Solder-Flux-Associated Failures in Electronic Assemblies

Failure mechanisms, evidence limits, and process controls

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Key Findings

Flux residue becomes a reliability risk when it remains at a susceptible location and is exposed to moisture, electrical bias, or reactive metal. The resulting failures include leakage, corrosion, and electrochemical migration. The controlling variable is not the flux label alone; it is the completed assembly process, including material sequence, geometry, cleaning, rework, drying, coating, and service environment.

- A visible residue or halogen peak is evidence to investigate, not proof of source or causation.
- Residue trapped beneath components can hydrate and dehydrate, producing intermittent leakage that disappears during dry retest.
- Sequential use of nominally no-clean paste and a more active wave or rework flux can create a residue system not represented by either material qualification alone.
- The strongest conclusions combine electrical behavior, failure-site location, morphology, chemistry, process history, and appropriate comparisons.
- Cleaning must be qualified on representative low-access hardware and followed by verified drying before coating or encapsulation.

1. Technical Context

Flux removes oxide and promotes wetting while a solder joint forms. After soldering, the remaining material is no longer the original flux. It is a mixture of resin, activators, reaction products, dissolved metal species, solvent remnants, and material acquired from the assembly. That mixture may remain benign on an open surface yet become consequential in a narrow gap, beneath a component, inside a via, or adjacent to conductors.

The term no-clean describes an intended residue under qualified conditions. It does not establish that every residue quantity is safe in every geometry, environment, or material sequence. Likewise, chlorine or bromine detected by EDS can be consistent with activated soldering materials but is not a unique fingerprint for a specific product. Sound attribution requires the chemistry to agree with location, damage, electrical response, and process history.

2. Failure Mechanisms and Evidence

2.1 Chloride-bearing residue can sustain metal corrosion

Case 1027 documented corrosion of immersion silver and the underlying copper. The corrosion product contained residual chloride together with detergent and hard-water indicators. The evidence therefore points to a cleaning-system problem rather than a simple flux-product diagnosis: activated residue, detergent removal, rinse-water quality, and drying were parts of the same process.

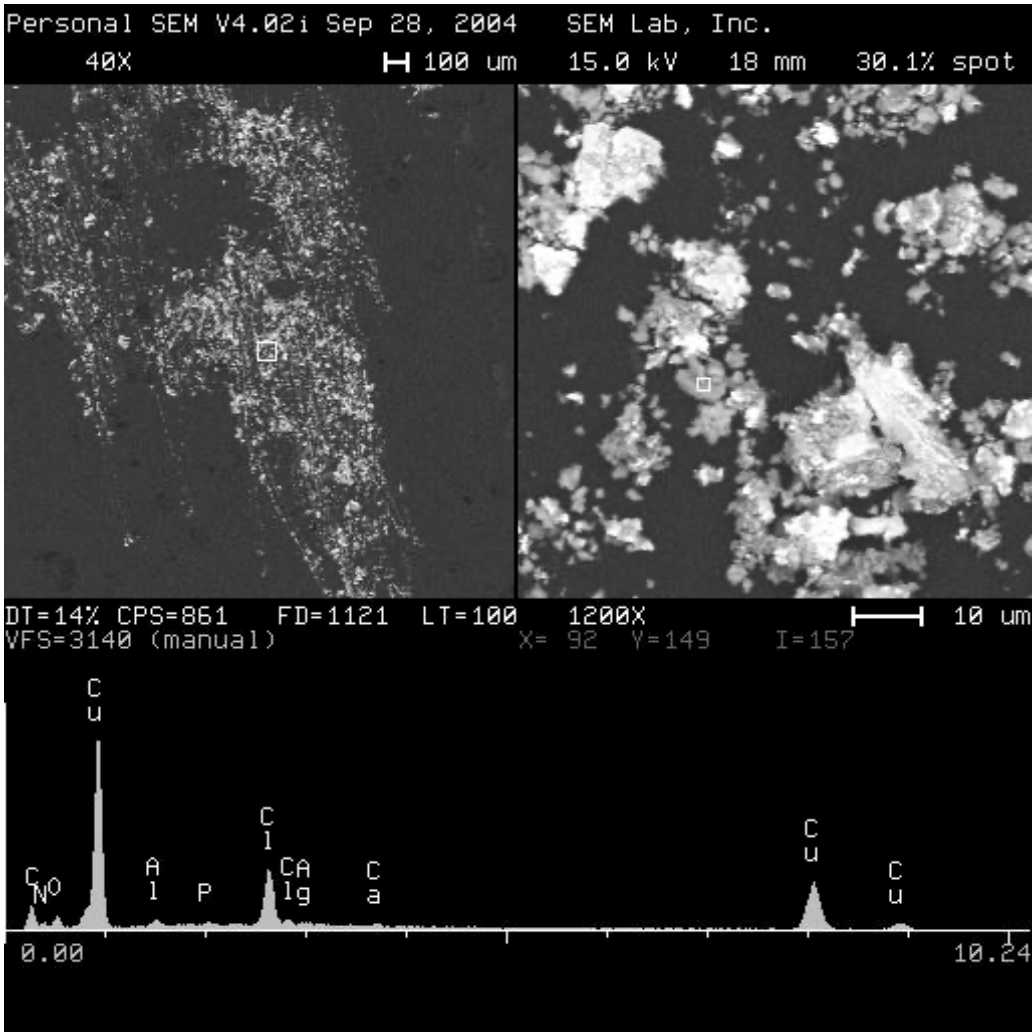

Figure 1. Case 1027: corrosion product at site 2 and its elemental spectrum. Chloride supports chloride-driven copper corrosion; phosphorus and the aluminum/calcium signal indicate that detergent and rinse-water residues also contributed to the local chemical environment.

2.2 Ionic residue can produce moisture-sensitive leakage

Case 2898 involved resistor networks with variable leakage between signals. Flux residue, corrosion products, and halide contamination were present under and around the devices. The reported leakage varied with ionic concentration, humidity, applied bias, time, and temperature. Hydration increased surface conduction; drying suppressed the symptom without removing the contaminant. A dry acceptance test could therefore pass an assembly while the underlying process defect remained.

Case 2898 - linked micrograph and EDS spectra

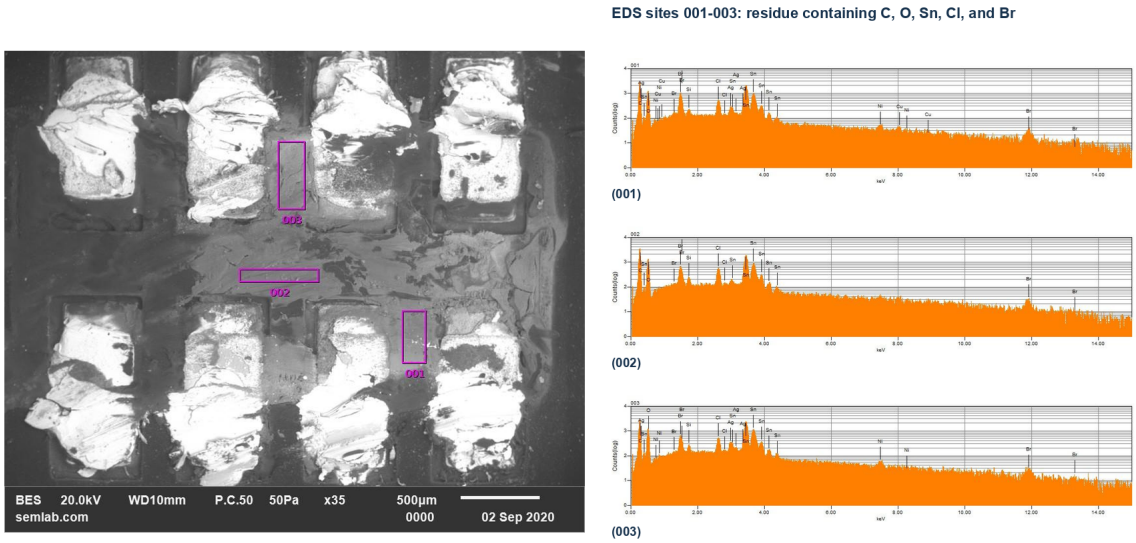

Figure 2. Case 2898: backscattered-electron image with EDS sites 001-003. The spectra collectively show residue containing carbon, oxygen, tin, chlorine, and bromine. The image establishes residue location and chemistry; the case electrical history establishes the moisture-sensitive leakage response.

2.3 Low-access geometry retains residue at the electrical surface

Case 2857 provides direct evidence beneath a failed capacitor. The material beneath the component occupied the same restricted region in which an external migration path could bridge the terminations. The investigation concluded that trapped solder-flux residue was the most likely cause of the reported external electromigration shorts. End-cap adhesion was a separate construction weakness that could aggravate the condition but did not replace the external path as the principal explanation.

Case 2857 - linked micrograph and EDS spectra

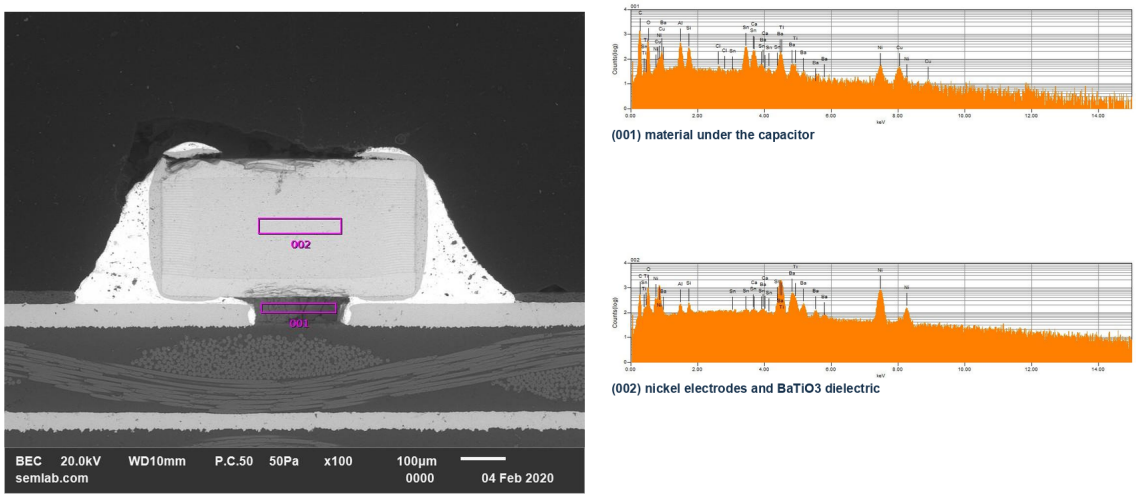

Figure 3. Case 2857: cross-section and corresponding spectra. (001) Material retained beneath the capacitor. (002) Nickel electrodes and barium-titanate dielectric. The geometry places retained material between the component and board where cleaning and drying access are restricted.

2.4 Sequential flux processes can create an unqualified residue system

Case 3087 documented corrosion and electrochemical migration beneath QFN devices. The process used no-clean SMT paste followed by a more active wave flux. The report concluded that existing paste residue could retain later activators and prevent their removal during cleaning. This failure mode is governed by the complete sequence: material compatibility, second-side exposure, component geometry, wash exchange, and drying. Qualification of each flux in isolation does not qualify the combined process beneath the product's actual packages.

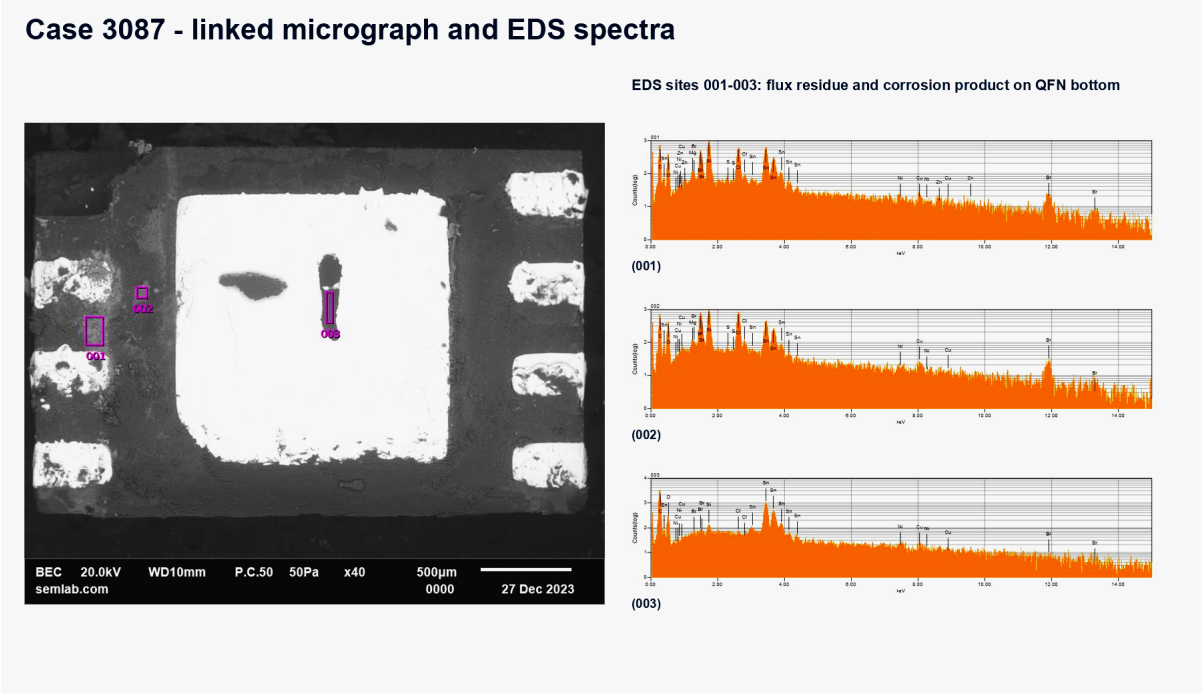

Figure 4. Case 3087: QFN bottom surface with linked EDS spectra. Sites 001-003 collectively represent flux residue and corrosion product on the package bottom. The family preserves the spatial relationship between the affected surface and the corresponding chemistry.

2.5 Leakage can progress to a permanent migration path

Case 1187 showed tin-lead electromigration paths on the resistor network and board surface. The report identified residual chloride, moisture or condensation, and electrical bias as the required conditions. The dendritic morphology matters because it moves the evidence beyond a generic residue observation: conductive material had grown across the insulating region between biased conductors.

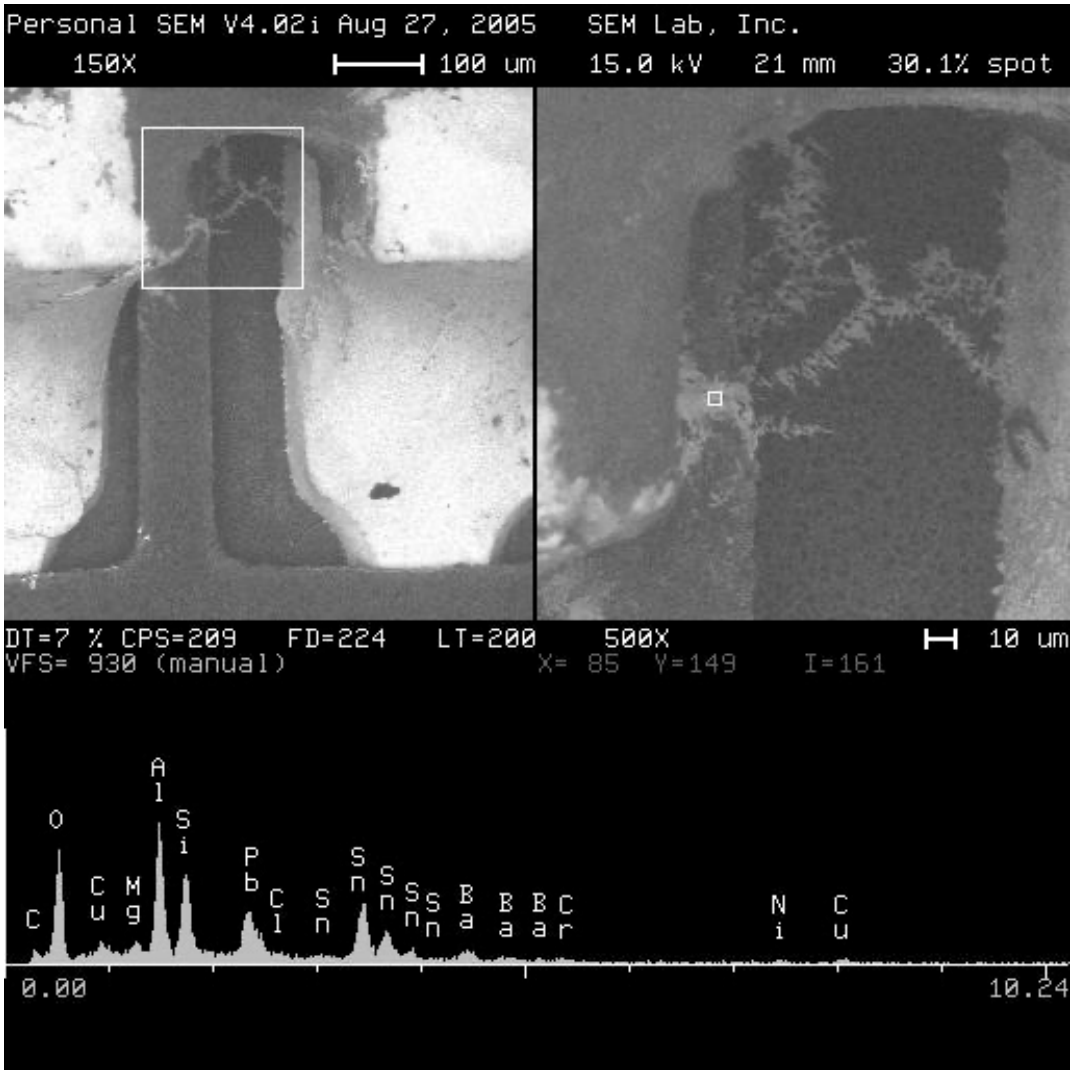

Figure 5. Case 1187: electromigration dendrites between pins 2 and 3 on the board surface. The overview establishes the conductor spacing; the higher-magnification view shows the dendritic path.

2.6 Entrapment can compound an independent manufacturing defect

Case 1080 demonstrates why flux-related evidence must be integrated with the underlying construction. A plating defect partly plugged a via and produced thin plating. Flux became trapped in the hole, and copper corrosion developed near the barrel fracture. The failure was not accurately described as flux alone: the plating defect created the vulnerable geometry, while retained reactive material and corrosion contributed to loss of continuity.

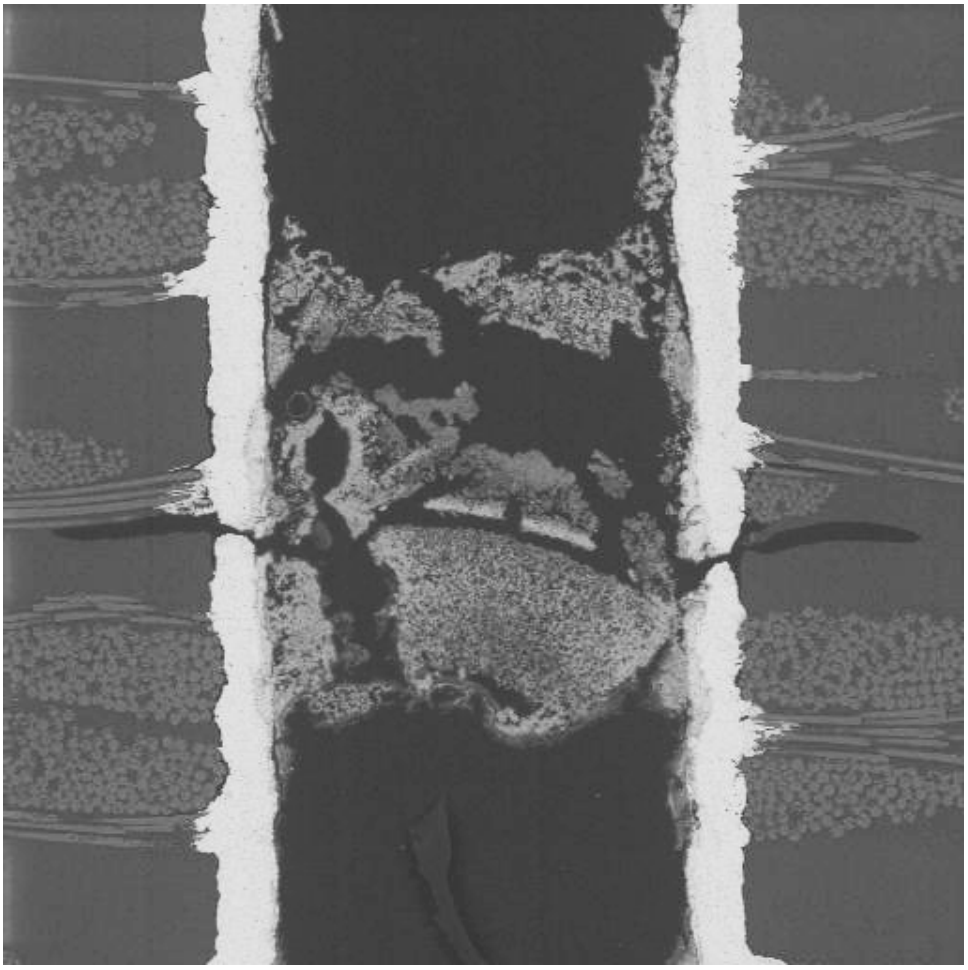

Figure 6. Case 1080: via microsection showing copper corrosion product near the barrel fracture. The image supports a combined mechanism involving a plating defect, flux entrapment, and corrosion.

2.7 The cases describe one failure chain with different endpoints

The six cases do not represent unrelated categories. They describe different points in the same physical chain. Residue first remains at a susceptible surface because the geometry or process prevents complete removal. Moisture then provides a conductive film or electrolyte. Dissolved ionic species increase surface conduction and participate in metal reactions. Applied voltage drives ionic transport, while exposure time determines whether the first observable result is reversible leakage, visible corrosion, or a permanent migration bridge.

The endpoint depends on the local materials and electrical conditions. A low-level surface path may produce intermittent current without visible damage. Reactive copper, silver, tin, or solder can corrode when the residue remains wet. Under sustained bias, mobile metal species can form a dendritic bridge. These outcomes can coexist: corrosion supplies mobile species, migration redistributes them, and drying temporarily increases resistance without reversing the material damage already produced.

This chain explains why corrective action aimed only at the failed component is often incomplete. Replacing a resistor network, capacitor, QFN, or board may restore operation while leaving the material sequence, inaccessible geometry, or cleaning process unchanged. Effective correction interrupts the chain upstream by preventing residue retention, removing ionic material, ensuring complete drying, or eliminating the environmental and electrical conditions that activate the path.

3. Evidence Limits

EDS identifies elements in the analyzed volume; it does not identify a commercial flux formulation. Chlorine and bromine may support an activated-residue hypothesis, but alternative sources include handling contamination,

detergent, hard water, environmental salts, laminate damage, and secondary soldering materials. Source attribution becomes defensible when site-specific chemistry agrees with the electrical symptom, process record, controls, and spatial distribution of damage.

Visible residue also has a limited meaning. Residue away from the failed circuit may be incidental. Conversely, a small amount under a component can be important if it lies between biased conductors and is exposed to moisture. Negative and mixed-cause cases must remain in the evidence base because they prevent a keyword search or isolated spectrum from being converted into a causal count.

Comparisons must also be interpreted carefully. A clean control supports a location-specific difference, but it does not by itself prove which process step introduced the material. A washed unit can demonstrate process sensitivity, yet board-to-board variation may limit the strength of the comparison. The most useful control changes one relevant variable while preserving component geometry, material history, electrical stress, and environmental exposure.

Image selection is part of the technical argument. A micrograph should show the claimed morphology or location, and an EDS family should retain the numbered analysis sites, matching spectra, and original site descriptions. A visually dramatic image that lacks this connection is weaker evidence than a restrained image family that allows the reader to trace each chemical result back to its analyzed region.

4. Failure-Analysis Sequence

- Preserve and photograph the assembly as received, including handling history and attempted cleaning.
- Reproduce the electrical symptom under controlled dry, humid, biased, and baked conditions when safe.
- Localize the failed circuit before destructive preparation and relate the electrical path to visible residue or damage.
- Use optical microscopy and SEM to establish geometry and morphology; use EDS for site-specific inorganic constituents and corrosion products.
- Use localized ion chromatography when ionic species and concentration matter. Use broad cleanliness tests for process monitoring, not site-specific source identification.
- Compare failed and unfailed units, washed and unwashed conditions, known materials, and intentional process changes.
- Verify corrective action by repeating the environmental and electrical condition that originally produced the symptom.

5. Process Controls

- Qualify the complete material and thermal sequence, including paste, wave flux, touch-up materials, cleaners, and coatings.
- Demonstrate cleaning and drying on representative low-access components rather than relying only on open-board coupons.
- Control wash chemistry, rinse-water quality, exchange beneath components, and final dryness.
- Treat rework as a controlled soldering process with material identity, application limits, cleaning requirements, and traceability.
- Do not coat, pot, or seal until cleanliness and dryness have been verified; encapsulation can trap contamination rather than neutralize it.
- Retain failed, control, and unfailed units so that source attribution can be tested rather than inferred from a single sample.

6. Conclusions

Flux-associated failures are system failures. Residue becomes damaging when chemistry, location, moisture, electrical bias or reactive metal, and time complete the mechanism. The reviewed cases show three recurring outcomes: reversible leakage, corrosion, and permanent electrochemical migration. They also show that flux

may be only one contributor when plating, adhesion, cleaning, rinse water, or process sequencing creates the vulnerable condition.

The practical control is to qualify and monitor the completed assembly process at the surfaces that matter. The practical analytical rule is equally direct: connect the electrical behavior to the failure location, preserve linked micrograph-and-spectrum families, state what each site represents, and stop the conclusion where the evidence stops.

References

IPC J-STD-004, Requirements for Soldering Fluxes, December 2023.

IPC J-STD-001, Requirements for Soldered Electrical and Electronic Assemblies, April 2024.

IPC-TM-650 2.3.25D, Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract, June 2005.

IPC-TM-650 2.3.28A, Ionic Analysis of Circuit Boards, Ion Chromatography Method, November 2012.

Case 1027, corrosion and cleaning-system evidence.

Cases 2898, 2857, 3087, 1187, and 1080, SEM Lab failure-analysis evidence.