible using Covalent's full suite of modern characterization tools.

\+ **Digital Platform**

Our data science department provides automation, advanced statistical analysis, and data modeling to extract the most insight from data.

A World-Class Analytical Lab
Designed for High-Volume Work

Metrology and Applications Experts
- 80+ Employees, >25% are PhDs

Cutting-edge Analytical Capabilities:
- 70+ state-of-art instruments staffed by experts in their metrology domain who guarantee quality data
- 100+ characterization techniques

Silicon Valley Lab located in Sunnyvale, CA
- High-volume lab delivers with speed and competitive pricing

Expert Failure Analysis Team

COVALENT METROLOGY

Julie Zhao, Ph.D
Manager

Tonu Sepp
Quality Lead

Jaemin Choi
Sr. Engineer

Cole Rademacher
Engineer

Jessica Batterman
Engineer

William Dailey
Analyst

Lincoln Grench
Analyst

Daene Ibalio
Analyst

Westley Bolosan
Analyst

Electronics and Semiconductors

- Consumer Electronics (phones, laptops, wearables, etc.)
- Batteries and Energy Storage (Li-ion, solid-state, fuel cells)
- Printed Circuit Boards (PCBs) and Interconnects
- Semiconductor Devices (ICs, microchips, transistors)
- Sensors and MEMS Devices

Metals and Metallurgy

- Structural Metals and Alloys
- Welding and Joining Failures
- Corrosion and Oxidation Mechanisms
- Heat Treatment and Metallurgical Defects

Polymers and Composites

- Polymers, Plastics, and Elastomers
- Adhesives and Sealants
- Fiber-Reinforced Composites

Industries and Applications

- Automotive and Transportation
- Medical Devices and Healthcare Equipment
- Chemical Processing and Industrial Equipment
- Renewable Energy (solar, wind, hydrogen, storage systems)

Our Approach to Failure Analysis

COVALENT METROLOGY

Our team will **tailor its approach and partner with you** to complete the product failure investigation.

" I just need data. "

Level 1

- **Access metrology support:** over 70+ state-of-art instruments with guaranteed quality data
- **Speed & competitive pricing** facilitated by Covalent's high-volume lab setup
- **Fast turnaround time** for raw data so you can implement solutions faster

" I need to understand what happened. "

Level 2

- **Analytical report** prepared by metrology experts
- **We design the method for you** Our materials and applications experts develop and manage testing workflows to achieve your goals
- **Efficient and Cost-effective** measurements, analysis, and insight

" Help me resolve my issue. "

Level 3

- **Full root cause analysis**
- **We work to understand your process** to contextualize our experts' investigation
- **Partner in problem solving** with our world-class analysis lab
- **Consult with experts** in material testing and relevant industrial applications

Beyond Diagnostics

COVALENT METROLOGY

Covalent FA team aims to give you more than great data.

Our goal is to **help you solve problems** by providing **actionable recommendations.**

Unexplained Failure

- Failure in the field
- Broken parts / abuse testing
- Process failing
- Low yield
- Quality issues
- Material property deterioration or material property determination
- Field-returned units / products

Diagnostic: Failure Analysis

- Define the problem
- Understand your process
- Hypothesize potential failure mechanisms
- Collect data and perform additional analysis as needed

Solution : Root Cause Analysis & Correction

- Comprehensively analyze all the information gathered
- Report findings and validate the hypotheses
- Recommend corrective actions
- Support implementation efforts
- Evaluate the consequences of the change
- Inform future product development

Our FA Approach: from Symptom to Solution

COVALENT METROLOGY

Diagnostic:
Failure Analysis

- Define the problem
- Understand your process
- Hypothesize potential failure mechanisms
- Collect data and perform additional analysis as needed

- Define the problem and understand the context though client discussion:
  - Background review: service conditions, design specs, and history of the issue
  - Understand your process, capture failure timeline and symptoms
  - Define and validate scope, urgency, and success criteria
- Hypothesize potential failure mechanisms and present an action plan
- Gather evidence
  - Collect failed parts, reference samples, and related documentation
  - Ensure proper chain of custody for sensitive or legal cases
  - Document condition through photos, measurements, and baseline tests
- Collect data and perform additional analysis as needed
  - Apply the most suitable analytical tools (SEM, EDS, FTIR, X-ray, etc.)
  - Simulate operating conditions if needed
  - Compare with baseline or reference materials

Our FA Approach: from Symptom to Solution

COVALENT METROLOGY

Solution :
Root Cause Analysis & Correction

- Comprehensively analyze all the information gathered
- Report findings and validate the hypotheses
- Recommend corrective actions
- Support implementation efforts
- Evaluate the consequences of the change
- Inform future product development

- Comprehensively analyze all the information gathered
  - Correlate lab data with real-world usage and known failure mechanisms
  - Identify root cause and contributing factors
  - Validate through repeat testing or cross-method confirmation
- Report findings and validate the hypotheses
- Recommend Solutions/ Corrective actions
  - Provide clear, actionable recommendations (design, material, or process changes)
  - Prioritize by cost-effectiveness and implementation feasibility
  - Support long-term prevention strategies and monitoring plans

Common Failure Analysis Projects

COVALENT METROLOGY

Project	Scope of work
Battery	Nondestructive evaluation of cells and destructive chemical analysis of cell components
PCB	Contamination, dielectric, copper traces, conformal coat
IC component	Electrical testing, solder joint inspection, decapsulation, wire bond inspection, IR thermography, delayering
Fractography	Fractographic inspection, origin analysis, stress at failure
Degradation/Aging	Microstructural evaluation, crystallography, chemical evaluation, mechanical properties
Insulation / TIM	Determination of specific heat, thermal diffusivity, and thermal conductivity
Thermal degradation	Decomposition kinetics, phase transformation temperatures
Bulk/trace composition analysis	Offer a full suite of semi-quantitative and quantitative composition analysis specific to material type and feature size

We are constantly growing our **in-house FA capabilities** and **expertise**.

Case Study: PCB Failure

PCB Failure Case Study

Problem

Client reported intermittent signal loss on high-speed PCB.

Potential connectivity issues have been isolated by client and narrowed down to specific traces/components

Common Failure Modes

Via and Interconnect Failures
Cracked microvias or through-holes, Poor via fill or barrel plating

Trace & Conductor Issues
Hairline cracks in copper, Delamination between copper and substrate, Electromigration/creep corrosion.

Connector & Component Solder Joints
Intermittent contact in press-fit or socketed connectors
Solder fatigue, Cold solder ,Head-in-pillow,

Environmental/Stress Factors
Thermal cycling, Vibration/shock

PCB Failure Case Study

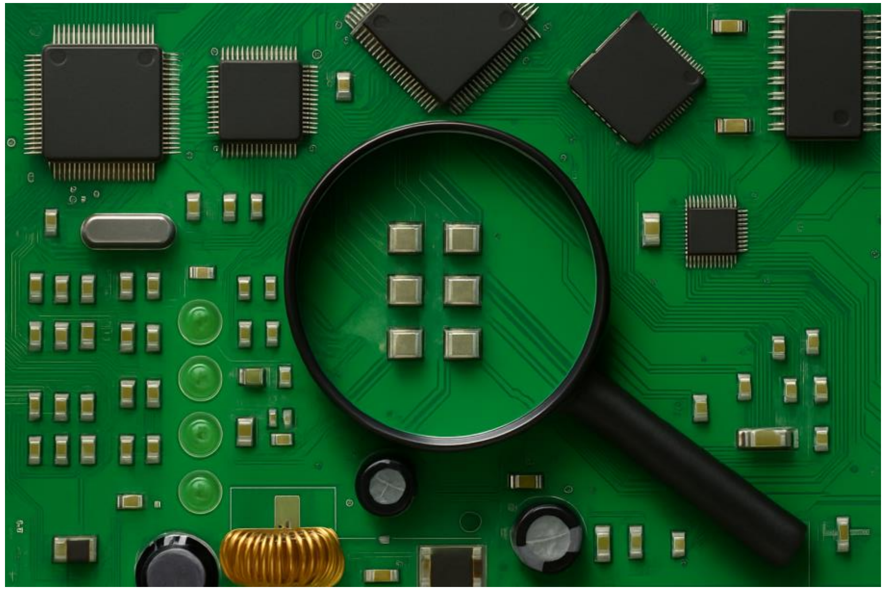
COVALENT METROLOGY

FA Process / Investigation

- **Visual inspection:**
- Inspect the assembly as received, confirm it meets the IPC standard – pay special attention to the components and traces of interest

- **Non-Destructive Testing - Symptom Capture**
- X-ray imaging: traces, component, solder, vias etc…
- Electrical test using a 4-wires method at room temperature and at specified temperature
- Perform measurement after several thermal cycling

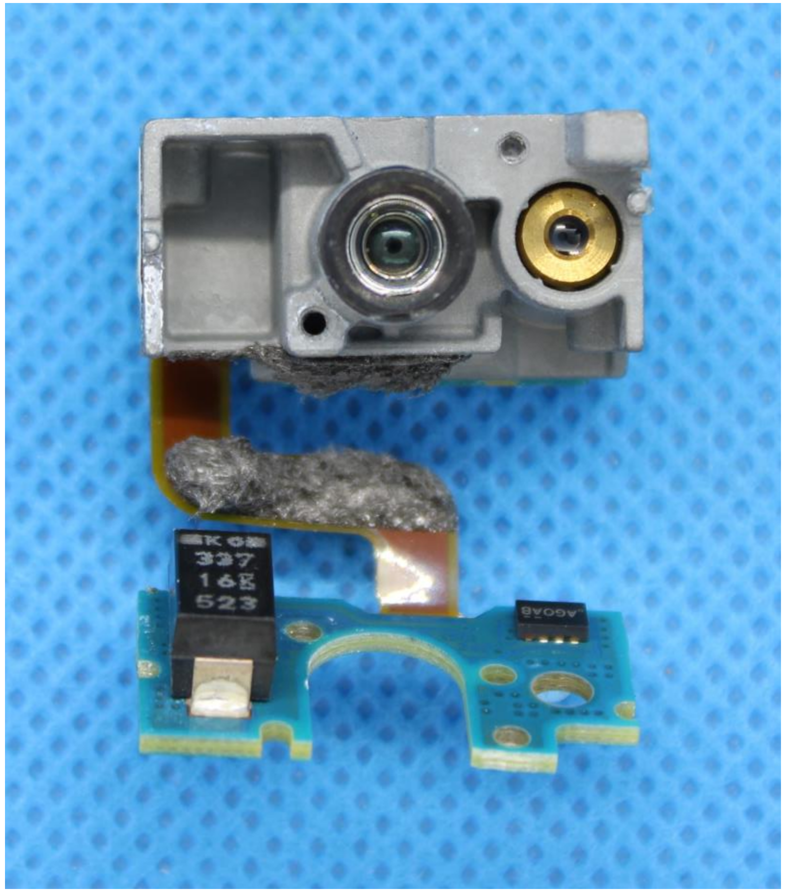
- **Destructive Analysis**
- Once defect isolated, perform cross-section of suspect area followed by SEM/EDS to potentially visualize small cracks and potential chemical changes or oxidation

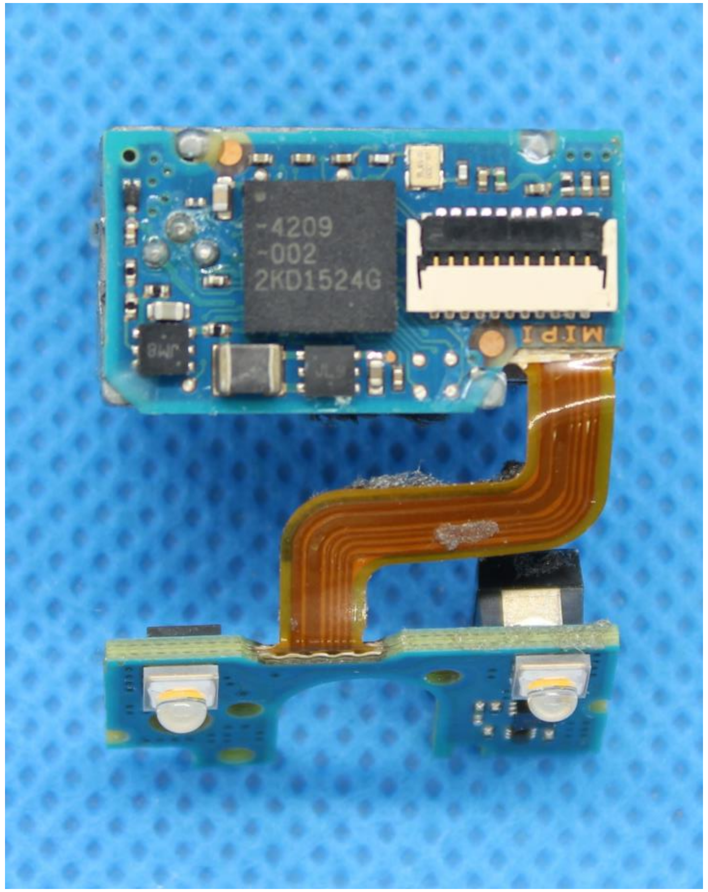


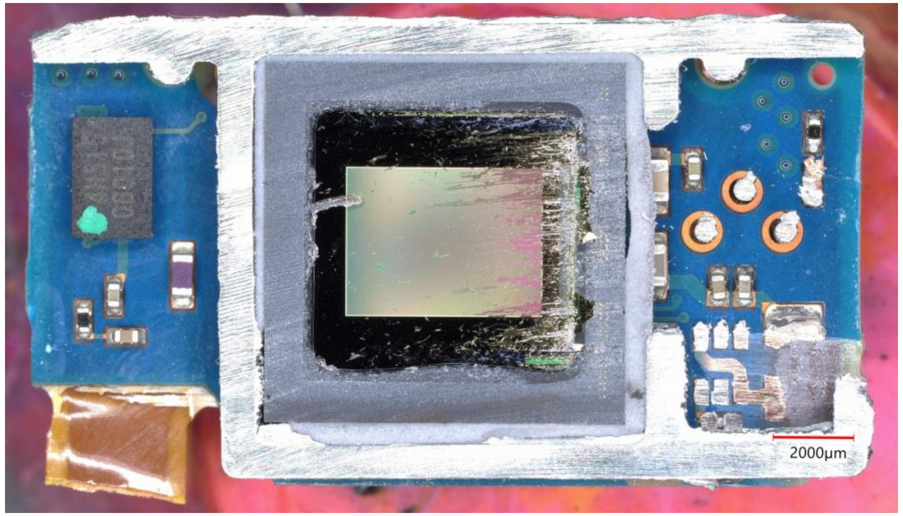
Collaborate with the client throughout the process to validate findings, isolate the root cause, and support issue resolution

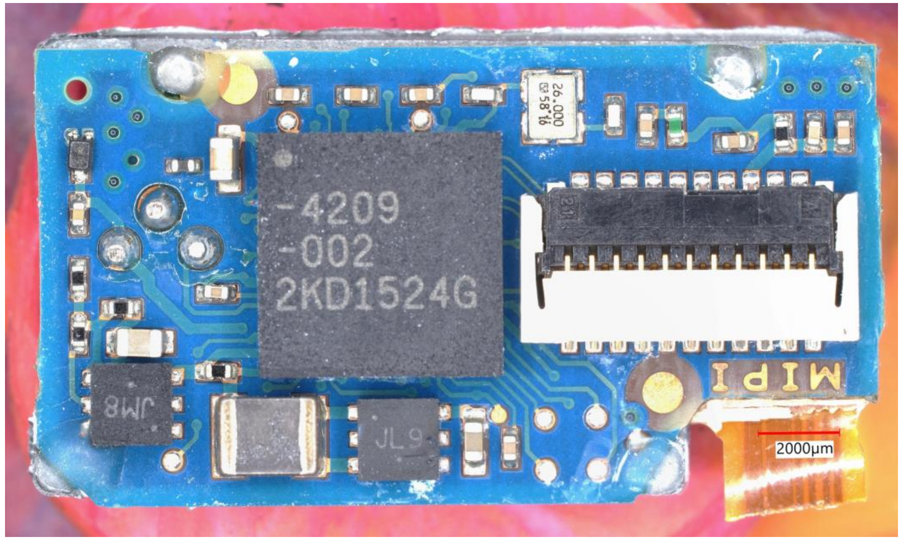
Overall Inspection: No Defect/Damages Visible

COVALENT METROLOGY

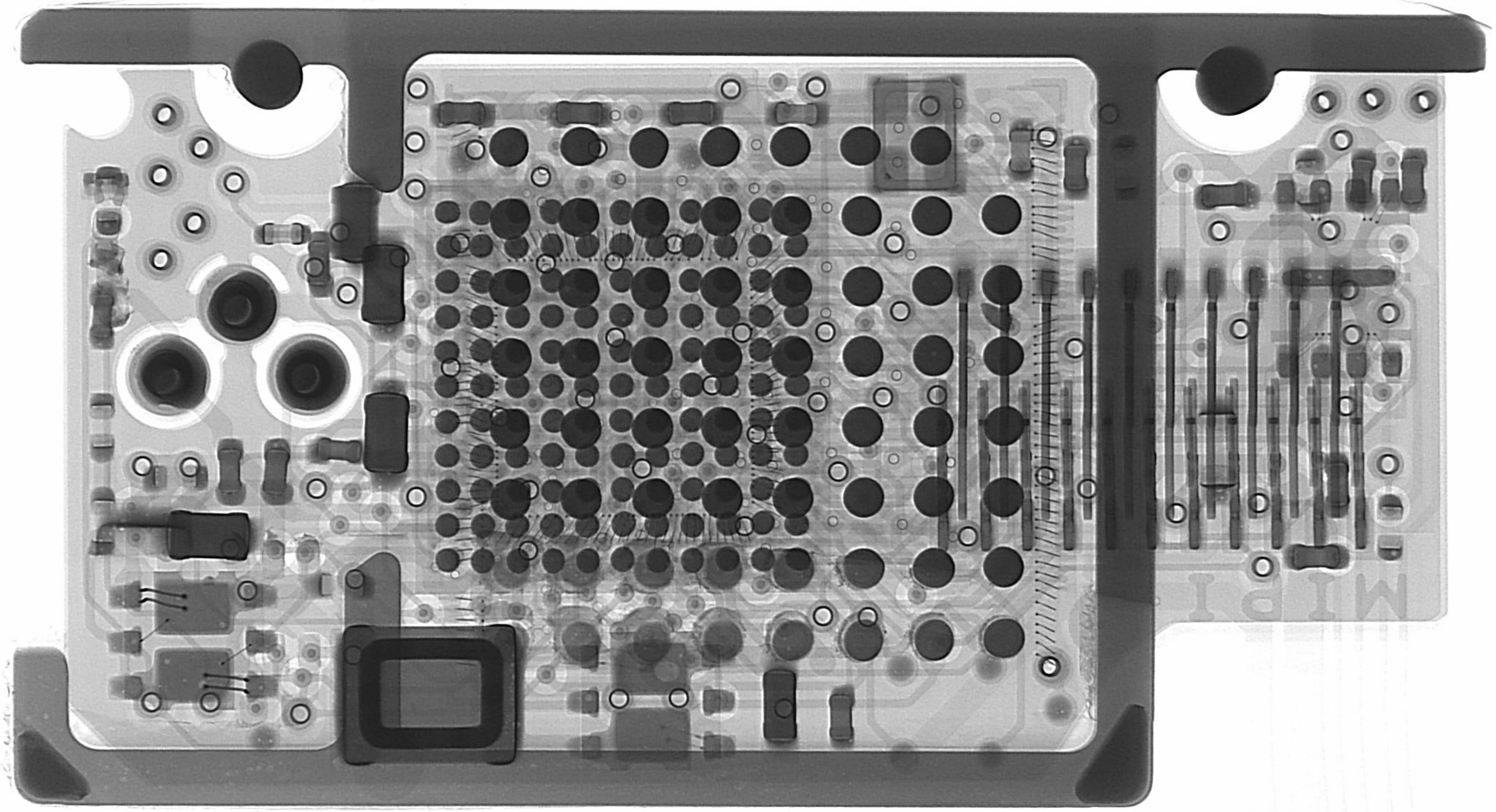








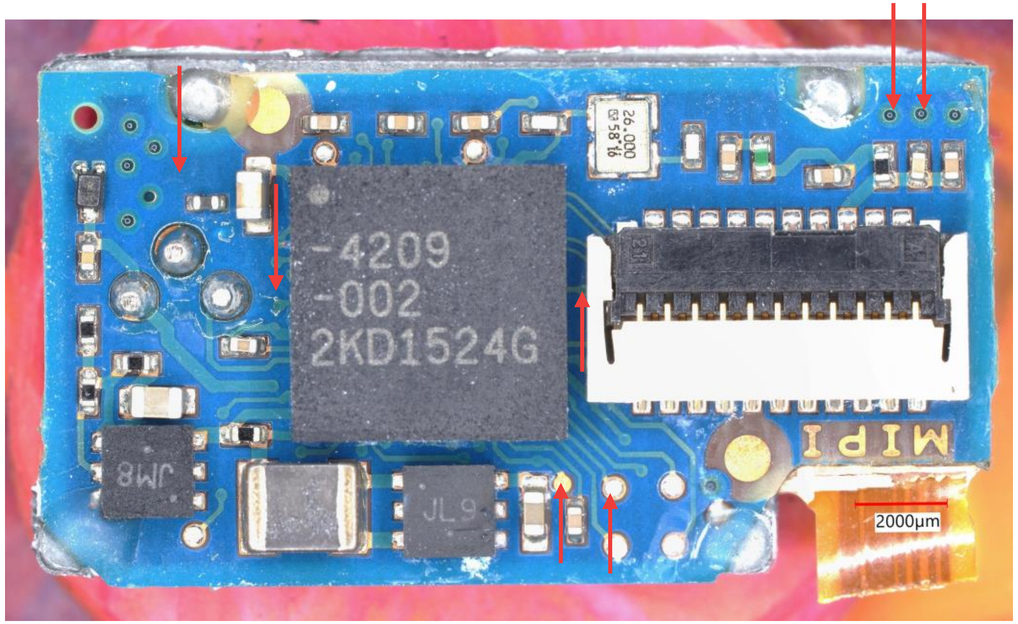
X-Ray Inspection: No defect/Damages Visible



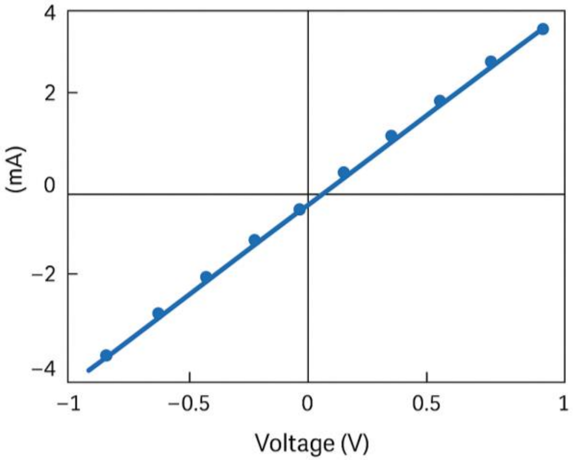
No misalignment, voids, cracks, clear open or incomplete vias, foreign particles or defects

Electrical Testing: Open at Elevated Temperature

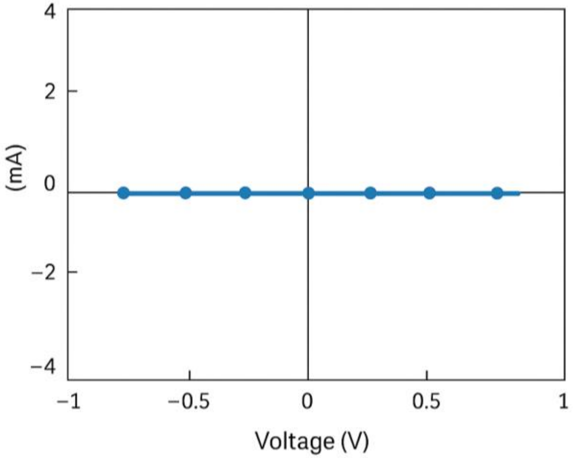
PCB electrical testing at suspect locations



Ohmic contact at room temperature



Open at elevated temperature

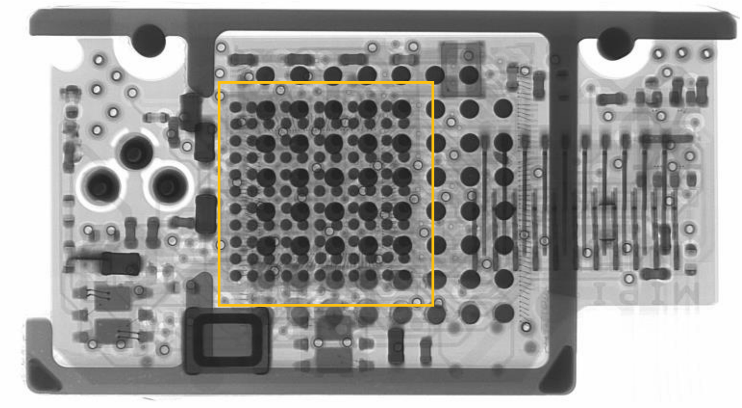


Working Hypothesis:

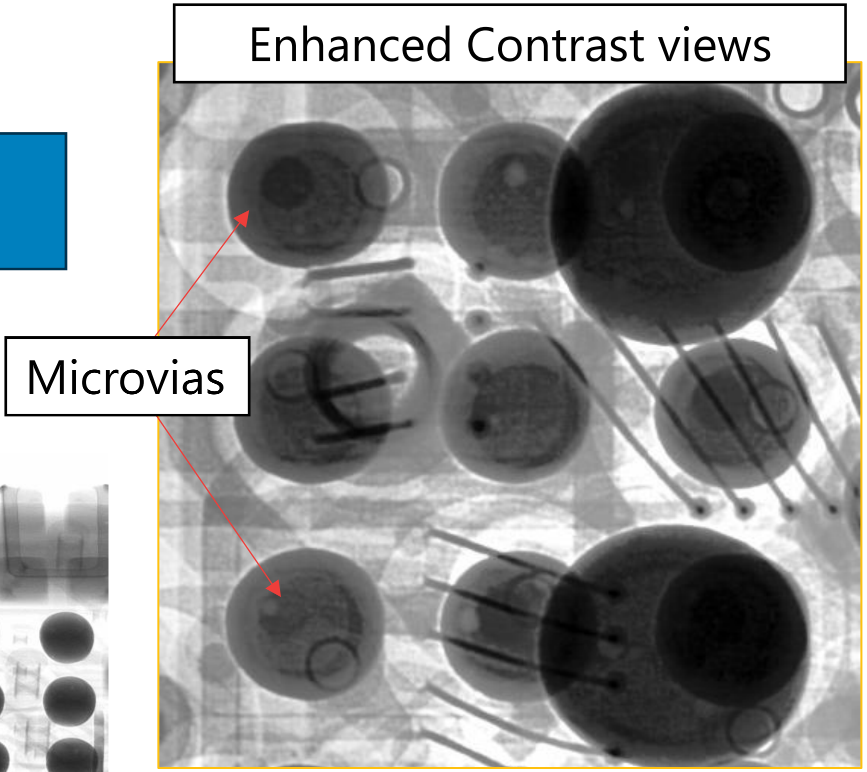
Possible cracks in a BGA/Trace/microvia along the suspect trace

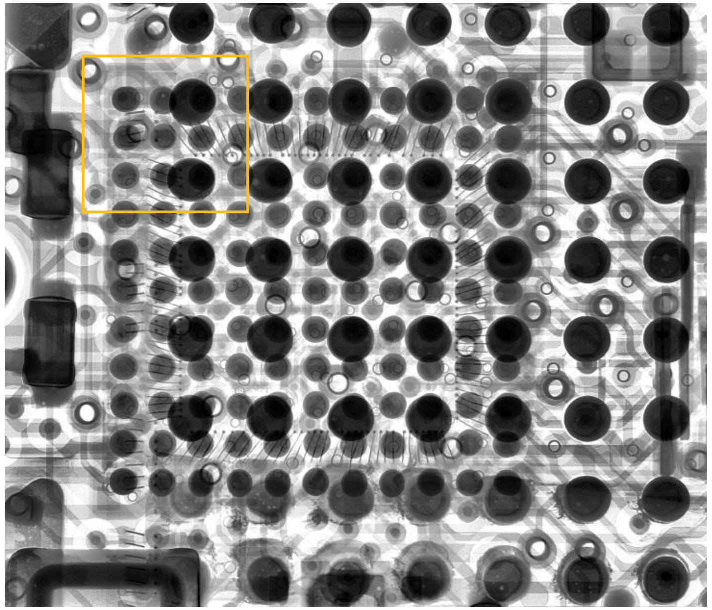
X-Ray Inspection: Potential Defective Microvias Located

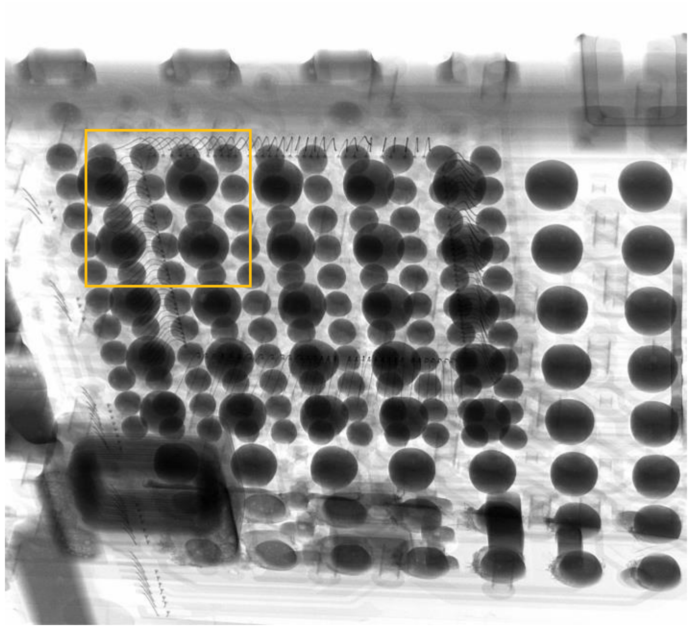
COVALENT METROLOGY



Locating potential defective microvias

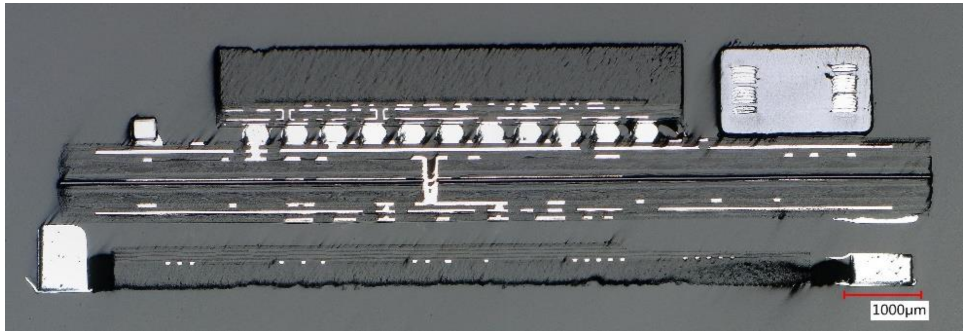


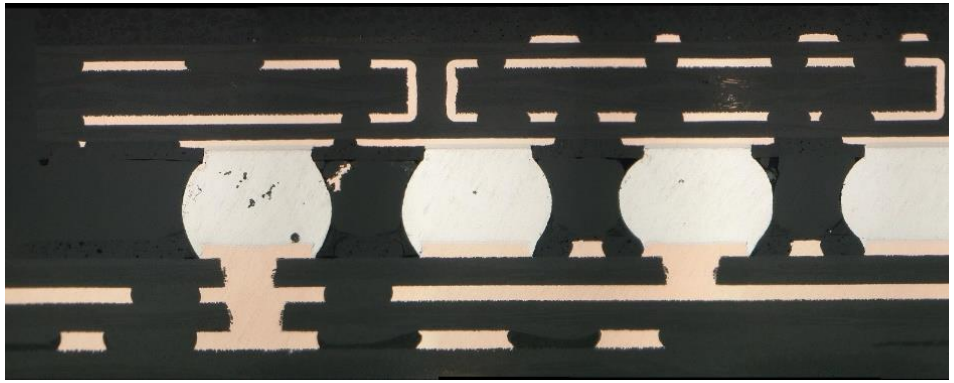


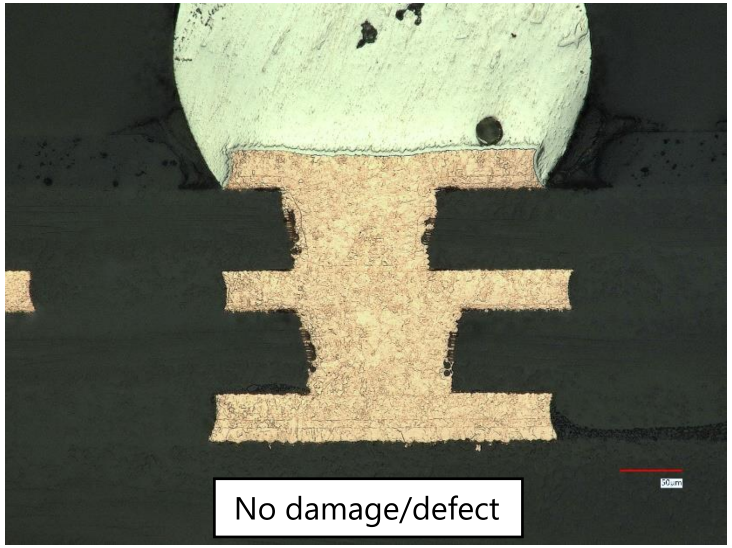


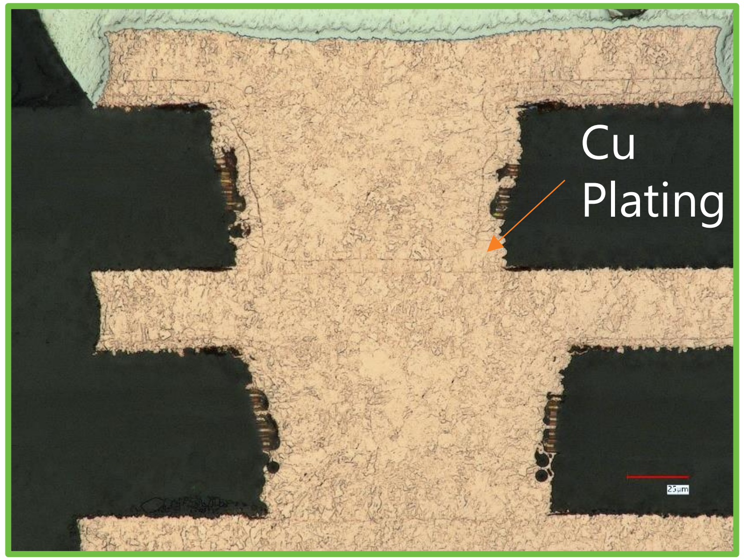
2D X-Ray can be effective for detecting some microvia defects, but its limitations in depth resolution may necessitate complementary techniques, such as 3D X-Ray (CT) or cross-sectional analysis, for detailed characterization.

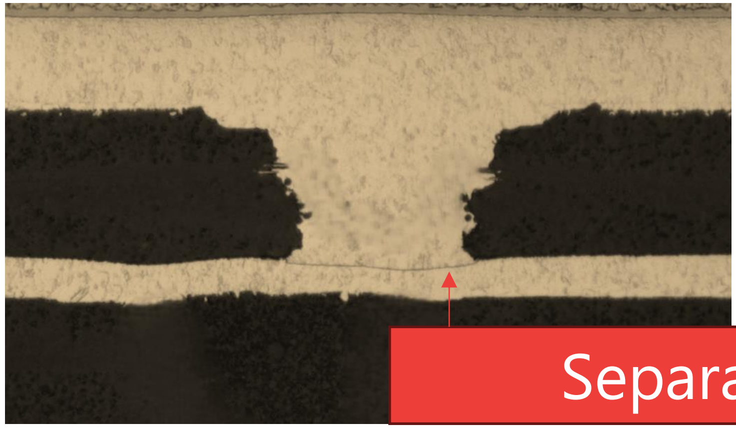
Optical Microscopy, Mechanical Cross-Sections and Etching

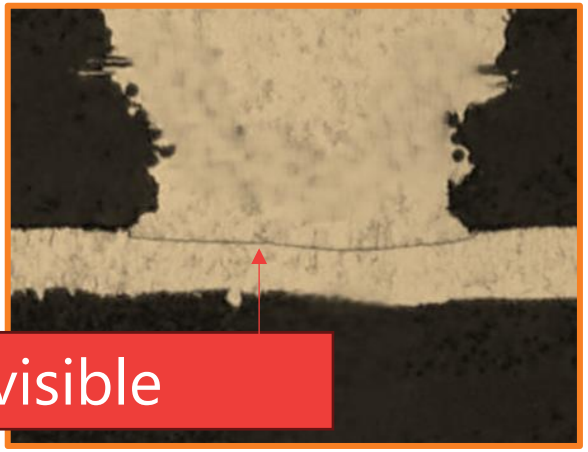




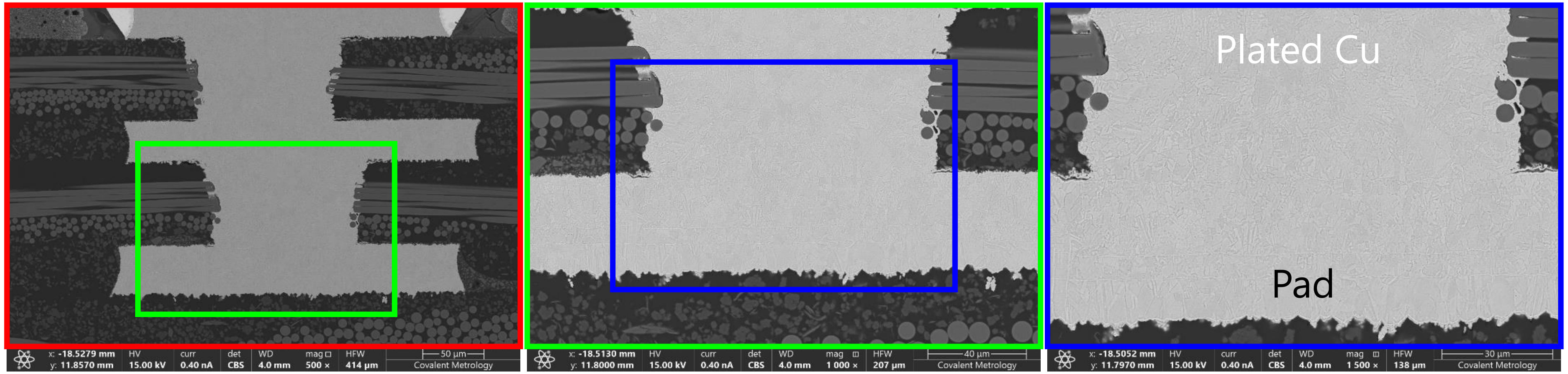


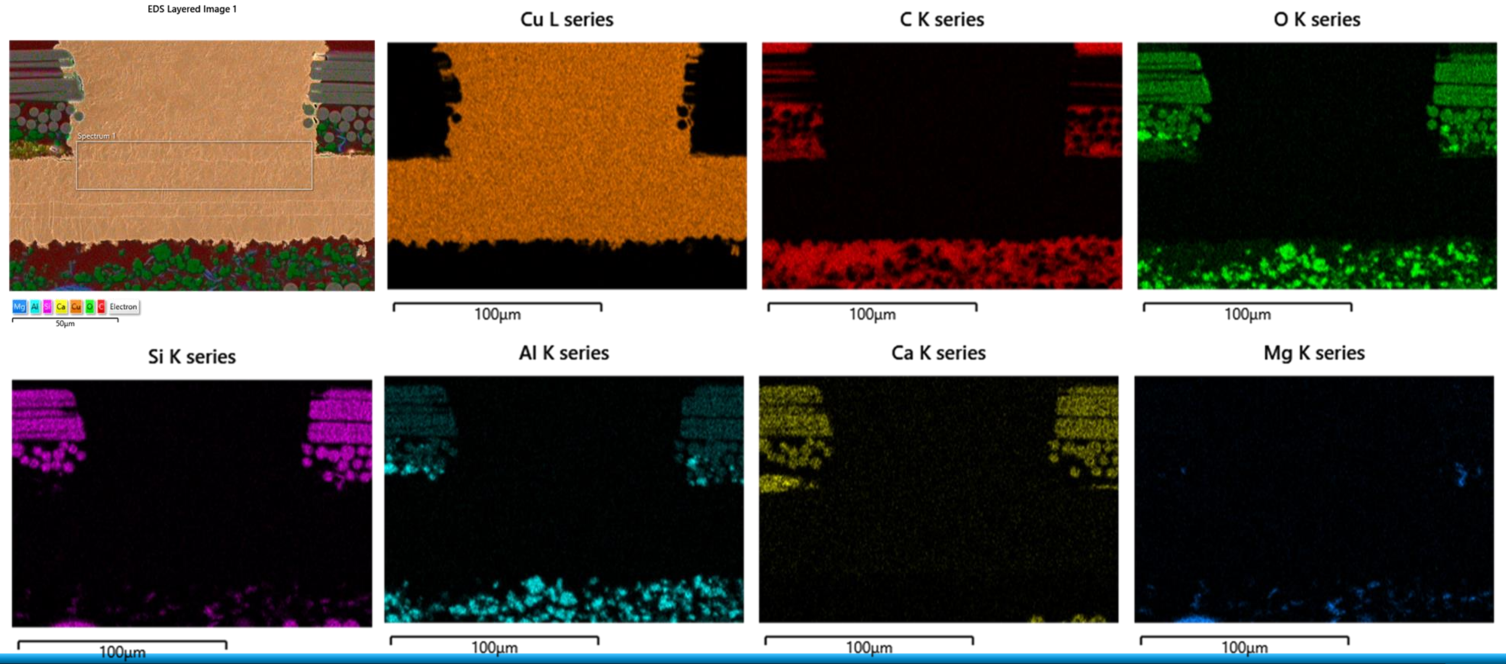






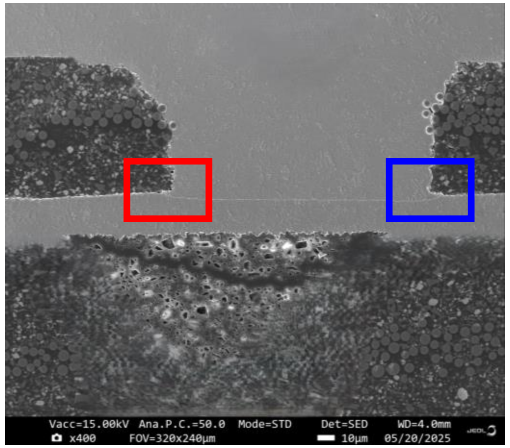
SEM/EDS Good Via

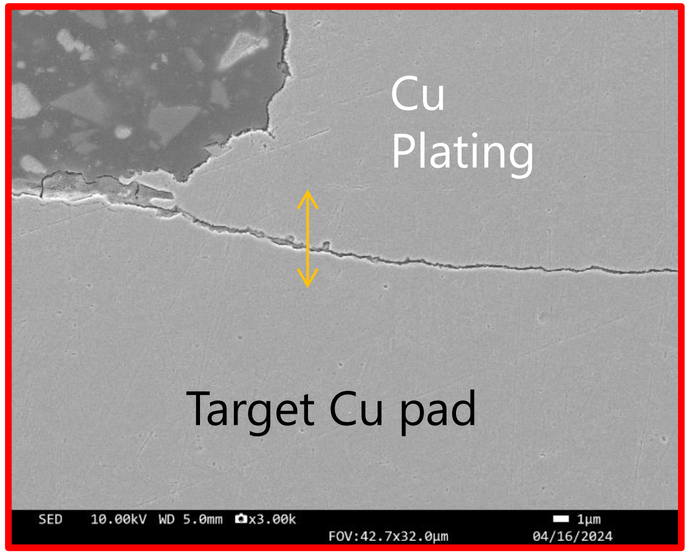


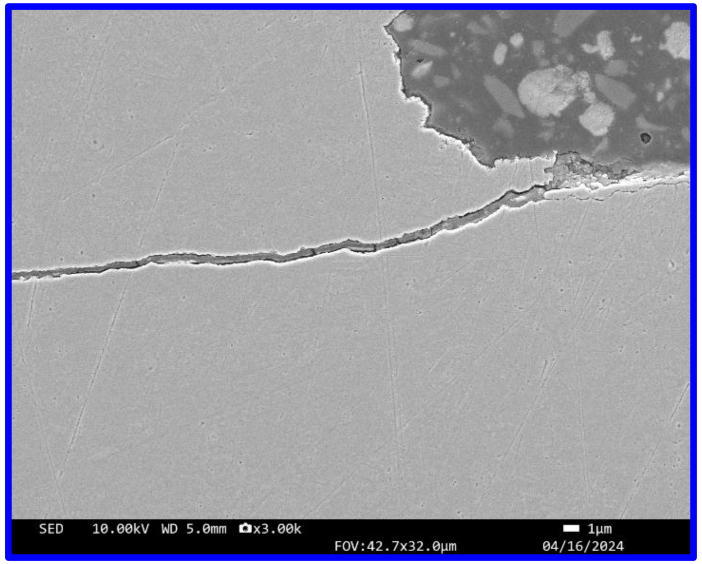


No crack, voids delamination or any structural irregularities.

SEM/EDS Bad Via



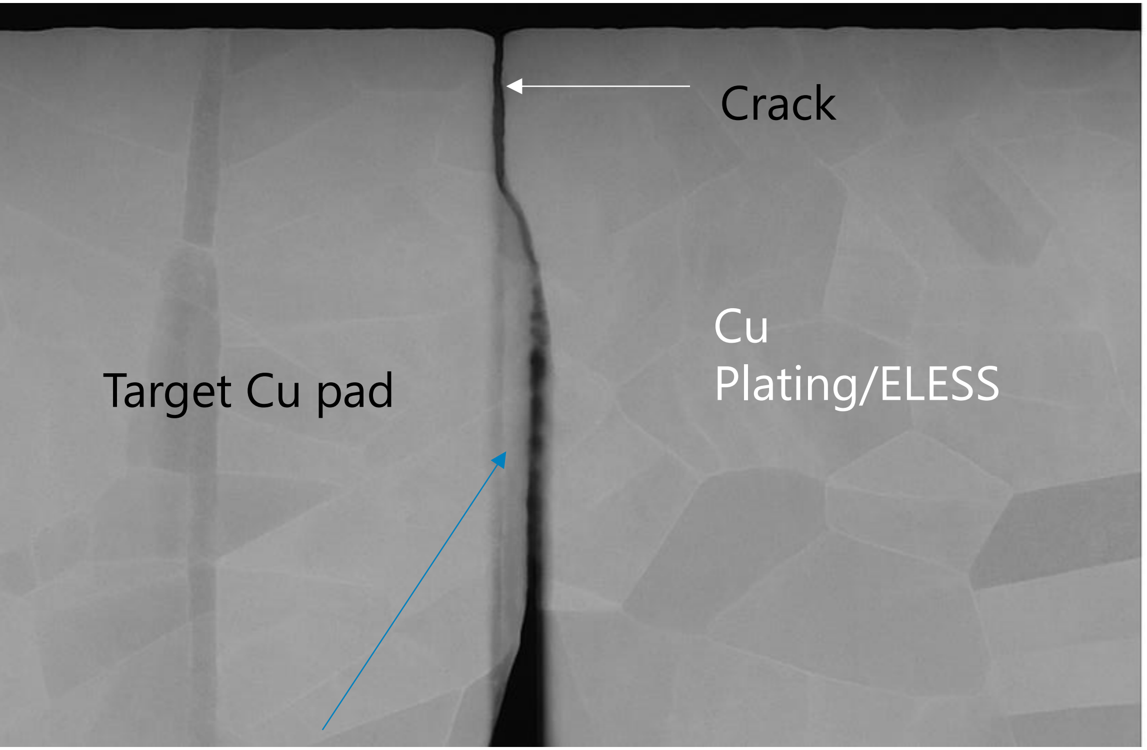


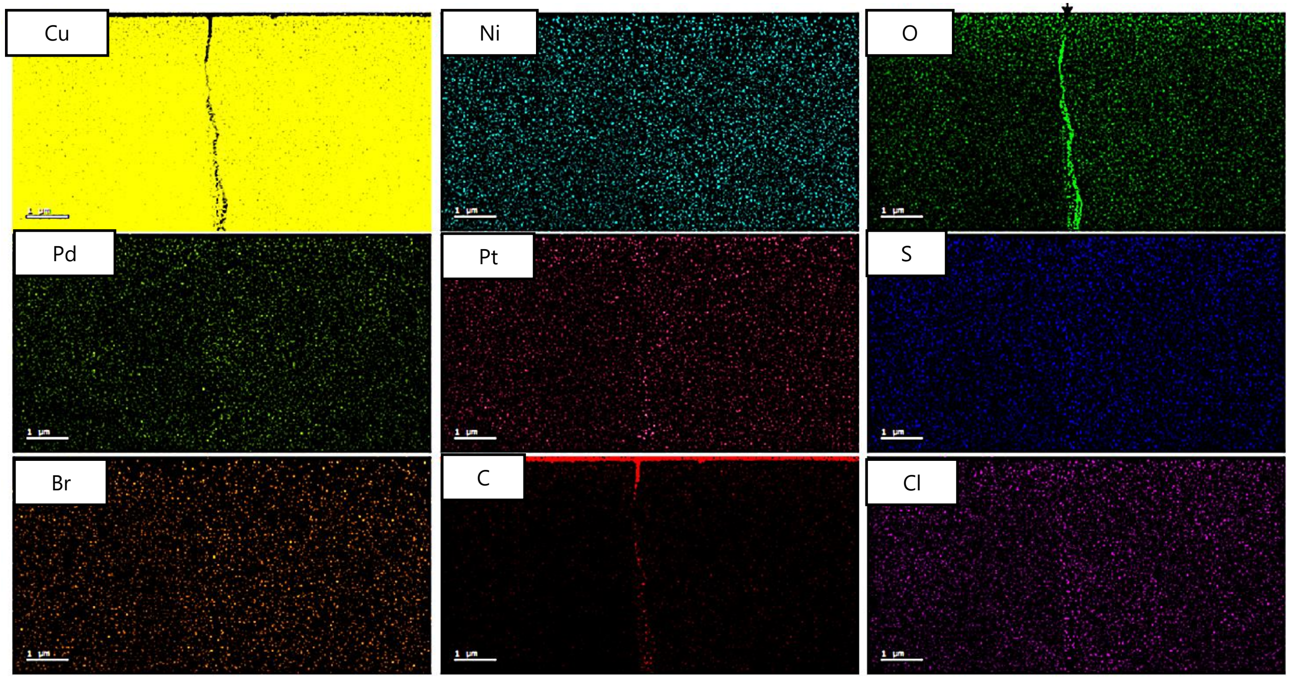


Crack visible – no oxidation/contamination/defect detected with SEM/EDS.

Extract Lamella at the crack location to understand contamination and/or microstructure issue

TEM/EDS Bad Via





High concentration of oxide present at the crack surface. No Ni or Pd layer typical from ELESS deposition were detected.

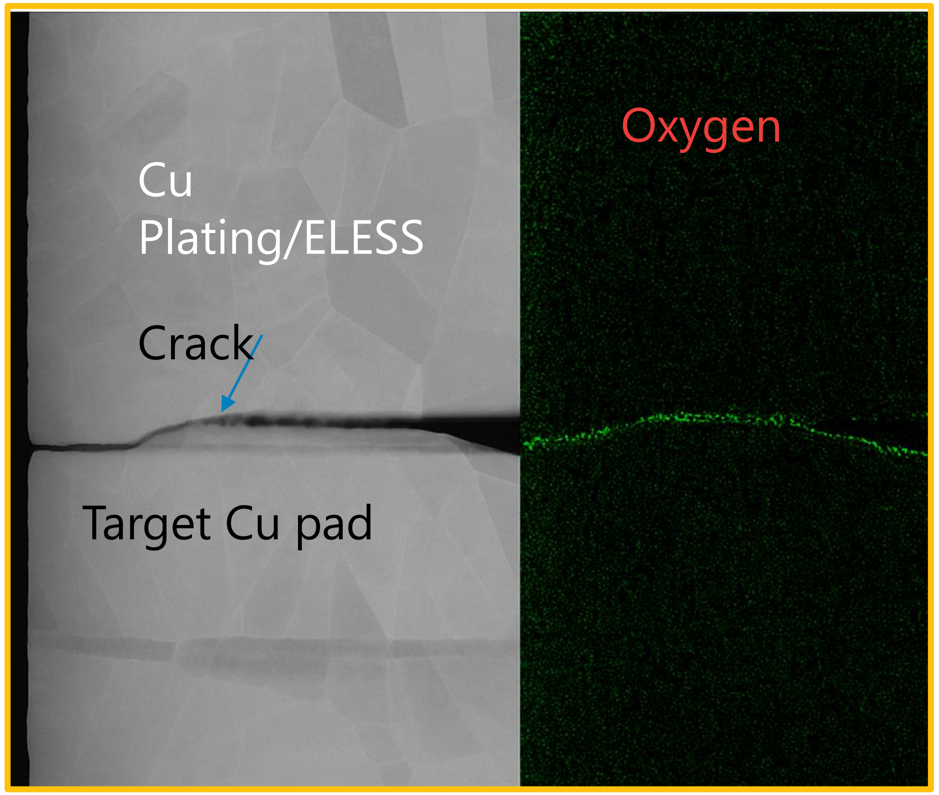
PCB Failure Case Study

COVALENT METROLOGY

FA Process

- **Root Cause Correlation**
  - Delamination at the interface between the copper plating in the via and the target copper pad led to electrical discontinuities and/or intermittent connections in the circuit.

- **Recommendations**
  - Process variables such as plating process parameters, including current density, bath chemistry, and agitation needed review followed by implementing reliability tests like IST (Interconnect Stress Testing) or highly accelerated life testing (HALT).



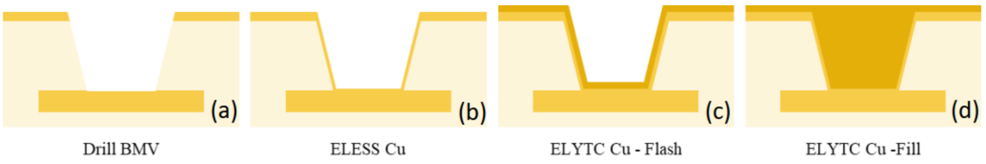


Figure 2. Generic Process Flow for Plated BMV Production.

Case Study: DC Generator Failure

Case Study: DC Generator Failure

COVALENT METROLOGY

Problem

Client reported DC generator experiencing abnormal noise/vibration during services.

Common Failure Modes

Most likely mechanical issue:

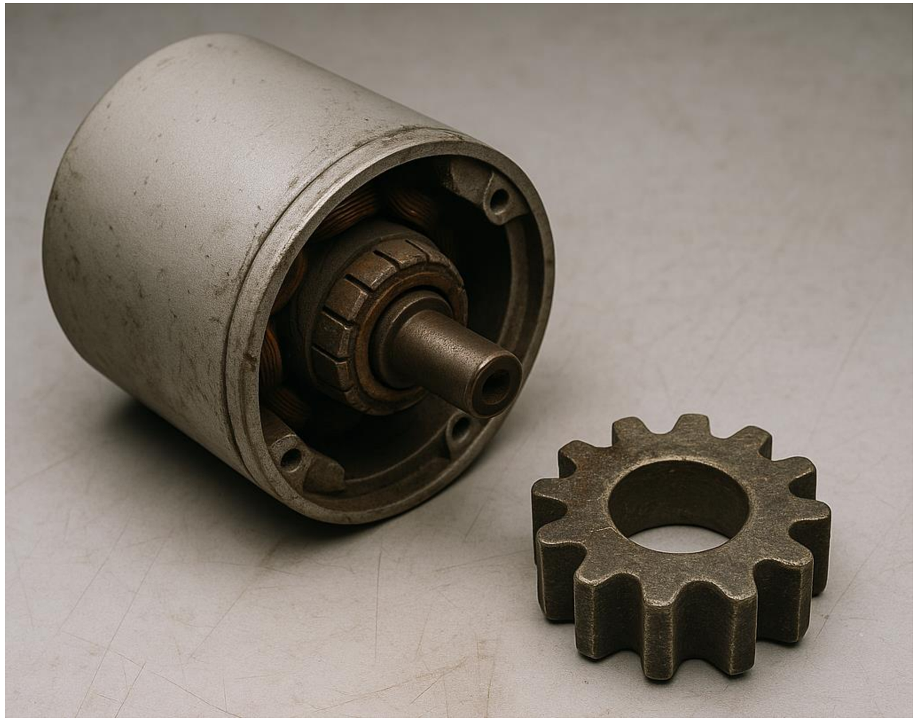
- Bearing degradation (most common)
- Shaft misalignment
- Cracked or fractured magnet
- Contamination → dust, oil, or debris causing imbalance, rubbing, or brush noise
- Rotor unbalance due to assembly error or material loss
- Loose component

Case Study: DC Generator Failure

COVALENT METROLOGY

FA Process / Investigation

- **Visual inspection:**
  - Inspect the assembly as received, isolate the specific failure location if possible.
- **Symptom Capture and Non-Destructive Testing**
  - Functional Testing (Output voltage)
  - General Inspection of the part as received
- **Destructive Analysis**
  - Motor tear down
  - Optical inspection and documentation of the parts (windings, shaft, magnets…).
  - Isolate issue and provide further investigative steps



- Generator opened and the following was observed:
  - Windings and shaft intact
  - Debris found inside the housing
  - Debris were found to be magnetic
  - Cracking observed on magnet surface

Case Study: Magnet Failure in a DC Generator

COVALENT METROLOGY

Actual Problem

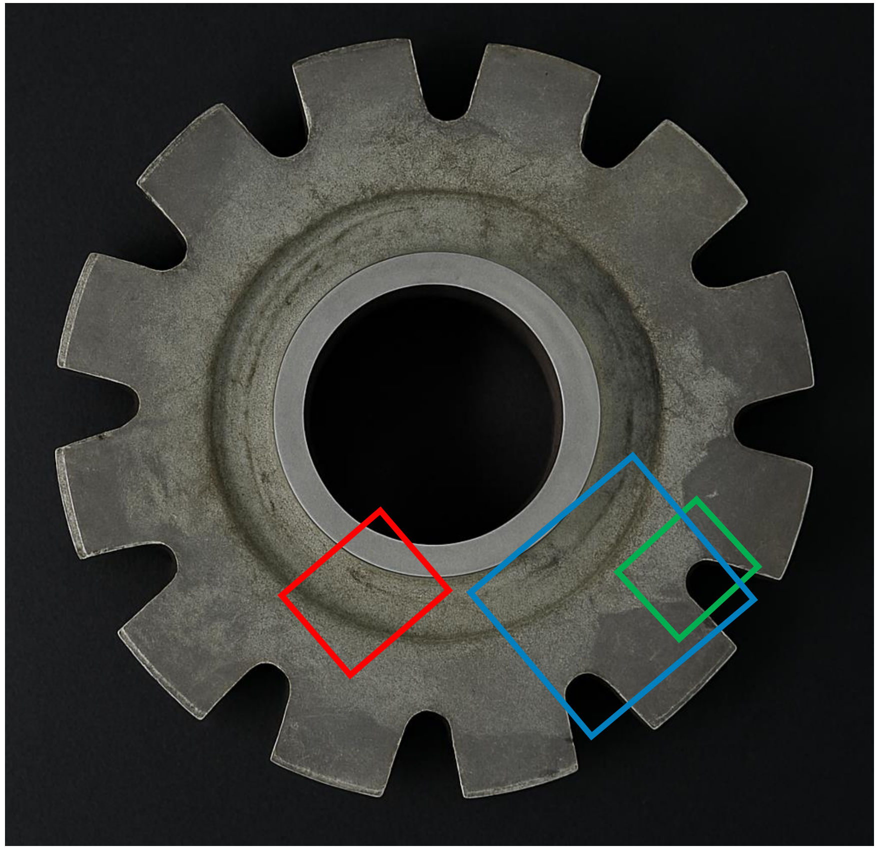
DC Magnet failed during operation

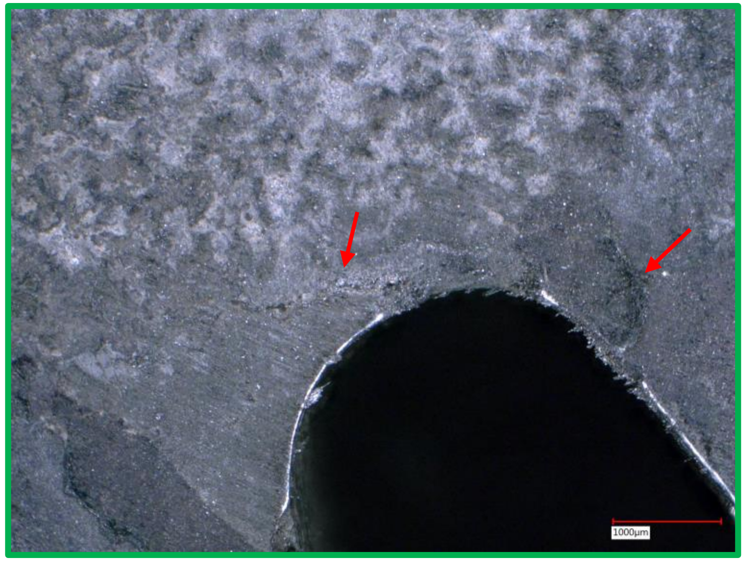
Magnet failure

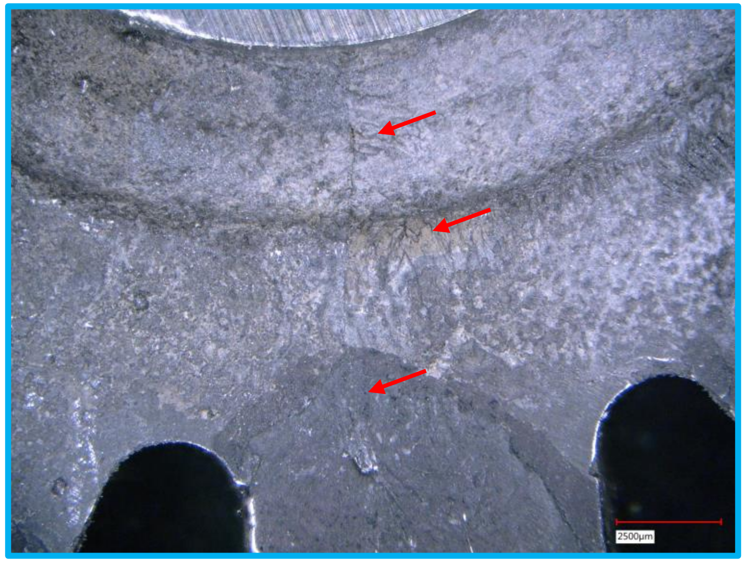
- **Mechanical cross-section** analysis to look for potential cracks, voids, microstructure and inspections via OM and SEM/EDS
- **Inductively Coupled Plasma Optical Emission Spectroscopy** (ICP-OES) to verify that the material meets tight specification windows and identifies trace contaminants that could weaken mechanical or magnetic performance.
- **Vickers Hardness** Nano-Indentation Testing to understand if mechanical properties are within expected specs
- **Cryo-fracture analysis**: Optical and SEM analysis of induced fracture surface to understand severity of cracking

Optical Inspection of Surface Cracks

COVALENT METROLOGY

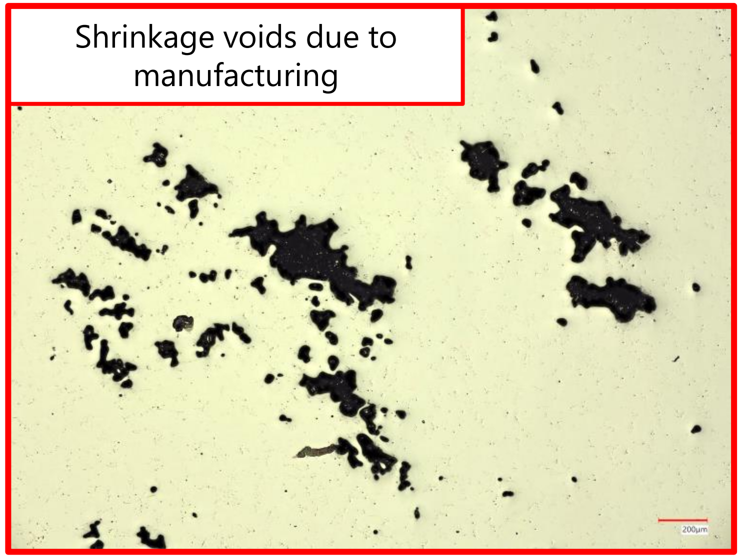


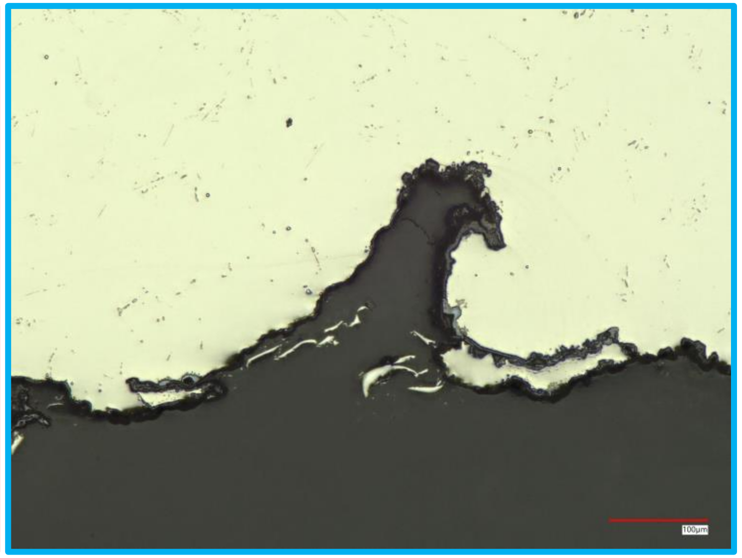


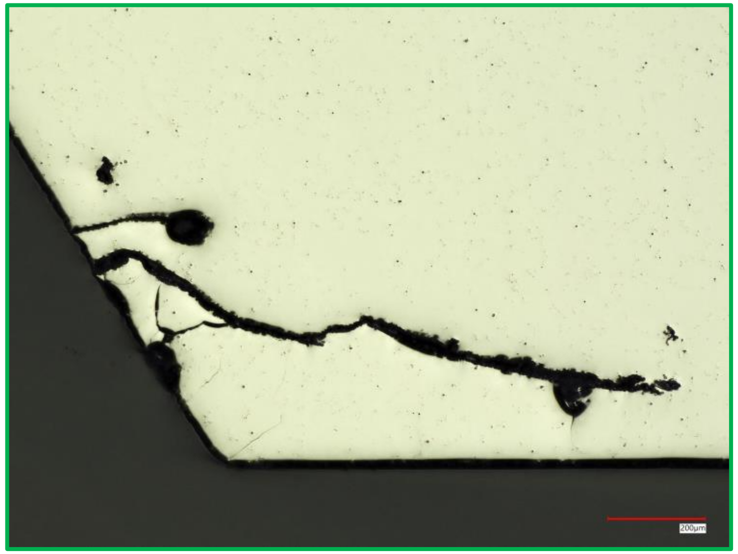


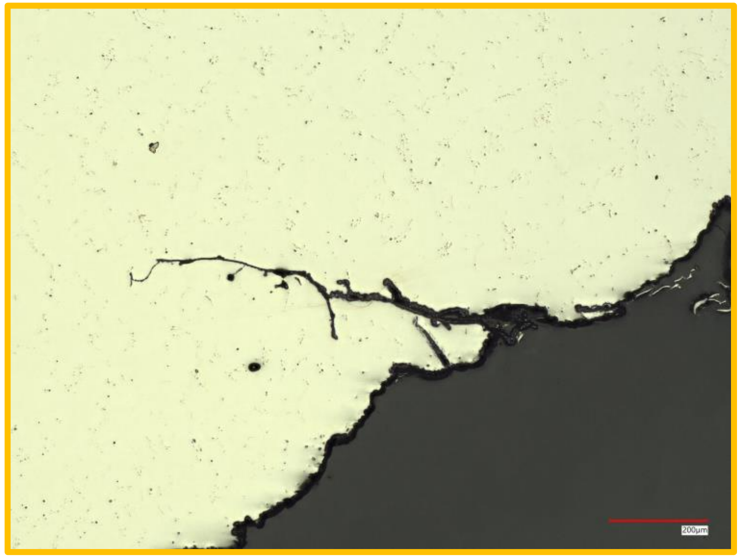
- Several **cracks** were found in the bulk of the magnet.
- To investigate the depth and severity of the cracking, mechanical cross-section, and cryofracture analysis were performed on the magnet.

Optical Microscopy: Magnet Cross-Section





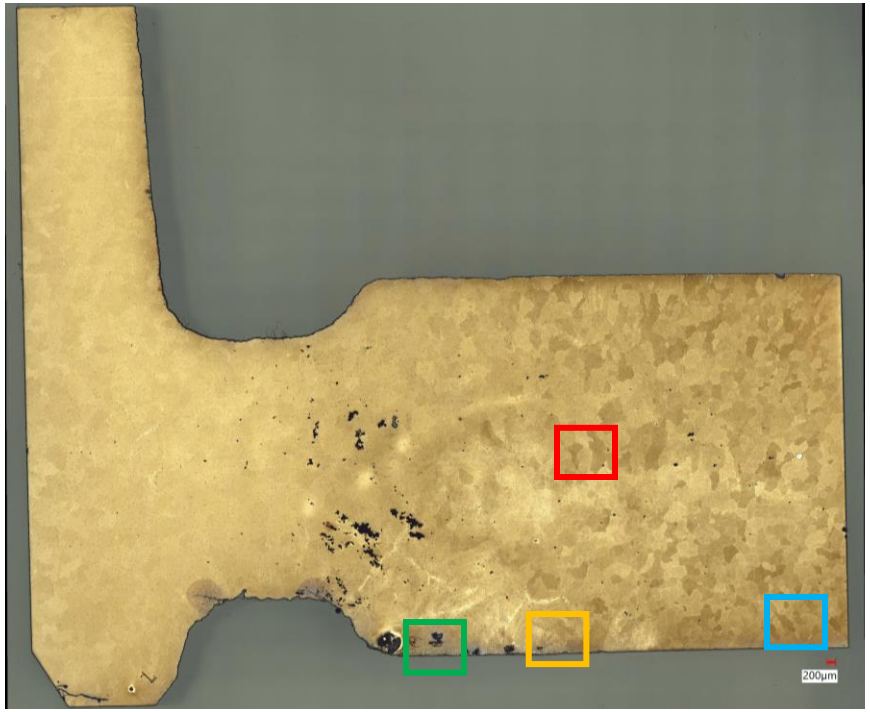


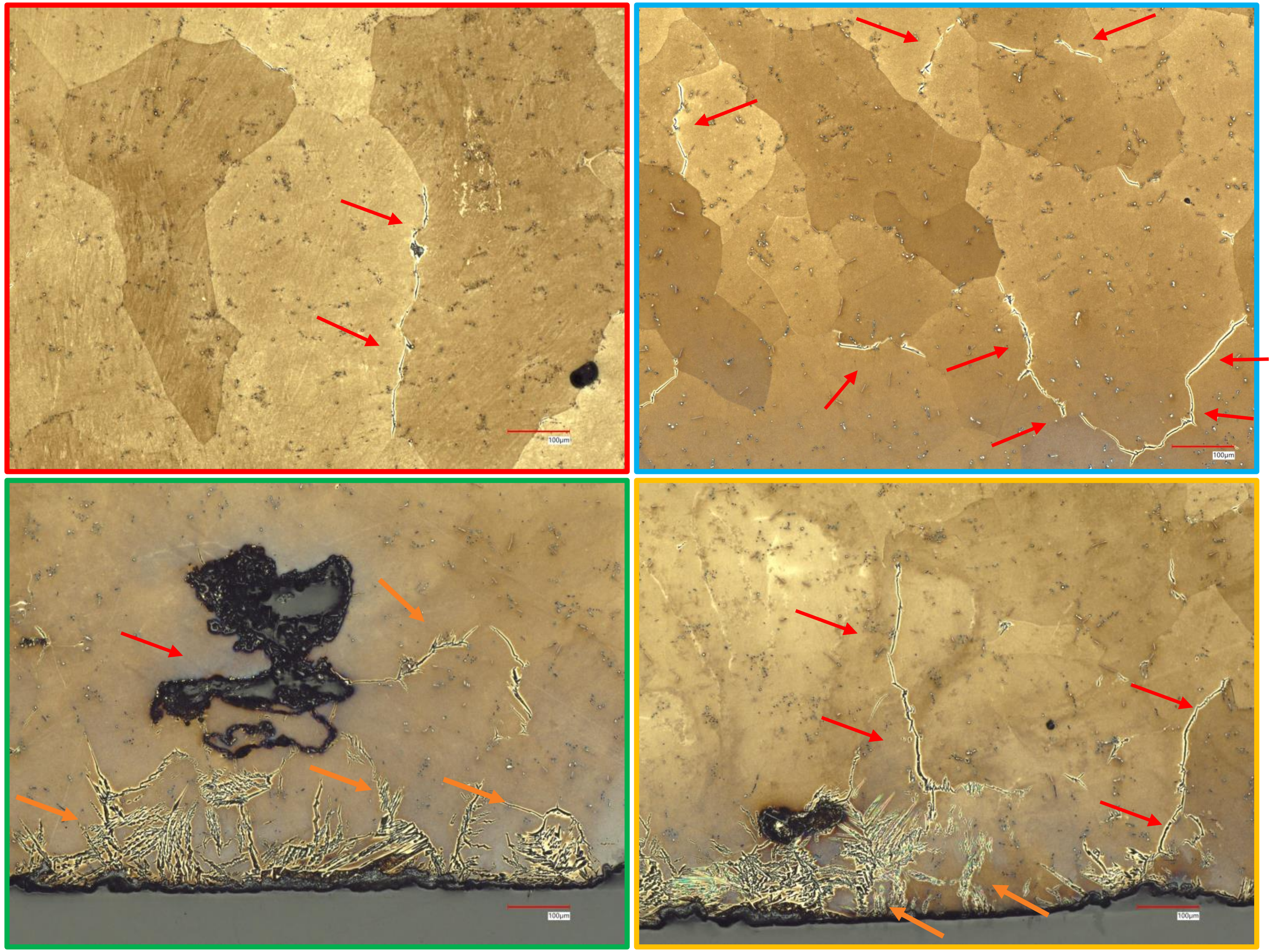


Several **cracks** were observed in the magnet near the edges of the cross-section
Shrinkage voids visible and are likely due to improper temperature process control (uneven cooling or too fast cooling)

Optical Microscopy: Magnet Cross-section, Surface Etching

COVALENT METROLOGY





- **Intergranular cracking** was observed throughout the magnet
- **Transgranular cracking** near the edges of the magnet – these often points to fatigue or stress corrosion cracking

ICP-OES: Compositional Analysis

COVALENT METROLOGY

Element	Magnet C_m (µg/g)	Magnet % wt
Al	126000	12.6
Co	281000	28.1
Cu	34100	3.41
Fe	530000	53
Ni	184000	18.4
Ti	97.5	0.01

合金	% Al	% Ni	% Co	% Cu	% Ti	% Fe
Alnico 1	12	21	5	3	-	59
Alnico 2	10	19	13	3	-	55
Alnico 3	12	25	-	3	-	60
Alnico 4	12	28	5	-	-	65
Alnico 5	8	14	24	3	-	51
Alnico 5DG	8	14	24	3	-	51
Alnico 5-7	8	14	24	3	-	51
Alnico 6	8	16	24	3	1	58
Alnico 8	7	15	35	4	5	34
Alnico 8HC	8	14	38	3	8	29
Alnico 9	7	15	35	4	5	34

Magnetic energy parameter table of aluminum nickel-cobalt ally magnet's 1-9. Sourced from Dongguan NST Magnetics Co., Ltd.'s magnet blog Alnico magnets 1-9 performance parameter datasheet

- Closely resembles an Alnico 5 type of magnet. Al is 4% higher, Co is 4% higher, Fe is 2% higher and Ni is 2% higher than accepted composition; however, results closely resemble this type of magnet compared to other types of Alnico magnets.
- Composition drift, segregation, or impurity pickup may contribute to brittle behavior.

Samples were scanned four times for each element

C_m	Element concentration, where the final concentration is $C_m \pm U_m$
U_m	Estimated measurement uncertainty (reported in both element concentration and % error of C_m)
C_m = < #	Indicates C_m is less than the measurement detection limit

Vickers Hardness Nano-Indentation

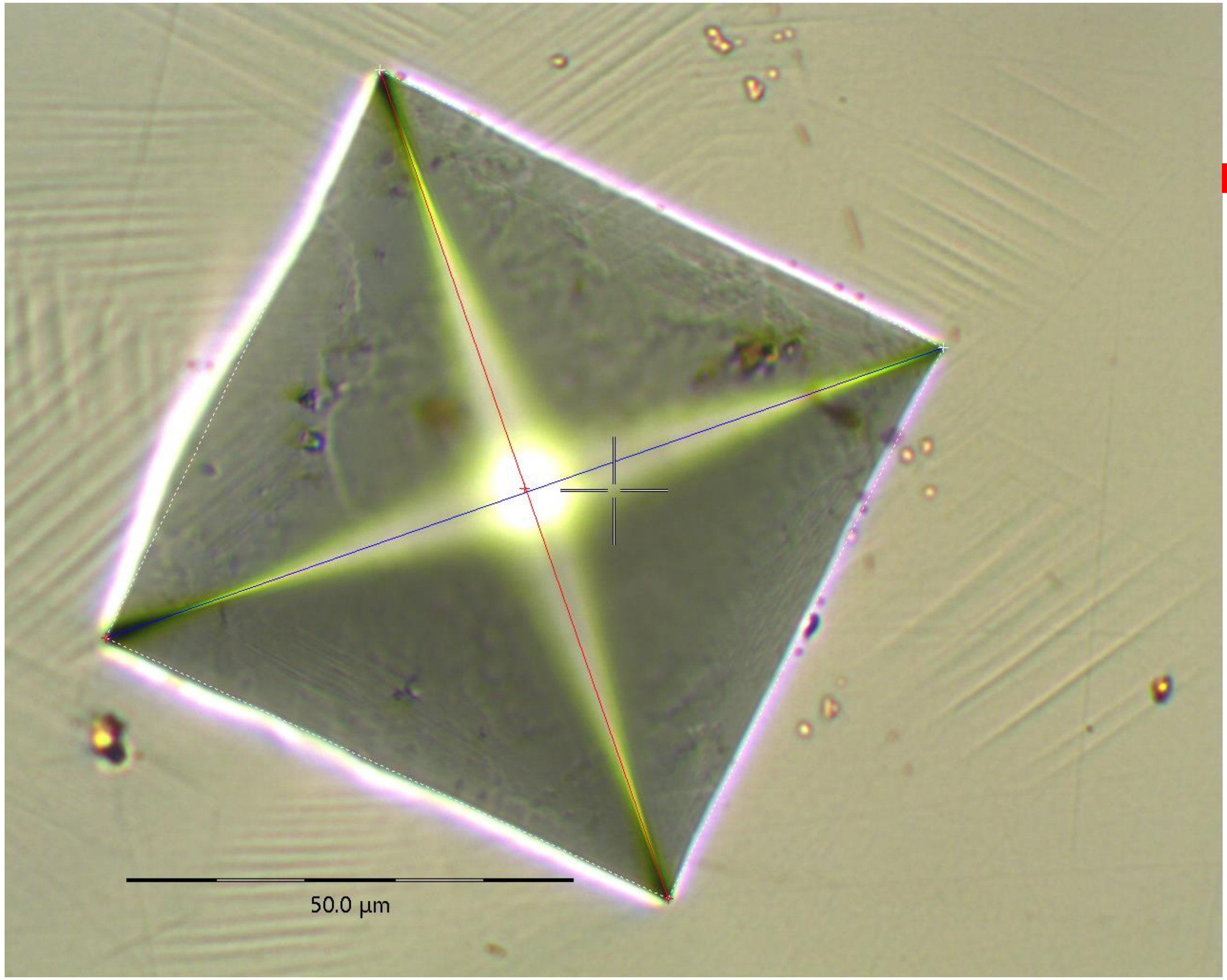


Image size

Width = 136 µm

Height = 108 µm

Hardness Vickers

D1 = 97.40 µm

D2 = 98.62 µm

Load 30.00 N

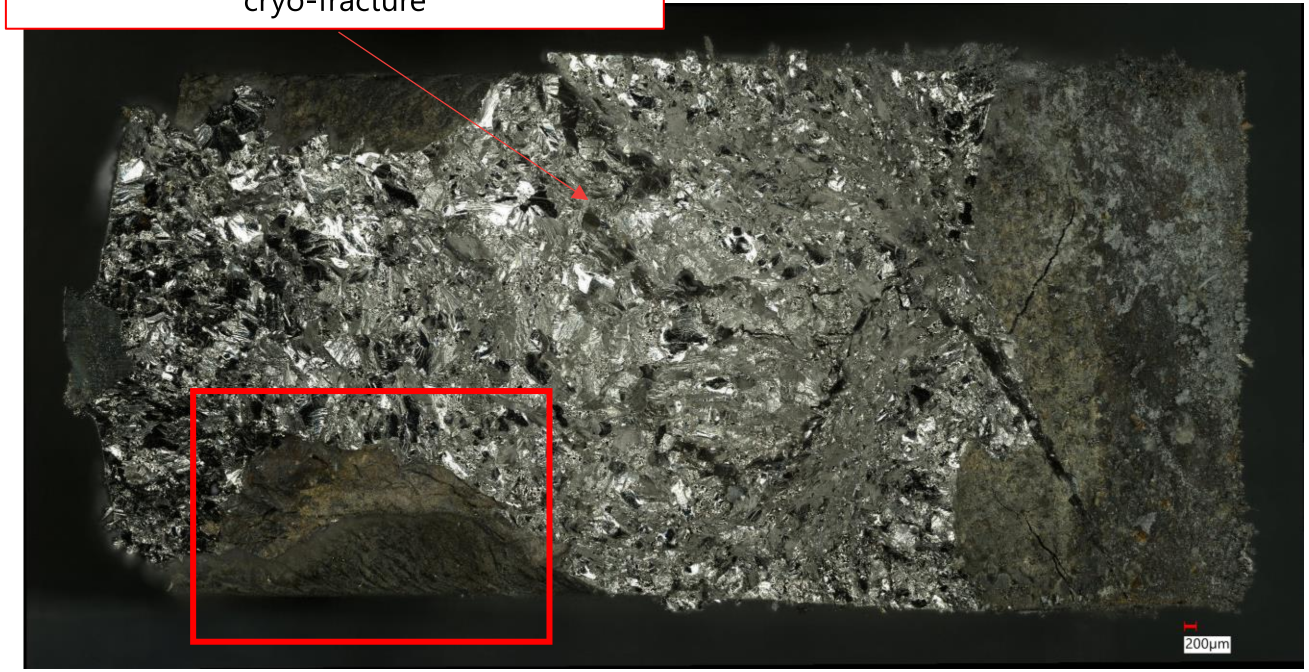
Hardness 590.59 HV 3.06

Hardness: 590.59 HV

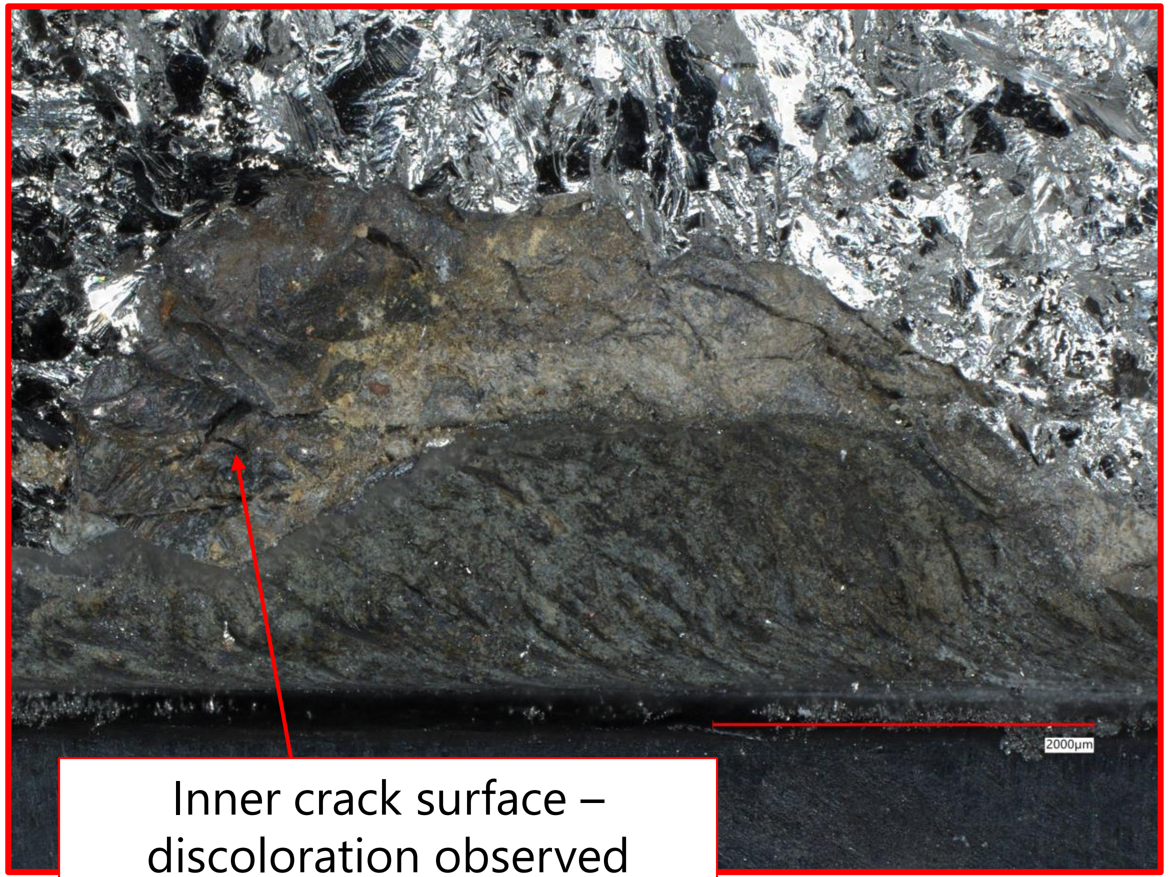
- The established Vickers hardness of alnico falls within the range of 520 - 700 HV
- The HV of the magnet is within the accepted specification

Cryo-Fracture Inspection

Brittle fracture surface exposed from the cryo-fracture

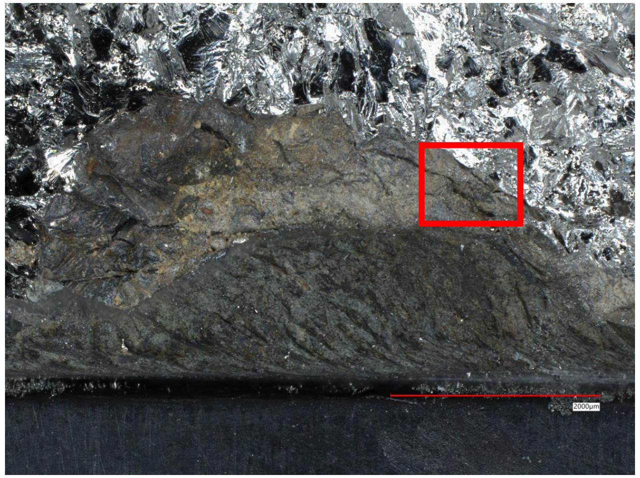


Inner crack surface – discoloration observed

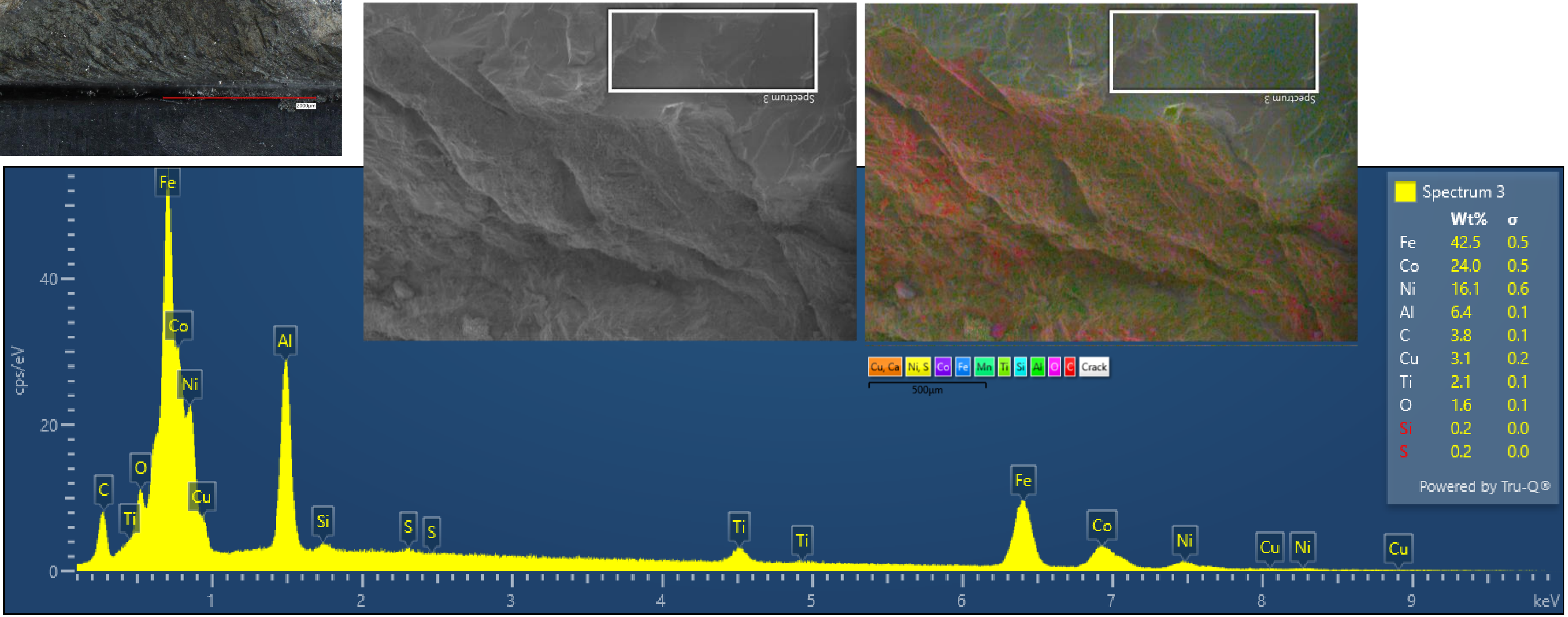


- Surface appearance differs from the crack surface to the material bulk
- Likely corroded surface was exposed from the cry-separation, indicating pre-existing cracks stemming from the magnets surface.

SEM/EDS: Cryo-Fracture Surface

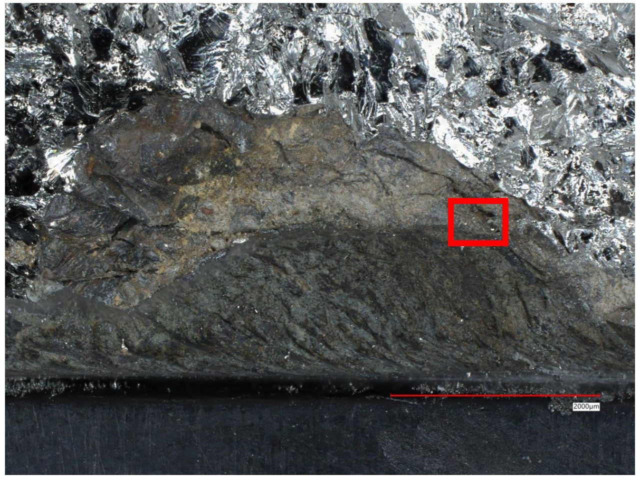


- SEM/EDS data was collected at the cryo-fracture surface to serve as a control to the area with suspected corrosion product

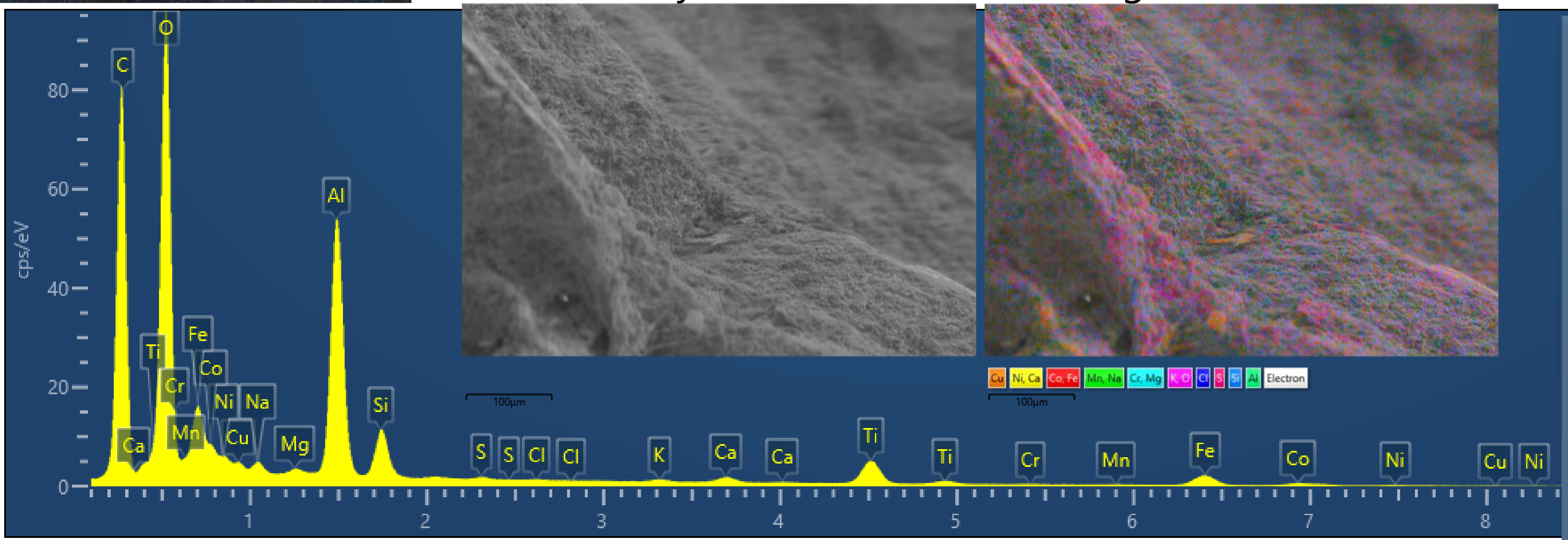


	Wt%	σ
Fe	42.5	0.5
Co	24.0	0.5
Ni	16.1	0.6
Al	6.4	0.1
C	3.8	0.1
Cu	3.1	0.2
Ti	2.1	0.1
O	1.6	0.1
Si	0.2	0.0
S	0.2	0.0

SEM/EDS: Corrosion Product



- SEM/EDS data were taken in the area covered in suspected corrosion product
- **O** concentration is higher than the cryo-fracture control surface, 29.2% compared to 1.6%.
- **Ca, Na, K, and Cl were found on the surface and** are indicative of the presence of corrosive species
  - The presence of these elements and elevated oxygen levels corroborates the hypothesis that the cracking observed near the edges of the sample is likely stress corrosion cracking



Map Sum Spectrum

	Wt%	σ
C	33.4	0.1
O	29.2	0.1
Al	10.5	0.0
Fe	10.3	0.1
Ti	5.7	0.0
Co	3.7	0.1
Si	2.1	0.0
Ni	2.1	0.1
Cu	0.9	0.1
Ca	0.7	0.0
Na	0.5	0.0
K	0.3	0.0
Cr	0.2	0.0
Mn	0.2	0.0
Mg	0.2	0.0
S	0.1	0.0
Cl	0.1	0.0

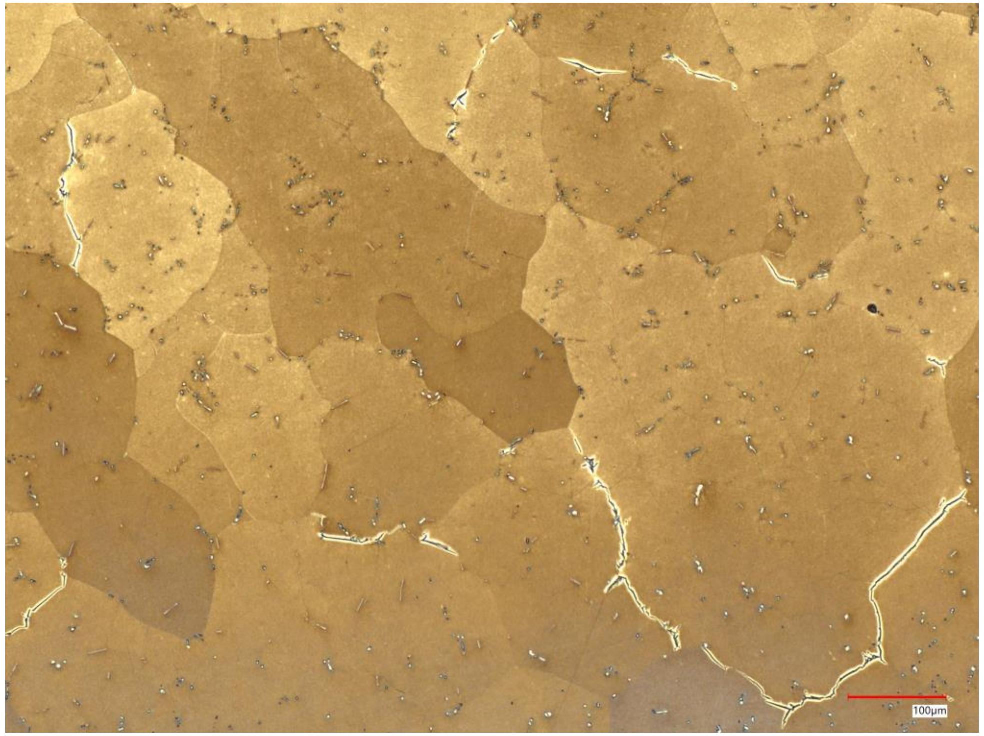
Permanent Magnet Failure Analysis

COVALENT METROLOGY

FA Process

- **Root Cause Correlation**
  - Material composition is slightly off specs and could be related to composition drift, segregation.
  - Transgranular and intergranular cracking observed near surface and in the bulk of the magnet
  - Analysis suggests creep and stress corrosion cracking
  - Component failure due to material degradation, thermal cycling, and corrosion

- **Recommendations**
  - Manufacturing: Use tougher magnet material or protective coating to reduce brittleness (SmCo, NdFeB, Alnico 8/9 – need to understand environment needs to support decision
  - Improve mounting design (mechanical support / adhesive bonding to minimize vibration-induced stress)
  - Add vibration/thermal cycling qualification testing for future designs
  - Include predictive maintenance checks (flux density + vibration monitoring)



Hidden cracks in the magnet grew silently causing debris to build up in the housing that eventually brought the generator down — our analysis revealed the true failure path.

Case Study: Ceramic Tube Furnace Failure

Case Study: Ceramic Furnace Tube Failure

COVALENT METROLOGY

Problem

Client reported that a polycrystalline alumina furnace tube fractured after installation during the first heating of the furnace. Once the furnace was cooled and opened, the failed tube was found by the technician.

Common Failure Modes

Mechanical Failures
Mechanical Stress and Impact

Thermal & Environmental Failure
Chemical Corrosion and Contamination, Material Degradation and Overheating, Thermal Shock, High-Temperature Creep

Manufacturing Defects:
Pores, Inclusions, Stress Concentration in Grain Boundaries

Case Study: Ceramic Furnace Tube Failure

COVALENT METROLOGY

FA Process / Investigation

- **Visual inspection:**
  - Inspect the fracture surface as-received to look for evidence of fracture origin and propagation direction.

- **Electron Microscopy:**
  - Examine locations of interest via scanning electron microscopy (SEM) to look for microscopic features indicative of failure mechanism
  - Corroborate findings from visual inspection

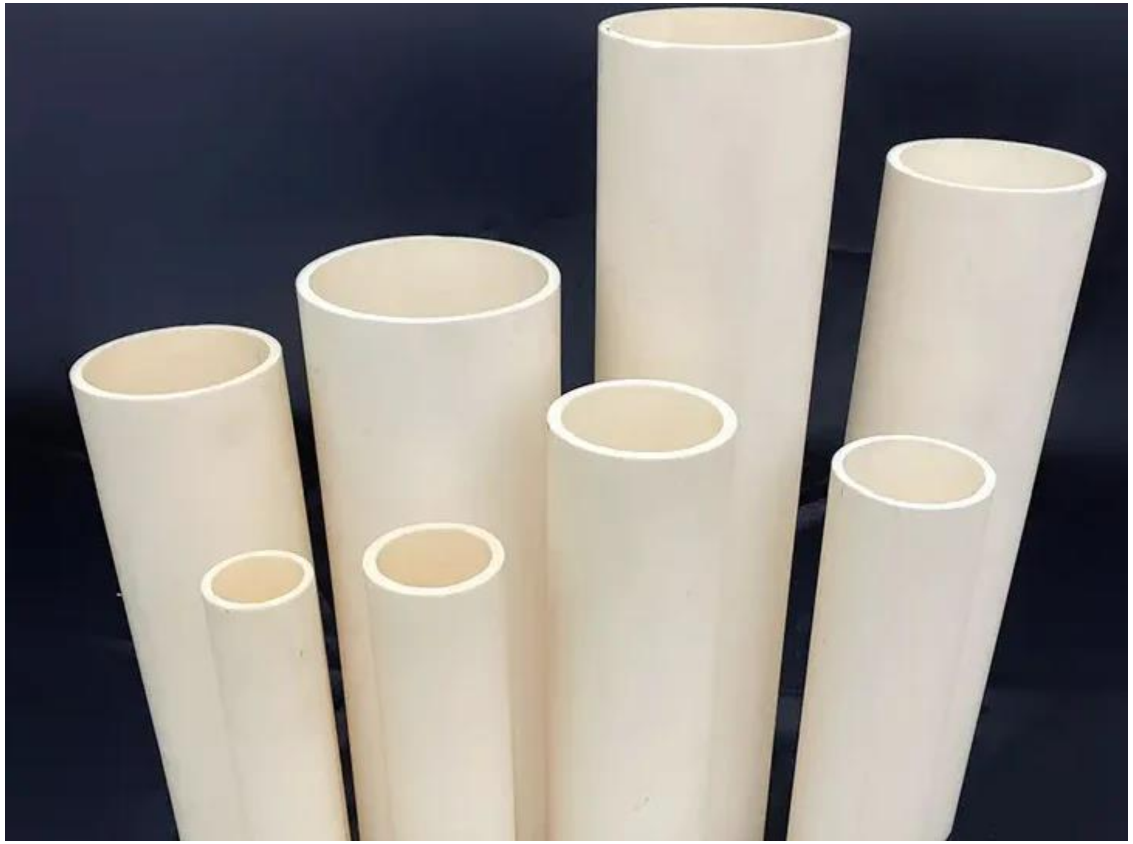
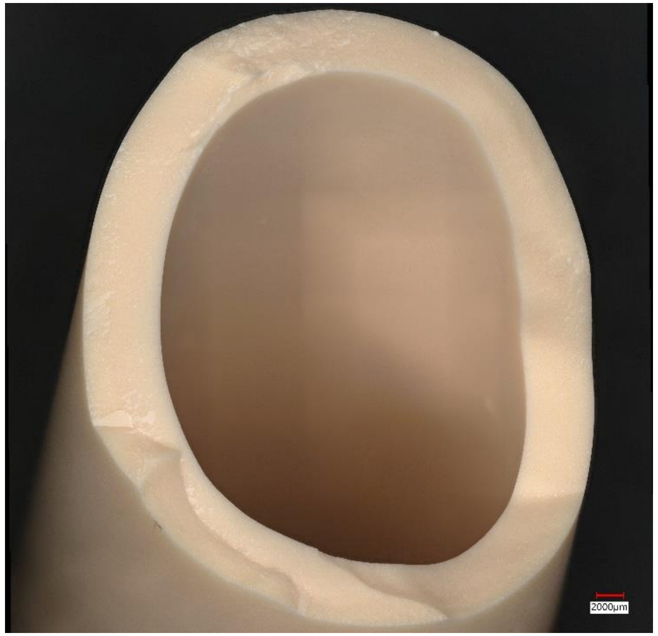


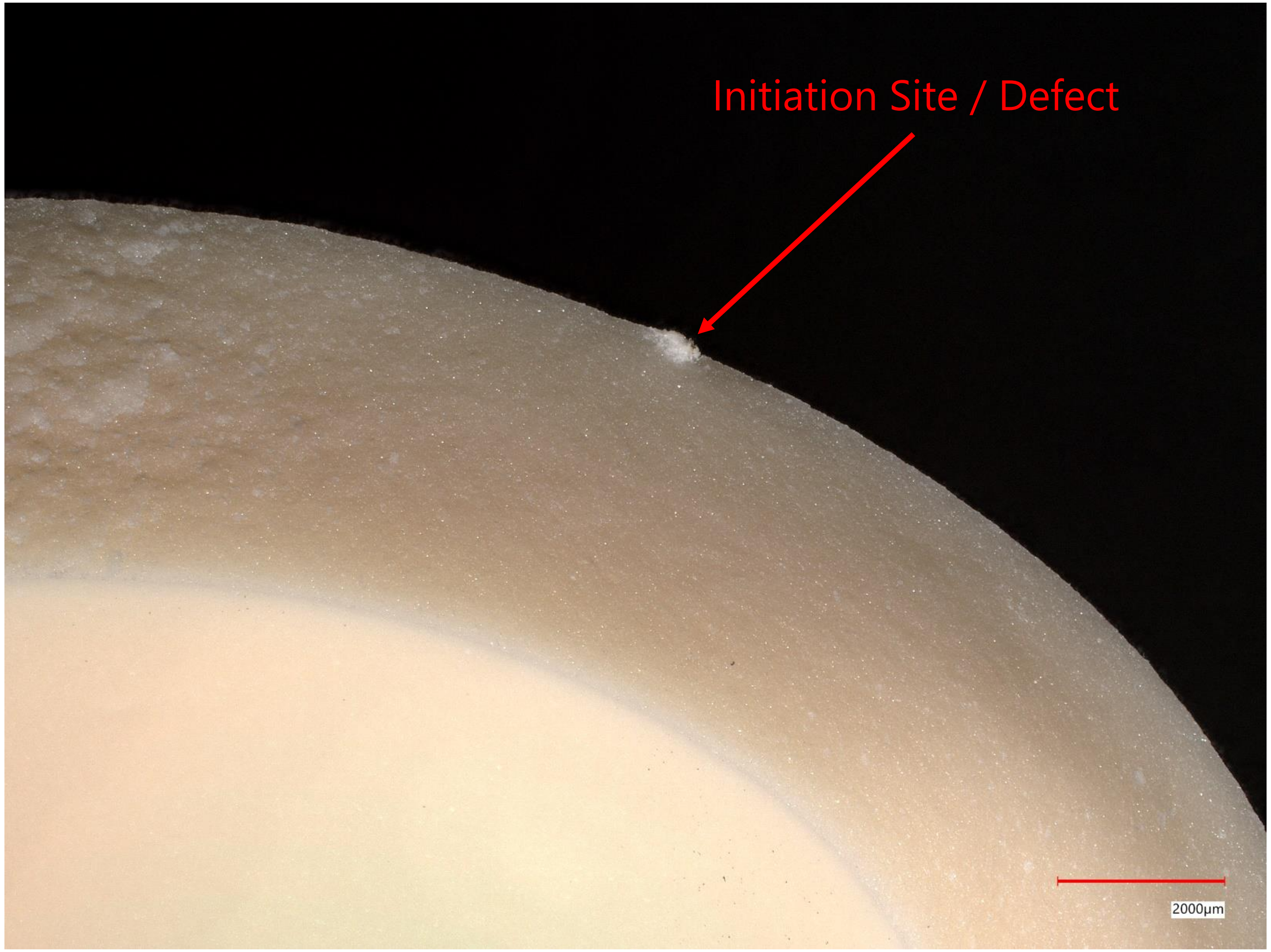
Photo Documentation

Photo documentation of the fracture furnace tube highlighting the mating half of the fracture utilized for optical and electron microscopic examination.

Optical Fracture Inspection

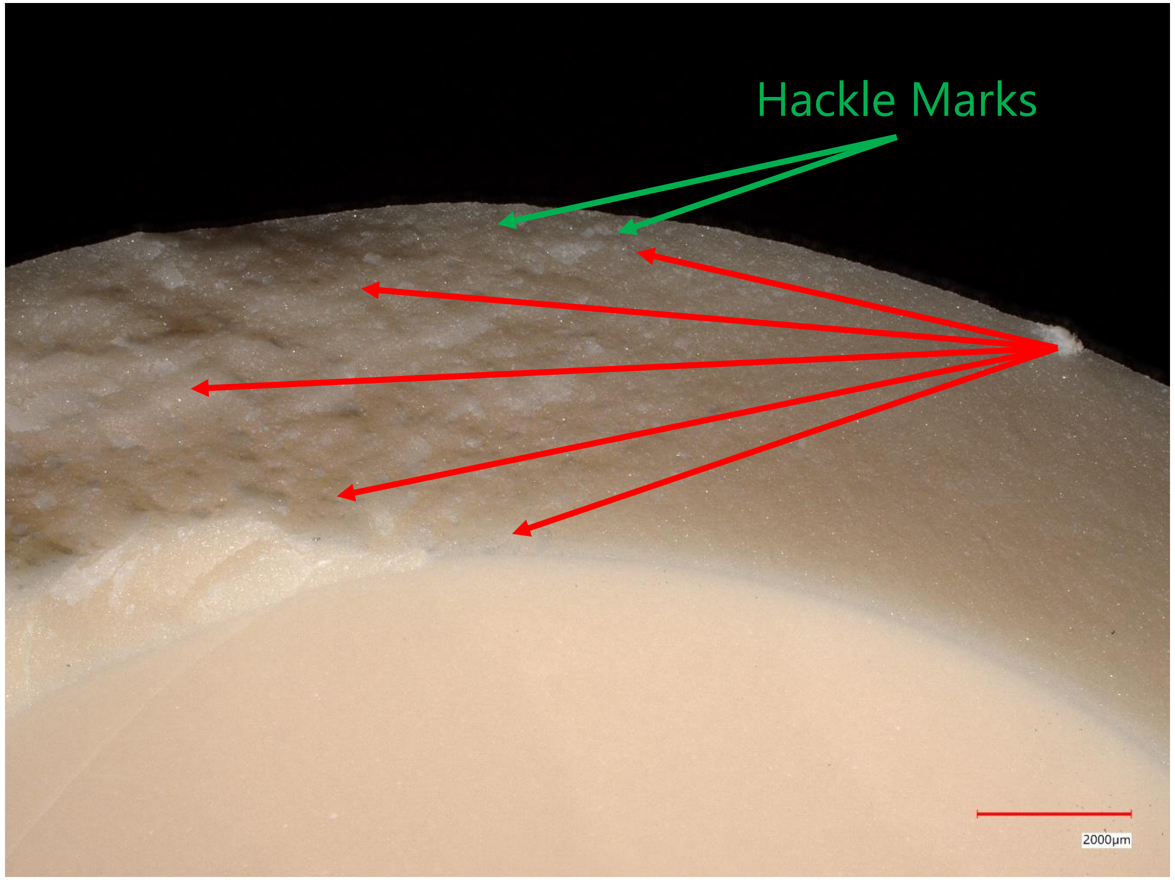
COVALENT METROLOGY

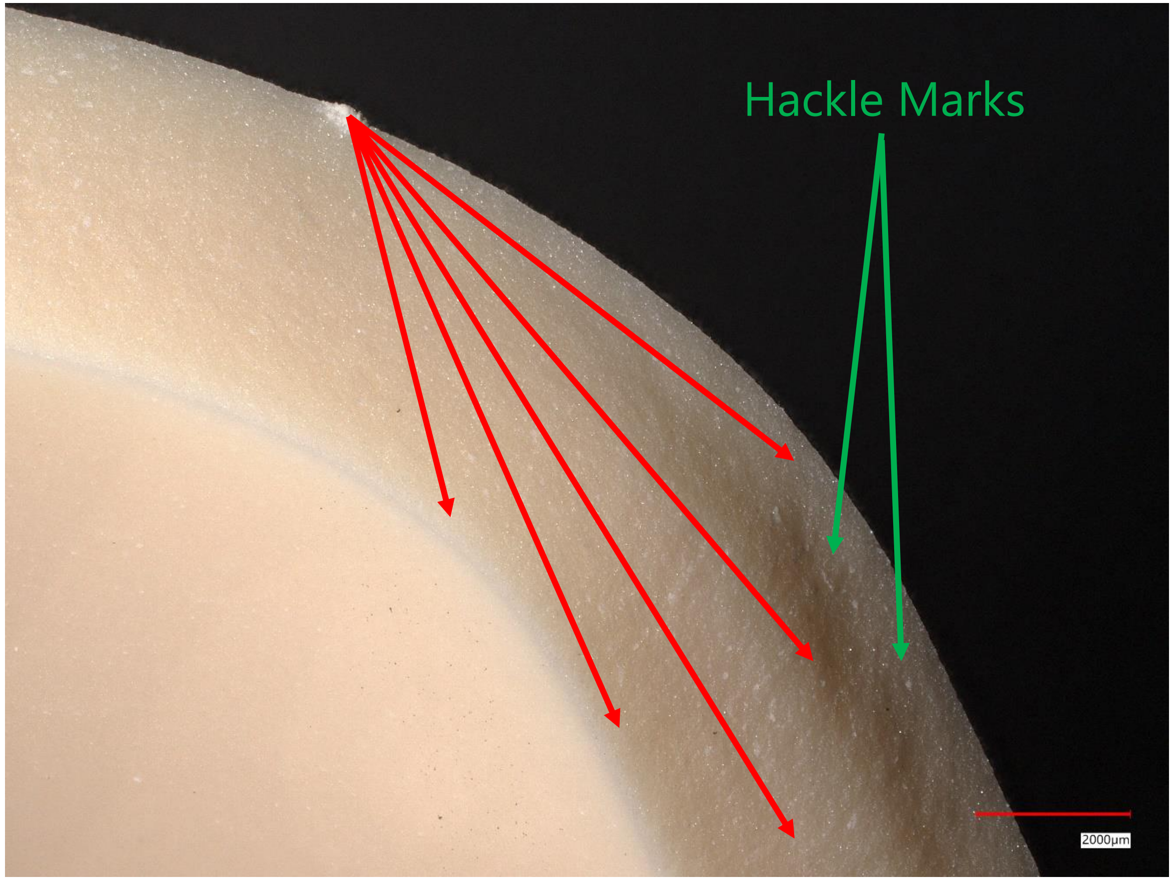




Optical image of the region of initiation where a defect can be seen on the outer edge of the fracture surface.

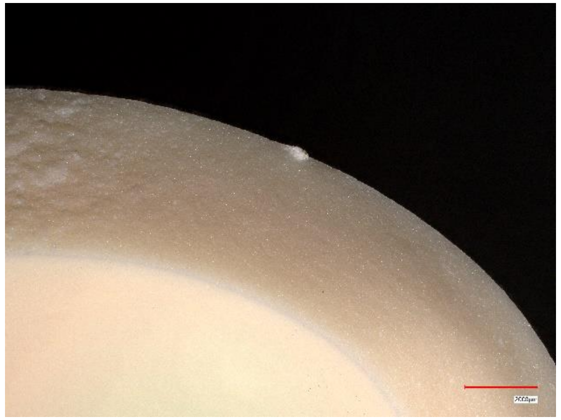
Optical Fracture Inspection

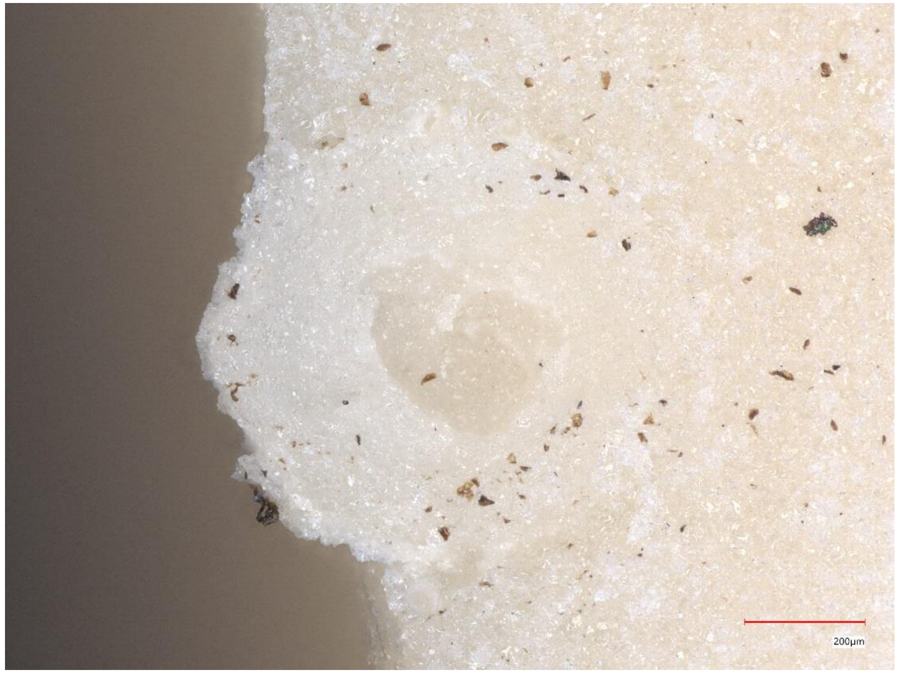




Optical image of the region of fracture initiation in different lightings to highlight hackle marks indicative of the direction of propagation. The red arrows show the direction of propagation starting from the defect.

Optical Fracture Inspection

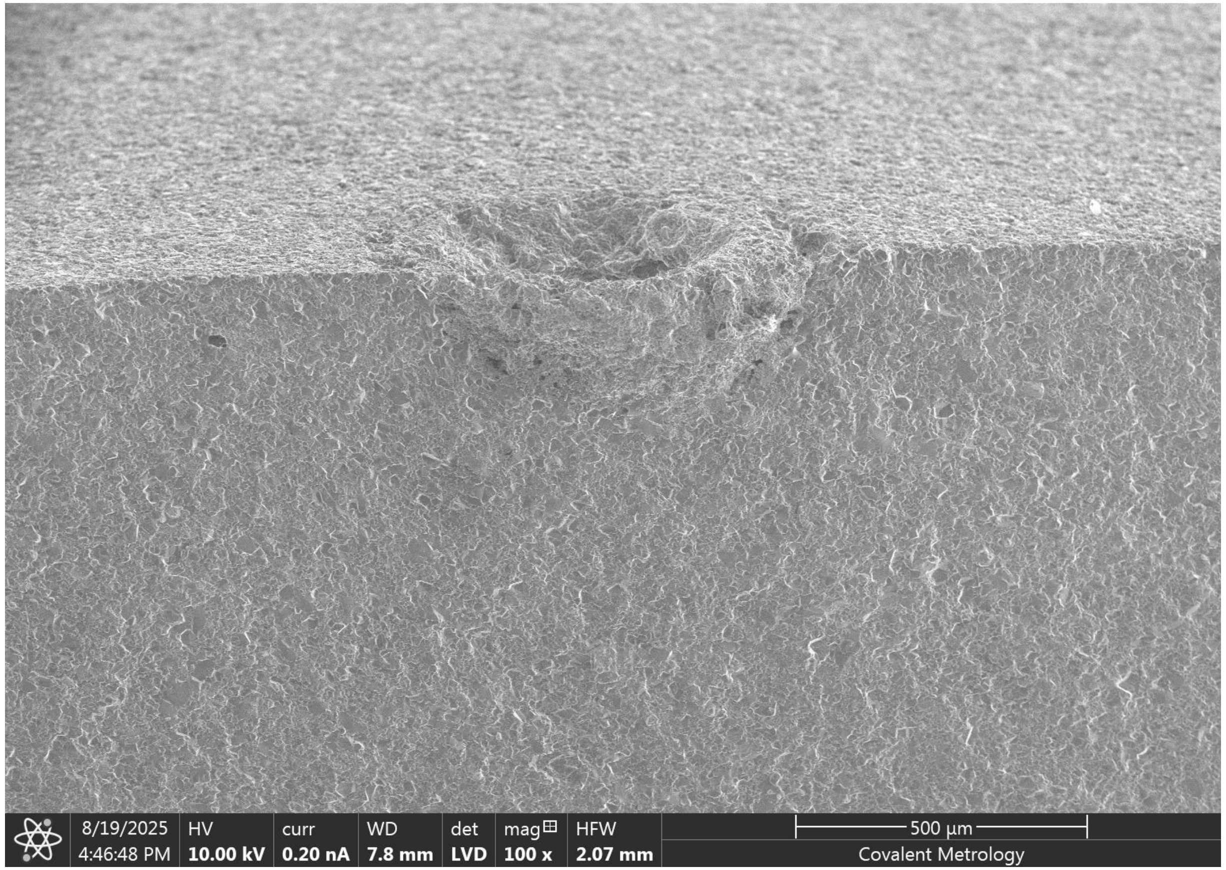


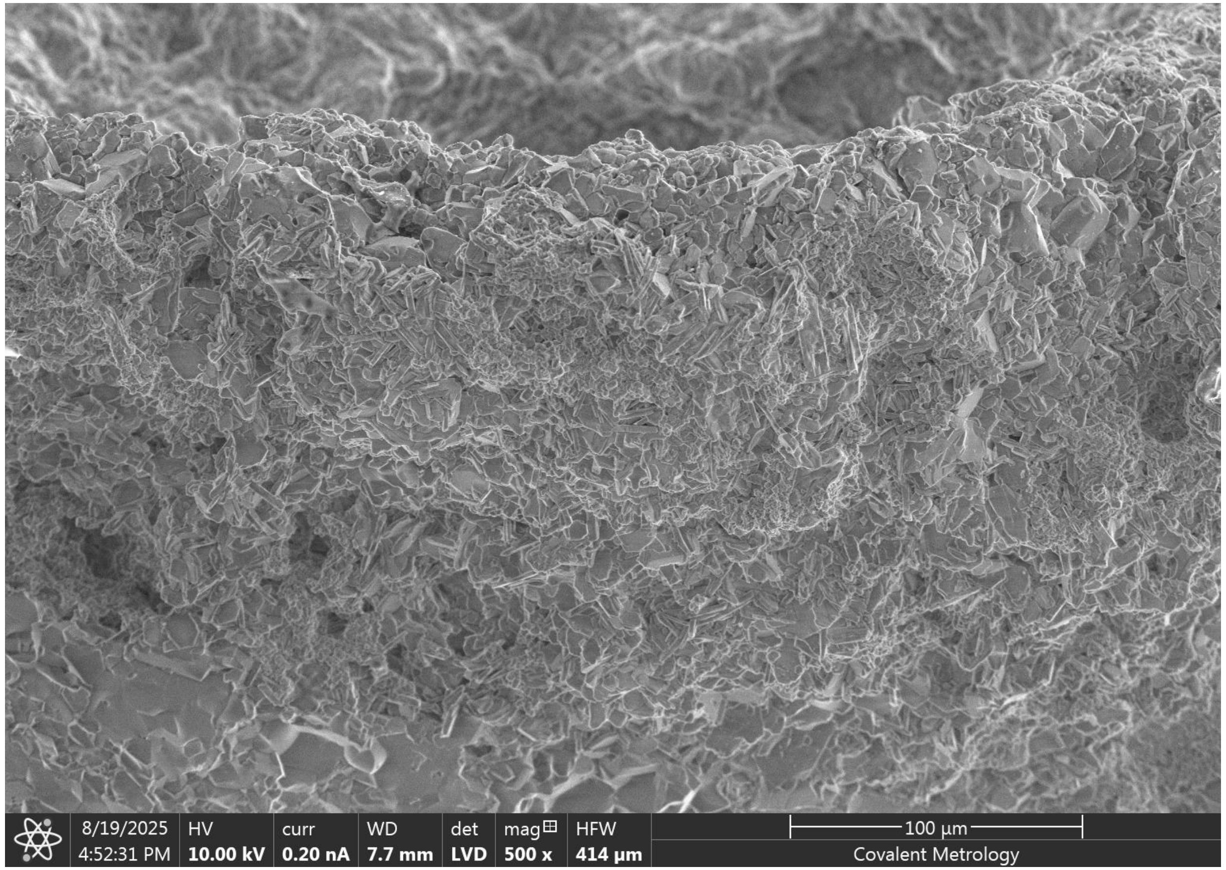


Optical images of the defect where the fracture originated. The defect appears to be some kind of cavity or pore, which would serve as a stress concentrator where cracking or fracture is more likely to initiate.

SEM Fracture Inspection

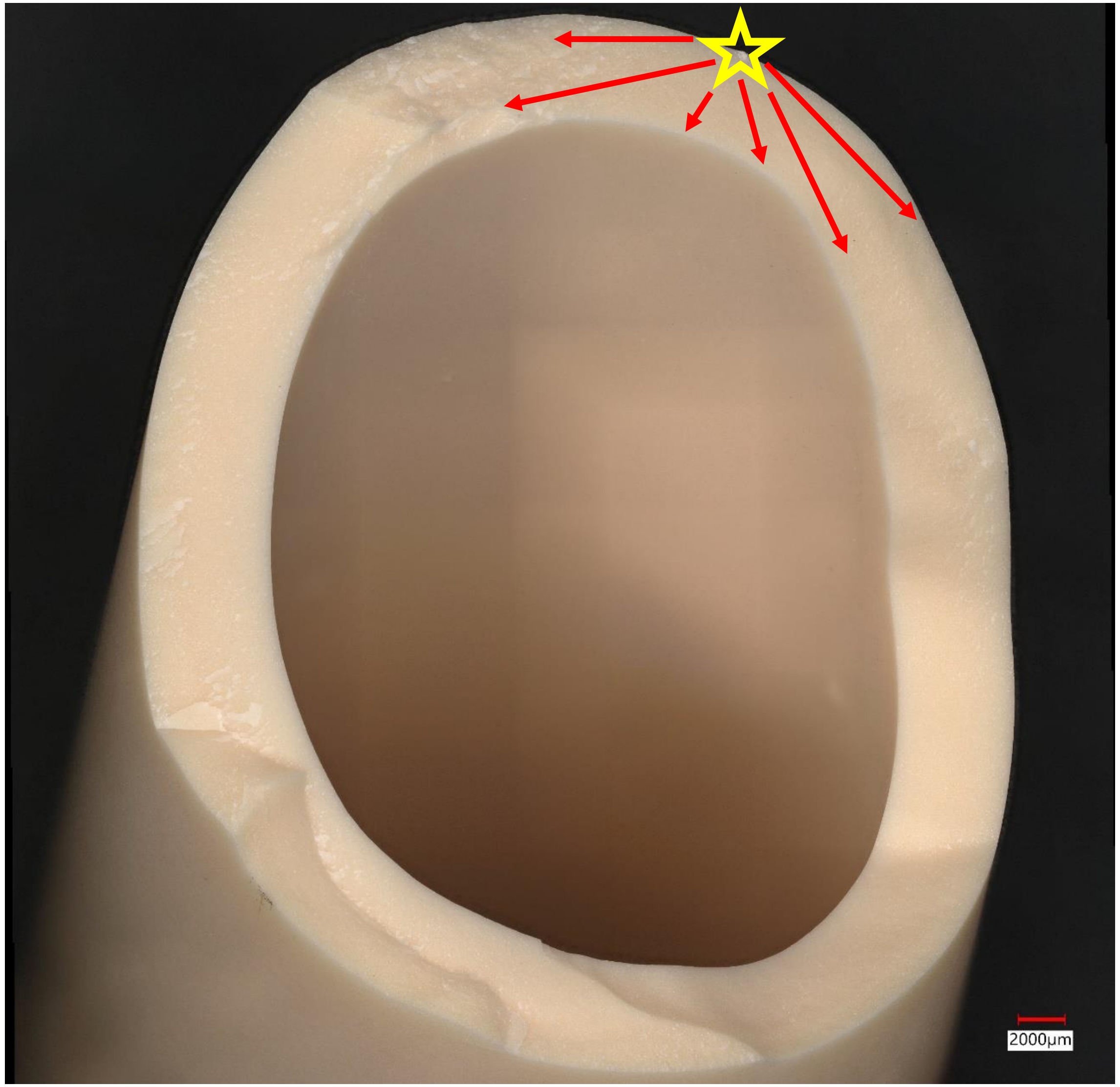
COVALENT METROLOGY





Scanning electron micrographs of the defect where the fracture originated. The variation in grain size and structure is indicative of incomplete sintering or a manufacturing defect.

Fracture Origin and Propagation Direction



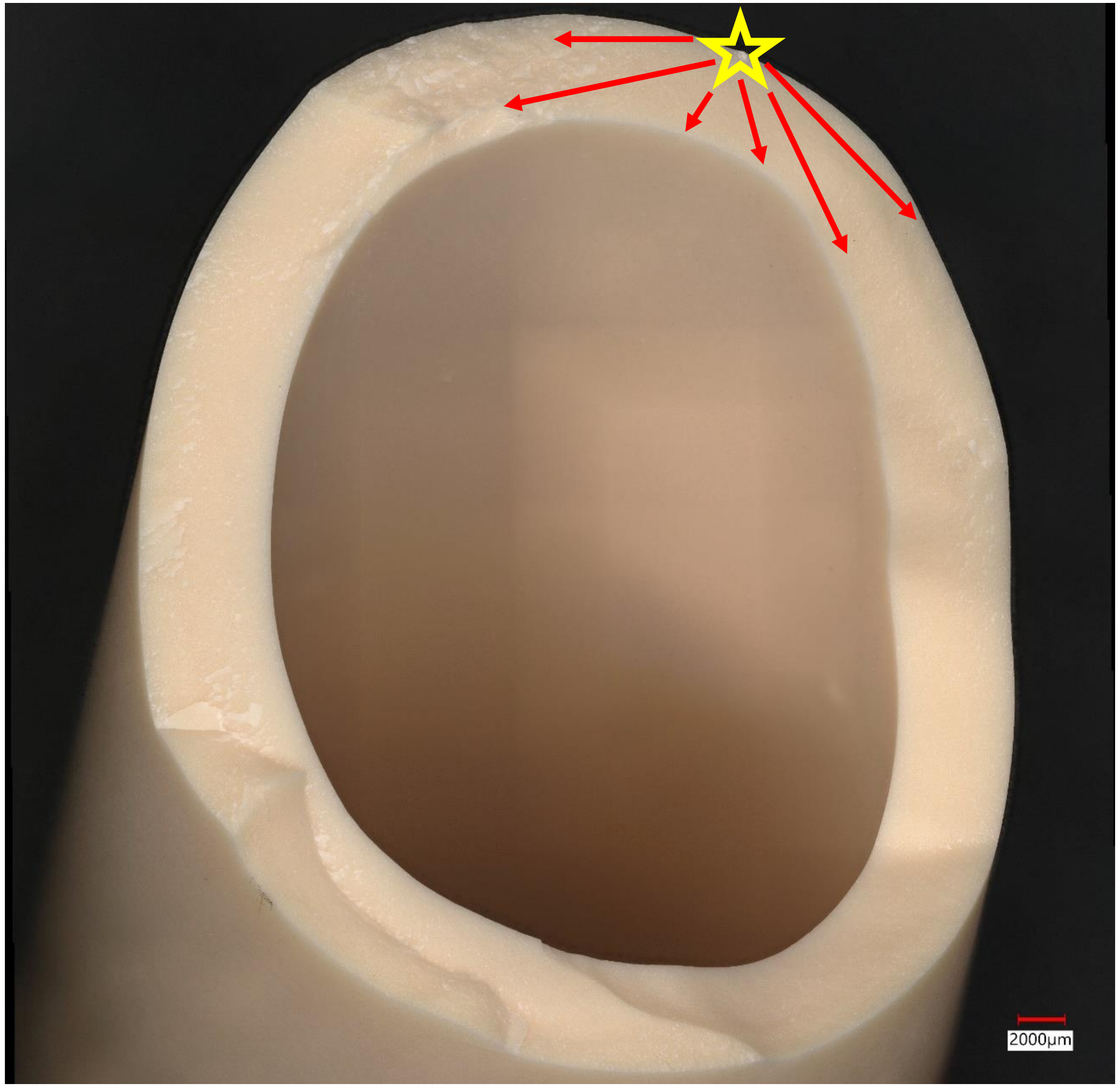
The fracture appears to have originated on the outer surface of the furnace tube where a cavity or pore was observed. The yellow stars indicate where the fracture initiated. The crack propagated outwards from the origin until the tube fractured. Based on the smooth morphology of the fracture surface, it is likely that the fracture took place in an instant.

Ceramic Furnace Tube Failure Analysis

COVALENT METROLOGY

FA Process

- **Root Cause Correlation**
  - Localized stress concentration from pore formation during manufacturing.
  - Brittle failure due to the localized stress, from porosity and heating of the tube, exceeding the stress required for fracture to initiate
- **Recommendations**
  - Manufacturing: Pores such as the one observed on the failed sample are commonly associated with incomplete sintering or pore forming agents. Investigation into the sintering profile and presence of pore forming agents could help to negate pore formation.
  - Quality Check: Samples should be visually inspected post-manufacturing to look for pores and inclusions that may result in failure when furnace tubes are exposed to in service conditions.



Conclusion – Why Partner with Covalent?

COVALENT METROLOGY

We are here to help - and we love a challenge

- **Expertise that matters** – deep technical knowledge and problem-solving mindset
- **Tools & techniques** – state-of-the-art lab and advanced FA methods
- **Resources & network** – strong supplier and partner ecosystem
- **Proven experience** – trusted across industries with successful case studies
- **Dedicated team** – we bring focus, passion, and excellence to every challenge

COVALENT METROLOGY

Thank you !

Acknowledgements:
- *Jessica Batterman, M.Sc.* for the DC Motor Analysis
-*Tonu Sepp* for the PCBA Failure Analysis

audrey@covalentmetrology.com

Sign-up for Free Discovery Consultations

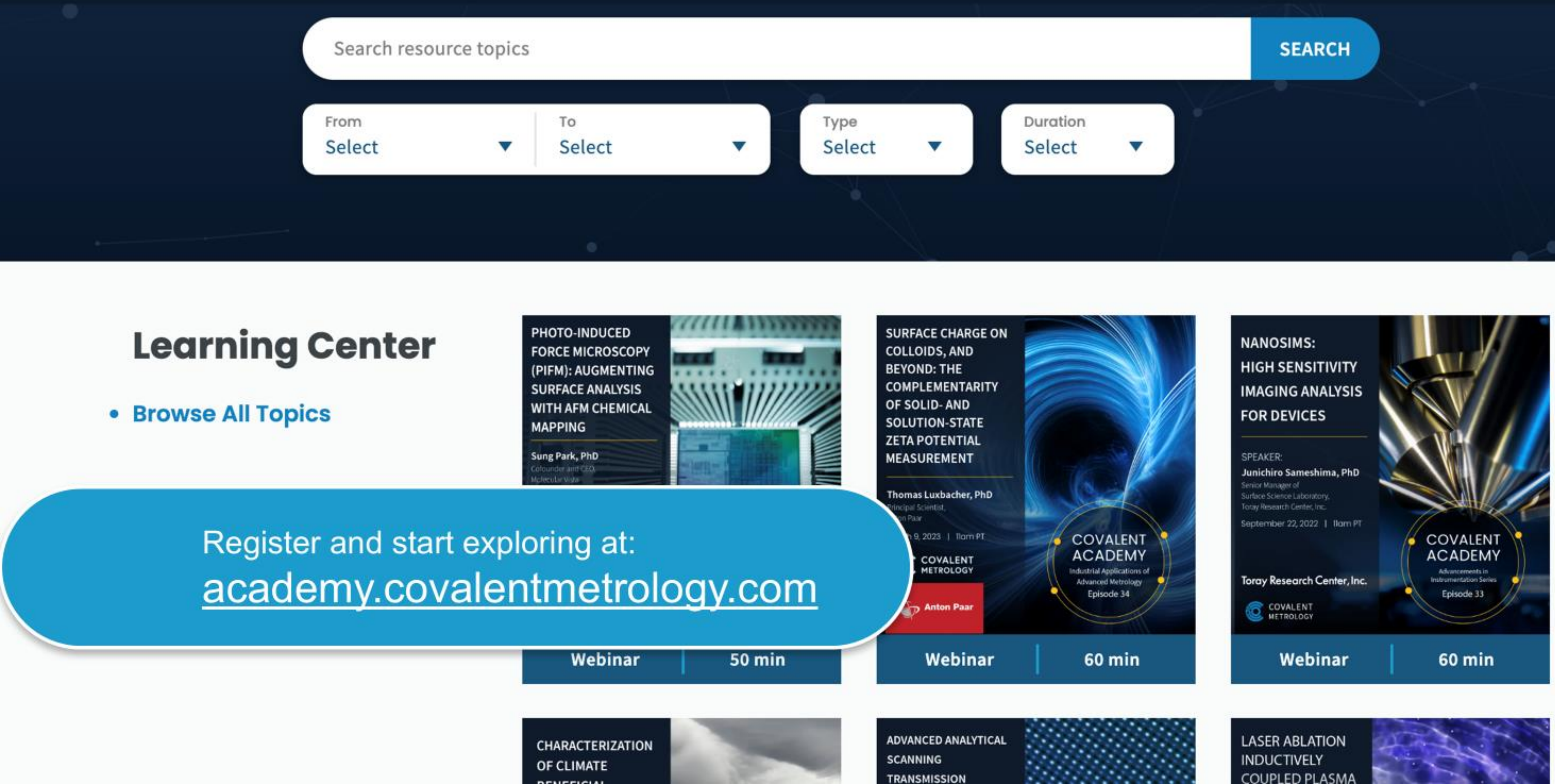
COVALENT METROLOGY

Want to learn more about Covalent's
Failure Analysis Services?

Talk with a Covalent Expert!

Schedule your Appointment now
with the link in the chat.

View On-Demand Recordings in the Covalent Academy



Register and start exploring at:
academy.covalentmetrology.com

Q & A Session

COVALENT METROLOGY

Thank you.