

Cross-Hatch Adhesion Testing - Best Practices

Fluid Color UV/LED Inkjet Printing

• Why Cross-Hatch Adhesion Testing?

- **Industry Standard:** Cross-hatch adhesion testing per ASTM D3359 Method B is the globally recognized laboratory method for evaluating whether a UV/LED inkjet ink film is properly bonded to its substrate. It is the correct method referenced in UV inkjet patent literature, ink qualification documents, and OEM acceptance criteria.
- **Scientifically Valid:** Unlike ad-hoc tape tests using mounting adhesive or transfer tape, ASTM D3359 controls tape tack, dwell time, pull angle (180°), and uses a scribed lattice grid, making results reproducible, comparable, and meaningful across batches, substrates, and operators.
- **What It Measures:** The test reveals the weakest adhesion interface — whether that is ink-to-substrate, coat-to-coat (primer / white / CMYK / varnish), or cohesive failure within the cured ink film itself. This information directly guides process corrections.
- **Benefits at a Glance:** Fast (under 5 minutes per sample) • Low cost • No special equipment beyond a cutter and standardized tape • Quantitative 0B–5B rating scale • Factors in the full process from surface prep through cure • Ideal for new substrate qualification, adhesion promoter validation, and production QC sign-off.

• The Correct ASTM Standard for UV/LED Inkjet

- **ASTM D3359 Method B — Cross-Cut Tape Test (Laboratory):** This is the preferred method for UV inkjet on rigid substrates (acrylic, polycarbonate, aluminum, glass, rigid PVC, etc.). Method B uses a multi-blade cross-hatch cutter to produce a precise lattice pattern of either 6×6 or 11×11 cuts at 1 mm or 2 mm spacing depending on film thickness. It is specifically recommended for coatings up to 125 µm (5 mils) — exactly the range of UV inkjet ink films.
- **ASTM D3359 Method A — X-Cut Tape Test (Field):** The X-cut variant is acceptable for field verification or thick coatings greater than 5 mils. For production lab sign-off on UV inkjet prints, **Method B is always preferred due to its higher resolution and repeatability.**
- **Companion Standards to Be Aware Of:** ISO 2409 (Cross-Cut Test) is the international equivalent of ASTM D3359 Method B and uses a 0–5 scale (reversed — 0 is best). ASTM D3002 is referenced in some UV ink patents for plastic substrates. For post-aging adhesion verification (after UV exposure, salt spray, or immersion), ASTM D3359 is run as a follow-on test after those conditioning procedures.

Cross-Hatch Adhesion Testing - Best Practices

Fluid Color UV/LED Inkjet Printing

• Equipment & Materials Required

- **Cross-Hatch Cutter:** Use a multi-blade cutter with hardened steel blades at 1 mm spacing for films under 60 μm , or 2 mm spacing for 60–125 μm films. Recommended tools: Gardco PA-2054 (11-tooth, 1.5 mm), BYK Gardner cross-cut kits, or equivalent ASTM D3359-compliant cutters. Replace blades regularly — dull blades tear rather than cut cleanly and will produce false failures.
- **Standardized Test Tape:** Use ONLY Permacel P-99 (formerly 3M 99) or equivalent tape specified in ASTM D3359. This tape has a defined tack level of approximately 36 N/25mm. Do NOT substitute with mounting tape, transfer tape, packaging tape, or masking tape — these have dramatically different tack values and will invalidate the test. The whole point of the standard is controlled tape tack.
- **Soft Brush:** A clean, soft-bristle artist's brush or the brush included with cross-hatch kits. Used to remove loose particles from the cut area before tape application — 5 strokes minimum.
- **Magnification Loupe or Camera:** 4–10x magnification helps accurately assess the percentage of squares with ink removal when rating borderline results.
- **Test Log / Data Sheet:** Document substrate, ink set, adhesion promoter used, cure energy (mJ/cm^2), date, operator, and resulting 0B–5B rating. This creates a traceable QC record for each substrate qualification.

• Step-by-Step Test Procedure — ASTM D3359 Method B

- **Step 1 — Surface Prep:** Ensure the print sample is at room temperature ($23 \pm 2^\circ\text{C}$). The test area must be flat and free of surface blemishes. Allow UV-cured prints to condition for a minimum of 30 minutes (or per ink manufacturer specification) before testing. Note: some adhesion promoter chemistries continue to crosslink for up to 24 hours post-cure.
- **Step 2 — Cut the Lattice:** Using the cross-hatch cutter and guide template, make 6 (or 11) parallel cuts through the ink film to the substrate surface. Rotate 90° and repeat to form the lattice grid. Apply uniform pressure — cuts must reach the substrate but not gouge it deeply. Use a single smooth stroke per cut line.
- **Step 3 — Brush the Area:** Brush the cross-hatched area 5 times with the soft brush at a 45° angle, then 5 times in the opposite direction, to remove all loose ink chips and debris before tape application.
- **Step 4 — Apply Tape:** Cut a 75 mm (3") piece of Permacel P-99 tape. Center it over the lattice and press firmly using the eraser end of a pencil or the back of the cutter tool. Smooth outward from center to eliminate air bubbles. Allow tape to dwell for 60 ± 30 seconds.
- **Step 5 — Remove Tape:** Grip the free end and remove the tape in a single rapid, smooth motion at as close to 180° (back over itself) as possible. A slow or angled pull changes the peel force and invalidates the result.

Cross-Hatch Adhesion Testing - Best Practices

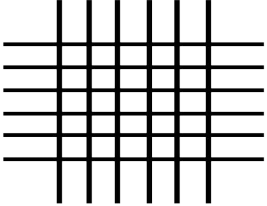
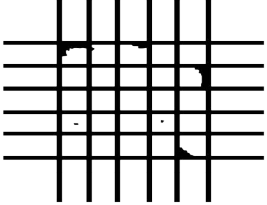
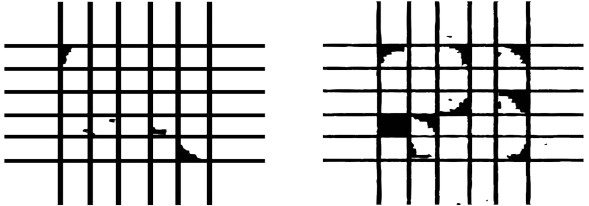
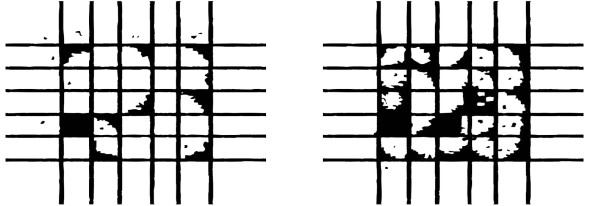
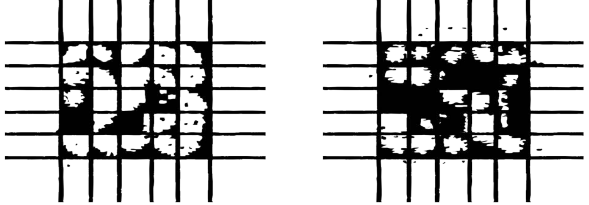
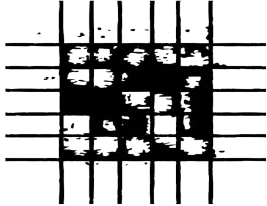
Fluid Color UV/LED Inkjet Printing

- **Step 6 — Inspect & Rate:** Examine the cross-hatched area immediately under good lighting and magnification. Compare to the ASTM D3359 reference diagrams and assign a 0B–5B rating (see Rating Scale section on next page).
- **Critical Surface Preparation Before You Print & Test**
 - **Clean the Substrate:** The surface must be dust-free, oil-free, and static-free before applying adhesion promoter or printing. Use IPA (isopropyl alcohol) wipe-down on most rigid substrates. Contamination is the single most common cause of 0B–2B failures.
 - **Check Surface Energy with Dyne Pens:** UV inkjet ink requires a minimum surface energy of 38–42 dynes/cm for acceptable wetting. Test with dyne pens before printing. Most untreated plastics (acrylic, polycarbonate, PE, PP) fall below this threshold and require corona treatment, flame treatment, or a chemical adhesion promoter.
 - **Apply Adhesion Promoter When Required:** For difficult substrates such as acrylic, glass, polycarbonate, or powder-coated aluminum, apply a compatible UV/LED adhesion promoter (e.g., Fluid Color GBR-1 GlassPRO) via wipe-on or inline jetting prior to printing. Allow proper flash/dwell time per the product data sheet before printing over it.
 - **Verify Cure Energy (mJ/cm^2):** Under-cured UV ink is one of the most frequent causes of cross-hatch failure. Use a UV radiometer to verify that your LED lamp is delivering the required cure dose at the print speed in use. A properly cured UV inkjet film should be tack-free, hard, and non-yellowing.

Cross-Hatch Adhesion Testing - Best Practices

Fluid Color UV/LED Inkjet Printing

• ASTM D3359 Method B — Rating Scale (0B to 5B)

ISO Class: 0/ASTM Class: 5B The edges of the cuts are completely smooth; none of the squares of the lattice is detached	
ISO Class: 1/ASTM Class: 4B Detachment of small flakes of the coating at the intersections of the cuts. A cross-cut area not significantly greater than 5% is affected.	
ISO Class: 2/ASTM Class: 3B The coating has flaked along the edges and/or at the intersections of the cuts. A cross-cut area significantly greater than 5%, but not significantly greater than 15% is affected.	
ISO Class: 3/ASTM Class: 2B The coating has flaked along the edges of the cuts partly or wholly in large ribbons, and/or it has flaked partly or wholly on different parts of the squares. A cross-cut area significantly greater than 15%, but not significantly greater than 35%, is affected.	
ISO Class: 4/ASTM Class: 1B The coating has flaked along the edges of the cuts in large ribbons, and/or some squares have detached partly or wholly. A cross-cut area significantly greater than 35%, but not significantly greater than 65% is affected.	
ISO Class: 5/ASTM Class: 0B Any degree of flaking that cannot even be classified by classification 4.	

Cross-Hatch Adhesion Testing - Best Practices

Fluid Color UV/LED Inkjet Printing

• Interpreting Results & Corrective Actions

- **5B Result:** Ink system, surface prep, and cure energy are all optimized for this substrate. Document parameters (adhesion promoter batch, cure dose, print speed, lamp age) and lock in as the approved production process.
- **4B Result:** Acceptable for most applications. Monitor batch-to-batch consistency. Consider whether end-use conditions (outdoor UV, chemical exposure, abrasion) require 5B performance.
- **3B Result:** Marginal. Investigate adhesion promoter coverage uniformity, surface cleanliness, dyne level, and cure energy. Re-test after adjustments before approving for production.
- **2B or Below:** Do not ship. Identify root cause: (1) Insufficient or incompatible adhesion promoter, (2) Low surface energy — below 38 dynes, (3) Under-cure — lamp energy too low or speed too fast, (4) Substrate contamination, (5) Ink-substrate chemical incompatibility. Test each variable independently.
- **Why a Mounting Tape 'Pull Test' is Not Valid:** Mounting and transfer tapes have tack values 3–10× higher than Permaseal P-99. When applied over an uncrosshatched ink film and pulled, they exceed the cohesive strength of any cured ink film regardless of adhesion quality. The test does not distinguish good adhesion from bad — it simply destroys the print. It is not an ASTM method and results cannot be compared, documented, or used for substrate qualification.

• Integrating Cross-Hatch Testing into Your QC Workflow

- **New Substrate Qualification:** Run ASTM D3359 Method B on every new substrate before approving it for production. Test with and without adhesion promoter to establish the minimum process requirements. Require a minimum 4B rating for approval.
- **Incoming Media QC:** Spot-test each new roll or sheet lot of critical substrates. Surface energy and cleanliness vary by lot — a 5B result from one shipment does not guarantee the next.
- **Adhesion Promoter Batch Validation:** When a new batch of adhesion promoter is mixed or received, print and test a control sample against the known-good reference. A drop from 5B to 3B signals a formulation or application issue before it reaches customer product.
- **Post-Aging Adhesion:** For outdoor or harsh-environment applications, run ASTM D3359 after conditioning samples per ASTM D4587 (UV weathering) or ASTM B117 (salt spray) to validate long-term adhesion performance.
- **Document Everything:** Record substrate type, adhesion promoter used (product, batch, application method), print mode, cure energy (mJ/cm²), lamp age (hours), operator, date, and 0B–5B result. This data is the foundation of a defensible quality system and makes root-cause analysis fast when adhesion issues arise in the field.