Introduction

Why Routine Caustic Etching Should Be Avoided Before Anodising and Chemical Conversion Coating

Technical guidance for designers, customers, surface treatment processors and quality professionals

Recommended default: clean and deoxidise with the least substrate attack that achieves the required coating performance. Specify and control etching when metal removal is necessary.

Routine caustic etching can consume dimensional allowance, alter texture and create local attack without serving a defined engineering purpose. A controlled non-etch cleaning route is the preferred starting point for precision and functional aluminium components. The case is strongest for chemical conversion coating; anodising also includes legitimate appearance-driven and process-specific exceptions.

Purpose scope and executive summary
This publication challenges the automatic inclusion of sodium hydroxide etching before chemical conversion coating or anodising. It explains when that operation is unnecessary, what damage mechanisms must be considered and how to select a controlled alternative. The objective is to preserve the aluminium component while delivering the cleanliness, surface condition and coating performance required by its design.

The principal audience is designers, purchasers, metal finishers and auditors responsible for wrought and cast aluminium parts. Attention is given to precision-machined, aerospace and defence hardware, susceptible alloys, assembled structures, blind holes and features that restrict drainage. Architectural and decorative anodising are discussed where an intentional etched texture is required; chemical milling and stripping are exceptions rather than the baseline route.

Cleaning, deoxidising and etching perform different functions. An inhibited soak cleaner removes process soils. An acid deoxidiser or desmutter removes oxide and appropriate residues. A caustic etch deliberately dissolves aluminium. Calling all three operations “cleaning” can conceal unnecessary material removal and its associated risks.

The recommendation is to begin with a qualified non-etch soak cleaner, effective rinsing and an alloy-compatible acid deoxidiser/desmut where required. Verify that this sequence achieves the specified coating performance and does not produce unacceptable substrate attack. “Non-etch” is a performance description under defined operating conditions, not a promise of absolutely zero metal loss.

Do not remove a mandated etch from an approved aerospace or bonding route without the required engineering approval. Do not substitute a generic acid dip for a validated deoxidising stage. Acid products can attack susceptible microstructures too, especially when fluoride, excessive exposure or depleted chemistry is involved. The complete process, including rinse conditions, is the unit to qualify.

Key decision: What measurable requirement justifies removing metal at this stage? If none is defined, replace by controlled cleaning and deoxidising.

Unless specifically called out as a requirement in contract or specification, caustic etching of Aluminium in surface treatments must be avoided.

What the standards and evidence establish

Chemical conversion coating

MIL-DTL-5541F, clause 3.2, requires a water-break-free surface after cleaning and rinsing. Its clause 6.6 prefers non-etch cleaners, especially for wrought alloys, warns about pitting and intergranular attack and advises **avoiding** alkaline etching, particularly on assemblies. Section 6 is explanatory, nonmandatory information: this is strong technical guidance, not an unconditional contractual ban.

Testing for substrate attack

ASTM F2111-22 provides a practice for testing and measuring intergranular attack and end-grain pitting caused by aircraft production or maintenance chemicals. Its scope includes cleaners, deoxidisers and etchants. It does not supply all qualification requirements or universal acceptance limits; those come from the applicable procurement, material or process requirements. It also recognises that water quality can affect the results.

Cleaning deoxidising and etching are different

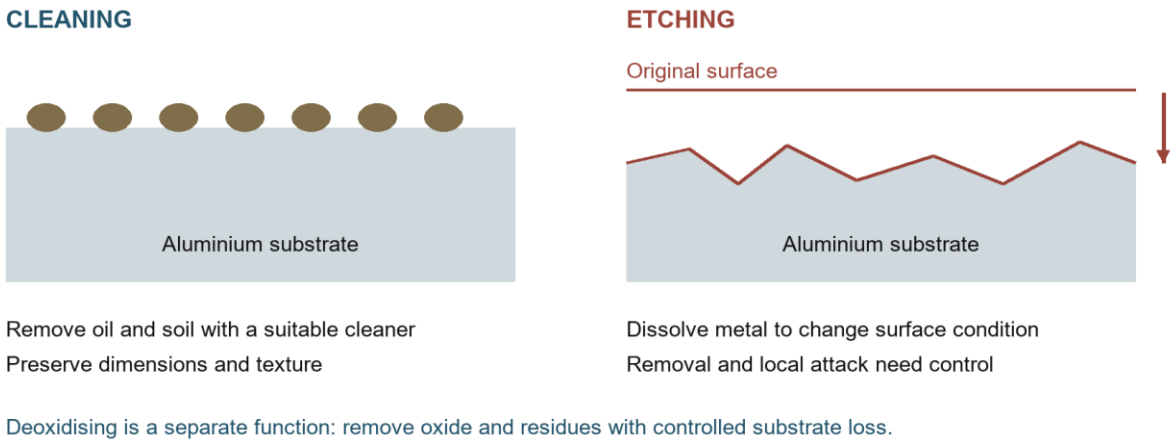


Figure 1. Cleaning removes soils; etching removes substrate. Deoxidising has its own controlled function. Geometry is illustrative.

Cleaning removes contamination

The cleaner must address the actual soils: machining oils, emulsions, handling grease, polishing residues and particulate contamination. Detergency, emulsification or other approved soil-removal mechanisms should do this work without relying on bulk dissolution of the aluminium. A cleaner may be mildly alkaline, neutral or acidic. Its pH alone does not define whether it attacks the alloy.

Deoxidising and desmutting condition the surface

Deoxidising removes oxide or heat-treatment scale as appropriate to the subsequent coating process. Desmutting removes the residual material left by previous chemical or mechanical treatment. One proprietary product may perform both functions. Chemistry must be matched to the alloy, oxide condition and residue; a copper-rich wrought alloy and a silicon-rich casting do not necessarily respond to the same product.

Etching is intentional material removal

A caustic etch can create a specified matte texture or remove a defined surface layer. It may reveal differences between grains or constituent particles. Even a visually even finish should not be assumed to represent uniform dissolution at the microscopic scale. The manufacturing route should identify the required change, its acceptance criteria and its permitted metal-loss budget.

Stage	Question to answer	Evidence to retain
Non-etch cleaning	What soil must be removed?	Soil-removal capability and alloy compatibility
Deoxidising/desmutting	What oxide or residue must be removed?	Clean, conditioned surface and controlled attack
Etching	What metal removal or texture is required?	Authorised purpose, measured loss and final finish

A dull surface is not proof of cleanliness. A water-break-free surface is useful evidence of wetting, but does not prove the absence of ionic contamination, smut or metallurgical damage.

Chemistry and metallurgy of caustic attack

Aluminium and its oxide are amphoteric: they can dissolve under sufficiently acidic or alkaline conditions. Strong caustic removes the surface oxide and permits dissolution of the metal. A useful simplified representation in aqueous alkaline solution is shown below. Actual bath speciation and rate depend on composition and operating conditions.

$$2\,Al + 2\,OH^- + 6\,H_2O \rightarrow 2\,[Al(OH)_4]^- + 3\,H_2$$

The reaction produces soluble aluminate species and hydrogen. Hydrogen generation is an operational ventilation and ignition-control issue; it is not, by itself, evidence of classical steel-type hydrogen embrittlement in an aluminium part. Follow the product safety data and the site's approved risk controls. Heat release, exposed area and loading also matter to safe operation.

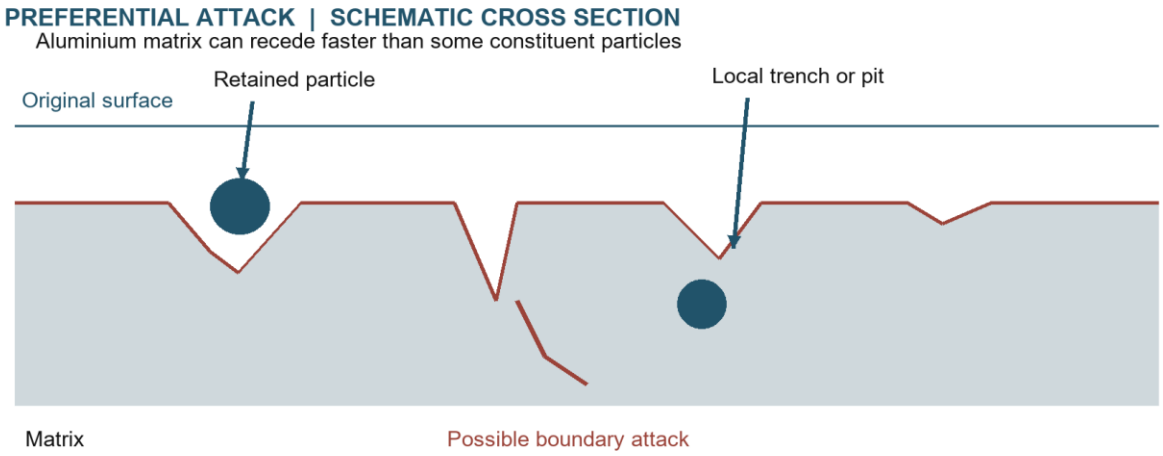


Figure 2. Possible differential dissolution around constituent particles and grain boundaries. Not all alloys or particles respond identically; the figure is not a prediction of attack depth.

Alloy microstructure changes the response

Aluminium alloys contain solute, precipitates and constituent particles with different chemical and electrochemical behaviour. Local differences can produce particle retention, undermining, detachment or preferential particle dissolution. Research on AA5754 and AA5052 reports different dissolution and particle-population changes in alkaline etching. Findings for these alloys should not be turned into a universal rate or failure rule.

Grain-boundary condition, heat treatment, prior processing and exposed working direction affect susceptibility. Copper-bearing phases, iron-containing particles and silicon-bearing residues require particular attention to product compatibility. An alloy-series label alone is insufficient to select a process or predict local attack.

Control the full exposure

Specify concentration, temperature, contact time, bath loading, dissolved aluminium, additives and replenishment criteria. Include transfer and drain time in the exposure assessment. A part carrying active solution continues to be exposed after it leaves the tank. Evaluate the least favourable credible conditions, including aged baths, permitted maximum dwell and interrupted transfers.

Material loss dimensions and surface texture

Caustic removal consumes real metal. Coating growth cannot be relied upon to restore the original component: a conversion film does not repair geometry, and anodising combines substrate consumption with outward oxide growth. Treat precleaning, deoxidising, deliberate etching and any stripping/rework as contributors to the dimensional budget.

A simple dimensional example

For uniform removal of depth e from each of two opposing surfaces, an external thickness falls by approximately 2e and a hole diameter increases by approximately 2e. If a process removes 5 µm from each side of a 10.000 mm plate, its thickness becomes approximately 9.990 mm before coating. The same depth inside a 10.000 mm bore gives approximately 10.010 mm. These are geometric illustrations, not recommended removal values or measured etch rates.

Real attack may be nonuniform. Threads, sharp edges, sealing lands, thin walls and small-radius features can respond differently from a flat coupon. Assess local dimensions and texture where function depends on them. A bath-average mass-loss result cannot reveal the deepest local pit.

Feature	Possible consequence	Recommended control
Fits and bearing seats	Loss of interference or excessive clearance	Final-condition tolerance and representative dimensional measurements
Threads and small edges	Profile change, crest loss or edge rounding	Defined exclusions or approved masking; verify critical features
Thin walls and cladding	Reduced section or consumption of protective cladding	Removal allowance and cumulative rework limit
Sealing and contact surfaces	Altered roughness, contact or sealing behaviour	Specified texture and functional acceptance
Fatigue-sensitive surfaces	Local pits may act as stress raisers	Engineering assessment and qualified attack limits

Measure removal and texture separately

Mass loss divided by exposed area and density gives an average equivalent removal depth. It is useful for monitoring, provided the test method controls oxide/residue removal, area and weighing uncertainty. Combine it with feature measurements, surface profilometry and metallography where warranted. State whether measurements describe average recession, maximum local penetration or surface roughness; these are not interchangeable.

Record roughness in the required parameters and locations, together with an agreed visual standard when appearance matters. Do not use roughening to conceal machining damage or to replace proper soil removal. The coating should be evaluated on the surface the approved route actually creates.

Recommended practice: allocate metal loss before processing, then verify the final part. Include repeat exposures and authorised rework in the allowance.

Pitting and differential particle attack

Local dissolution can leave pits, trenches around particles or cavities after particles detach. Such features may be confused with pre-existing casting porosity, machining damage or corrosion. Establish the incoming condition and compare representative before-and-after specimens. A satisfactory overall colour or matte appearance does not establish freedom from local substrate damage.

Intergranular attack

Intergranular attack follows susceptible grain-boundary regions or adjacent material. It may extend below the visible surface and therefore needs an appropriate sectioning and examination method. The possibility is explicitly recognised in the conversion-coating guidance and in aircraft chemical-process testing. It is a risk to control, not an inevitable result of every caustic exposure.

End grain pitting

End-grain pitting concerns preferential attack at surfaces exposing the ends of the worked grain structure, for example cut ends or machined features in wrought stock. The relevant orientation may not be represented by a coupon cut parallel to the product surface. Include exposed end-grain faces when the component or specification makes them relevant. ASTM F2111 provides the measurement framework; it does not prescribe one maximum depth for all aluminium parts.

Condition	Useful observation	What the observation cannot establish
General etch recession	Mass loss or dimensional change	Maximum local penetration
Particle-related pitting	Surface microscopy and selected sections	All grain-boundary attack from appearance alone
Intergranular attack	Sections with documented preparation and measurement	Service acceptability without engineering limits
End-grain pitting	Relevant end orientation and sections	Compatibility of other stock directions or tempers

Recommended qualification approach

Use the specified alloy, temper, product form and working direction. Where there is no agreed criterion, obtain engineering agreement before processing critical hardware. Include realistic soils and the complete cleaner–rinse–deoxidiser route, and test deliberate etching separately if it is added. Challenge the upper permitted exposure and appropriate bath-age conditions without assuming that harsher chemistry is the only relevant variable.

Retain specimen identification, bath condition, time and temperature, preparation method, magnification, measurement locations and results. Use an appropriate unprocessed comparison to distinguish manufacturing structure from process-induced attack. Coating corrosion or adhesion tests complement this examination but do not measure the same property.

Changing to acid deoxidising does not remove the need to qualify substrate compatibility. Control both alkaline and acid stages against the applicable acceptance criteria.

Preferred non etch preparation sequence

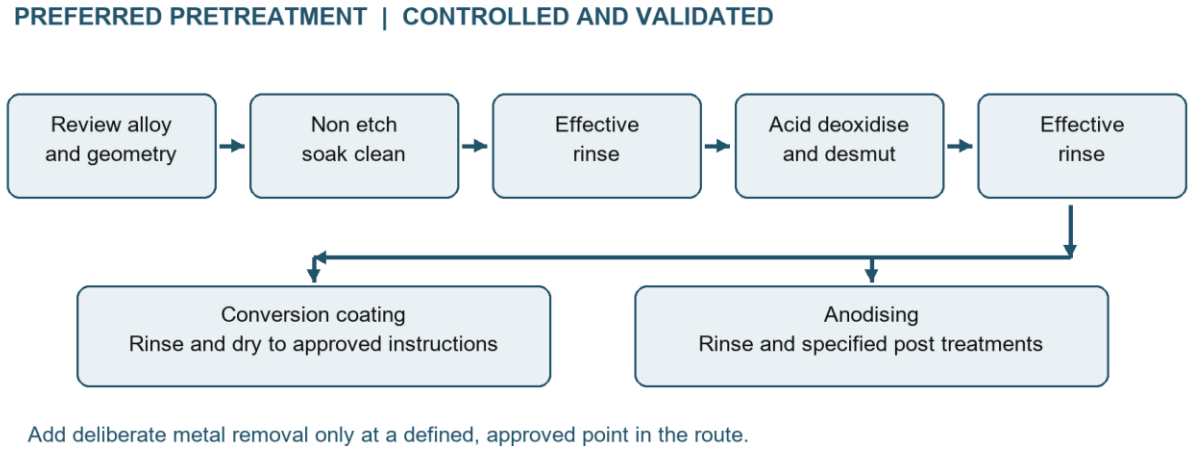


Figure 3. Recommended starting route for functional aluminium parts. Labels are conceptual; controlled supplier and customer instructions define the actual operations.

Select the chemistry for the part and its soil

Use an inhibited, aluminium-compatible soak cleaner with demonstrated removal of the actual production contamination. Obtain supplier operating limits and compatibility information for the relevant alloys. Verify non-etch performance under the permitted concentration, temperature, dwell and bath-age range. Avoid a cleaner that works only by consuming enough metal to lift off the contamination.

For difficult soils, approve a compatible preclean or mechanical method where necessary. Control abrasives, polishing compounds and handling contamination. A repeatable cleaning process should not depend on informal scrubbing that changes texture or introduces embedded particles. Segregate alloys and soils when their requirements differ materially.

Control deoxidising and desmutting independently

After effective cleaner rinsing, use a proprietary acid deoxidiser/desmutter suitable for the alloy and subsequent coating. Determine whether oxide, heat-treatment scale, copper-rich residues or silicon-rich smut must be removed. Fluoride-bearing or other aggressive formulations may be necessary for some conditions but require specific control of substrate attack. Product labels alone do not demonstrate compatibility.

Do not treat a simple acid neutralisation dip as a proven deoxidiser/desmutter. Conversely, a deoxidiser may perform neutralisation but still requires adequate preceding and following rinses. Set endpoints, transfer windows and contamination limits in the approved instruction rather than extending dwell until the surface looks bright.

Demonstrate the alternative before releasing production

Compare the proposed route with the approved baseline using representative material and features. Measure soil removal, residual smut, dimensions and local attack as appropriate; then apply the coating and evaluate its specified properties. Include realistic loading and the geometry that is hardest to rinse. Verify any required corrosion, paint adhesion, electrical contact, thickness, seal or bonding tests.

Where oxide condition or an approved process permits omission of a deoxidising stage, demonstrate this through qualification rather than forcing an acid dip into every route. The preferred sequence is a starting framework, not an instruction to override an authorised process. Retain approved limits and reaction plans for excursions.

Recommended route for conversion coating

For functional chemical conversion coating, begin with a route that preserves the manufactured surface and avoids unnecessary bulk metal dissolution. Match the coating product, application method, type/class and subsequent paint system to the contract. Do not infer that a product qualification alone qualifies every possible preparation route.

1 Contract and incoming condition review

Confirm material, critical dimensions, coating requirements, areas to mask and whether assembled geometry can be treated and rinsed. Record pre-existing corrosion, stains or surface damage.

2 Preclean where needed and non-etch soak clean

Remove the actual machining and handling soils within the approved operating window. Avoid unapproved iron-bearing abrasives where MIL-DTL-5541 applies.

3 Effective rinse and cleanliness verification

Demonstrate the specified wetting condition. Use a suitable water-break check on accessible areas, supported by other checks for recesses or residues.

4 Alloy-compatible acid deoxidise and desmut

Condition the surface using the qualified product and dwell. Omit only when the validated route allows it. Include attack control for susceptible material.

5 Effective rinse and controlled transfer

Remove acid and residues, verify solution exchange in recessed features, and meet the permitted wet-transfer interval.

6 Apply the specified conversion coating

Use approved bath limits and application method. Preserve the chosen coating system; an unintended acid or alkaline carryover can alter its reaction.

7 Specified post-rinse drying and inspection

For conventional rinse-required products, rinse with controlled-quality water and dry to product instructions. For an authorised no-rinse product, use its approved route instead. Inspect and perform the required process-control and conformance tests.

What to verify at release

Confirm coating continuity and serviceability together with the required corrosion and adhesion performance. For low electrical resistance applications, use the agreed test conditions; appearance alone is insufficient. Confirm that critical dimensions remain within tolerance and that recessed features do not bleed out after drying.

ASTM F22 describes a qualitative test for hydrophobic films. Its limitations include rough/porous surfaces and areas that cannot be observed; it is not a general chemical-residue assay. Use it as a defined control, not as the sole proof of complete preparation.

Where a contract requires etching, retain and qualify that operation. Where it does not, assess non-etch preparation as the baseline and document any reason to add metal removal.

Recommended route for anodising

Choose preparation around the required anodic coating and function. Protective, hard, decorative and adhesive-bonding anodising have different performance priorities. An as-machined functional component does not automatically require a decorative matte etch. AAC identifies separate nonetched and etched preparation designations.

1 Review alloy coating and finished geometry

Confirm the invoked standard and edition, coating thickness, colour, sealing or bonding requirements, masking and rack contact positions. Include allowance for oxide growth and substrate consumption.

2 Preclean where needed and non-etch soak clean

Remove soils with a validated, alloy-compatible cleaner. Check that any residual film does not interfere with subsequent conditioning or current distribution.

3 Effective rinse

Remove cleaner carryover and demonstrate exchange in pockets and holes. Inspect the wet surface where the approved route requires it.

4 Conditional specified surface modification

Add an etch, brightening or mechanically disturbed-layer removal step only where the required finish or approved process calls for it. Control metal loss, then rinse and condition the surface in the approved order.

5 Qualified acid deoxidise and desmut followed by rinse

Remove oxide and residues within the validated window. Where the route uses another approved preparation method, follow that method. Transfer within the approved interval.

6 Specified anodising and subsequent rinses

Control electrical contact, electrolyte condition, temperature, current/voltage programme and time to the invoked procedure. Confirm that narrow or closed features can be treated as required.

7 Dye seal or bonding treatment as specified

Apply the required post-treatment. Do not assume that every anodic coating is sealed: structural adhesive-bonding routes may require an unsealed surface. Observe cleanliness and time limits before primer or bonding.

8 Dry inspect and test

Verify dimensions, coating thickness and the applicable appearance, corrosion, wear, seal or adhesion requirements. Include feature coverage and retained-solution checks.

Removing unnecessary etching does not mean omitting essential oxide removal or surface conditioning. Validate coating formation and performance on the proposed prepared surface.

Legitimate exceptions and controlled etching

An etch is justified when it achieves a specified and validated result that cannot be omitted from the authorised route. The concern is habitual metal removal without a defined purpose, not the existence of controlled etching as an engineering operation.

Legitimate case	Required justification and controls
Specified matte or satin decorative finish	Agreed texture/appearance reference, alloy response, metal allowance and coating performance. An etched aesthetic is an intended change, not a cleaning criterion.
Contract or OEM process mandates the stage	Follow the controlled route. Submit any alternative for the required approval and qualification before production substitution.
Defined surface layer must be removed	Demonstrate the layer condition and removal endpoint; bound the total loss and local attack. Do not assume all machining disturbance requires caustic removal.
Qualified adhesive-bonding preparation	Retain validated surface preparation and transfer limits. Demonstrate durability with the specified bonding system; generic coating tests are insufficient.
Chemical milling or intentional dimensional removal	Treat as a distinct engineered metal-removal operation with masking, removal-rate and dimensional controls.
Authorised stripping and rework	Use an approved stripping route, determine remaining allowance, and limit cumulative cycles. Inspection of the old coating does not establish substrate acceptability after stripping.

A decision record for every retained etch

Record the requirement, approval, alloy/temper/product form, allowed average and local loss, appearance target, bath limits and full dwell window. Include transfer, rinsing, verification and rework allowances. Assess the result against the final part drawing.

Alternatives are not automatically harmless

Acid etching, bright dipping, blasting and abrasion can also damage the substrate. A substitute must preserve the required result. Lower average removal does not prove lower maximum pit depth; brightness does not prove bond durability.

A primary study of cast A535 found that controlled alkaline etching reduced surface intermetallics and improved anodic-film characteristics under the tested conditions. This is a legitimate counterexample to any claim that etching always worsens performance. It does not validate those conditions for other alloys or establish that every part should be etched.

Compare total route costs, including dissolved aluminium, sludge, rinsing, energy and rejects. Quantify environmental savings using line data at equivalent coating performance and production volume. EPA supports carryover reduction and improved rinsing, not a part-specific business case.

Guidance for designers, customers and finishers

Designers and customers

Specify the required function and finished condition clearly: coating standard/edition, type or class, thickness where applicable, colour/texture, sealing or bonding requirements, critical dimensions, masked areas and permitted rack contacts. Identify alloy, temper, product form, clad surfaces and any susceptibility or fatigue-critical areas. An ambiguous request for “standard pretreatment” invites inconsistent routes.

Review blind holes, narrow passages, permanent joints and mixed-material assemblies before release. Give the finisher enough information to assess access, wetting, drainage and coverage. Discuss treatment before assembly or approved masking when permanent entrapment is foreseeable. A drainable design supports rinsing but does not itself prove coating coverage.

Suggested purchase order wording for adaptation

Use a qualified aluminium-compatible non-etch cleaning and controlled deoxidising/desmutting route unless the drawing or approved process requires deliberate metal removal. Any added etching or change to a mandated route requires the applicable engineering authorisation. Maintain specified final dimensions and surface condition and demonstrate adequate rinsing of recessed features. [Complete part-specific limits and approval references before issue.]

Use this wording only after aligning it with the governing specification and existing approval obligations. Define any metal-loss or local-attack limit and the corresponding test method explicitly; do not leave the finisher to infer an acceptance threshold from this publication.

Metal finishers and process owners

List cleaning, deoxidising, desmutting and etching as separate purposes in the work instruction. Review habitual etch stages against the actual requirement. Retain approved exceptions and train operators to distinguish poor soil removal from an oxide or smut problem. **Extending etch dwell to solve a cleaner failure transfers the problem into the substrate**.

Establish control of bath condition, oil loading, time, temperature, additives and rinse performance (use the 1-minute rule). Define response to delayed transfers, a dropped rack, depleted cleaner, rinse-water excursions or failed cleanliness checks. Contain affected work, assess exposure and obtain the required disposition; do not repeat a full route automatically on dimensionally sensitive parts.

Use representative coupons and, where needed, sacrificial geometry or first-article parts. Flat coupons are helpful for coating control but may miss end-grain attack, trapped-liquid contamination and feature-specific dimensional loss. Record changes to product, supplier, alloy range, agitation, loading or rinse design and assess requalification obligations.

Accountability without unsupported accusations

Describe an unexplained caustic stage as a legacy or habitual process choice that needs review. It may have originated in an appearance requirement or an earlier approved route. The appropriate challenge is to the technical justification and evidence, not to the competence or motives of an individual finisher.