ZINCOR SYSTEMS

CASE STUDY 01

Coating delamination from a machined metal surface

Photographic analysis of adhesive failure on a milled/turned substrate

Figure 1. Extensive coating separation from a machined metal surface. Milling/turning marks and locally exposed base metal are visible.

Key finding: Adhesive failure at the metal/coating interface, most likely caused by inadequate preparation of the machined surface and possible contamination by machining fluid.

1. Summary of findings

The photograph shows a machined metal component with clearly defined milling or turning marks. The protective coating separates in large, cohesively intact sheets, while an almost clean machined metal surface remains underneath. This morphology is most consistent with adhesive failure at the substrate/coating interface, rather than fracture within the coating film.

The primary technical concern is not the coating chemistry itself, but the condition of the machined substrate. The surface is relatively smooth and directional and often carries a microscopic film of cutting oil, emulsion, corrosion inhibitor or residual coolant/lubricant. Unless it is properly degreased and mechanically profiled before coating, the binder cannot achieve adequate wetting, true contact area or mechanical anchoring.

Confidence level

High confidence in the adhesive-failure classification. Moderately high confidence in the proposed cause: the photograph strongly supports inadequate preparation of the machined surface, but final confirmation requires records of degreasing, abrasive preparation, the coating system and the actual fracture plane.

2. What the photograph shows

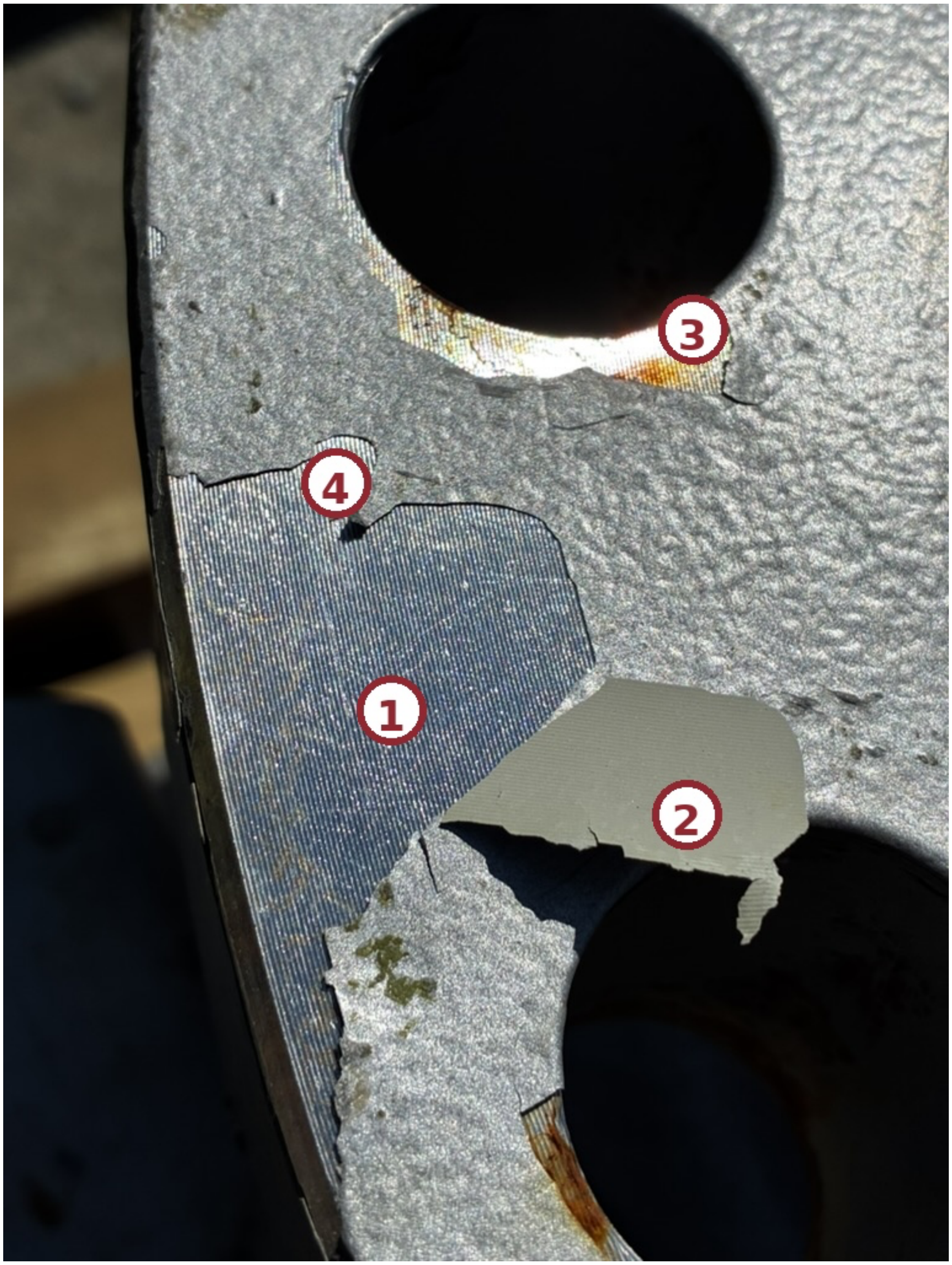


Figure 2. Numbered zones used for the analysis. The labels were deliberately applied without text boxes so that surface details remain visible.

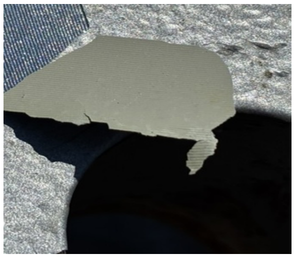
1 - exposed machined surface: Parallel machining lines remain visible on the substrate. Almost no cohesive primer residue is present, indicating that failure propagated directly along the metal-coating interface.

2 - detached coating sheet: The film remains relatively intact and flexible. Its cohesive strength is greater than its adhesive strength to the substrate.

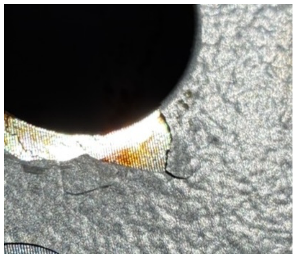
3 - local corrosion near the opening: Brown discoloration occurs along edges and damaged areas. It is probably a secondary consequence of base-metal exposure after local loss of protection, not the primary cause of widespread peeling.

4 - directional milling or turning marks: This topography may look rough, yet it can still provide a low effective profile in the direction of separation and limited area for three-dimensional coating anchorage.

Machining marks and a clean fracture plane



Detached film remains intact



Corrosion and coating break at the edge

3. Most likely failure mechanism

3.1. Residual contamination after machining

Milling and turning almost always involve oils, emulsions or coolant/lubricant fluids. Even when the surface looks dry, a thin organic film may remain in the microgrooves. This film lowers the surface energy of the metal and prevents complete wetting. The coating then bonds to a weakly attached contaminant layer instead of the metal itself.

For good wetting, the surface tension of the liquid coating must be sufficiently low relative to the substrate surface energy. Organic oils substantially reduce that energy, increase the contact angle and reduce actual binder-to-metal contact. The result can be a visually sound film with poor initial adhesion.

3.2. Insufficient profile and directional machining marks

A machined surface may have clearly visible grooves, but this is not equivalent to a controlled abrasive profile. The grooves are regular and directional, often with rounded peaks and few undercut microcavities. The coating therefore has too few three-dimensional anchoring points. If peel stress develops parallel to the machining marks, the crack can propagate easily along the metal/coating plane.

3.3. Oxide film on steel

Freshly machined steel rapidly forms a nanometre-scale oxide layer. A thin, compact and clean oxide is not necessarily harmful, but moisture, residual emulsion or storage time may produce a weak boundary layer. If coating is applied without immediate preparation, adhesion depends on the stability of that film rather than the strength of the base metal.

3.4. Film stress as a driver of propagation

After drying or chemical curing, the coating develops residual tensile stress. A thicker and stiffer film stores more elastic energy. When adhesion is weak, that energy becomes the driving force for delamination growth. Water and temperature cycling further reduce interfacial strength, allowing a small initial defect to develop into large sheet-like peeling.

Important diagnostic distinction

High DFT, thermal cycling or mechanical bending can accelerate separation, but without a pre-existing weak bond to the machined surface they would not normally produce such a clean and extensive fracture plane.

4. Ranking of possible causes

Possible cause	Likelihood	Link to photograph	Confirmation
Residual cutting oil / emulsion	Very high	Clean adhesive failure on machined metal	Water-break test, solvent wipe, FTIR, degreasing-process review
Insufficient mechanical preparation	Very high	Visible milling/turning marks without controlled abrasive profile	Profile measurement, microscopy, preparation records
Primer unsuitable for smooth metal	High	Film is cohesively sound but releases from substrate	TDS, manufacturer recommendation, test patch
Flash rust / oxide boundary layer	Medium	Local corrosion and possible delay between machining and coating	Record review, cross-section and microscopy
Excessive DFT / internal stress	Medium	Explains propagation in large sheets	DFT map and laboratory cross-section
Incorrect mix ratio / incomplete cure	Low to medium	Possible only if film is soft or tacky	MEK rub, hardness, DSC/FTIR if required

5. Root-cause verification plan

- Process documentation. Establish whether machining was wet or dry, which fluids were used, how degreasing was performed, how much time elapsed before coating, and whether additional abrasive preparation was carried out.
- Fracture plane. Examine the metal substrate and the underside of the detached film. Record the percentage of adhesive and cohesive failure and note any oily, glossy or powdery boundary layer.
- Adhesion. Perform pull-off testing in accordance with ISO 4624 or ASTM D4541 on sound and boundary areas. Record both MPa and the type and percentage of failure.
- Contamination. Conduct a water-break test on a representative cleaned surface, targeted solvent wiping and, where needed, FTIR analysis of organic residue.
- Topography. Measure roughness and inspect the surface under magnification. Compare the actual profile with that recommended for the specified primer.
- Comparative test patch. Prepare three variants: degreased only; degreased plus mechanical abrasion; and fully abrasive-prepared. After cure, compare adhesion and fracture planes.

6. Recommended repair procedure

- Remove all coating that lacks a sound bond. In large continuous areas, local patching is unreliable because delamination may continue beneath apparently intact film.
- First perform thorough degreasing using a method compatible with the machining fluid present. Solvent cleaning requires clean cloths and multiple passes; spreading oil is not cleaning.
- After degreasing, carry out abrasive cleaning or another controlled mechanical profiling method to obtain a clean, uniformly matte surface. The target preparation grade and profile must follow the coating-system specification and manufacturer TDS.
- Remove dust and verify cleanliness before coating. Protect the surface from hand contact, oil in compressed air and condensation.
- Apply a primer explicitly approved for machined carbon steel and the intended surface profile. Do not rely on the fact that the same product previously performed well on blast-cleaned steel.
- Control DFT by coat. Avoid unnecessarily heavy applications that increase shrinkage and residual stress.
- Before full repair, prepare a test patch and, after complete cure, confirm the pull-off result and an acceptable fracture plane.

7. Conclusion

The damage is most consistent with adhesive failure of the coating from a machined metal substrate. Clear milling/turning marks, an almost clean surface after separation and an intact detached film indicate that the coating cohesion exceeded its bond to the substrate. The most likely cause is a combination of residual organic contamination after machining and the absence of a controlled abrasive profile, possibly compounded by an unsuitable primer and high internal film stress.

The inspector’s most important task is to confirm the fracture plane and establish the actual substrate condition. Without this, repair may simply repeat the same coating system on an equally smooth or contaminated surface, causing the failure to recur.

8. Study limitations

This analysis is based on a single photograph. No data were available on the metal grade, coating system, preparation, DFT, environment, age or adhesion-test results. The conclusions therefore represent a professionally ranked hypothesis and a verification plan, not a final forensic determination.

9. Relevant standards and literature

1. ISO 8501-1 - Visual assessment of steel-surface cleanliness after preparation.
2. ISO 8503 - Roughness characteristics of blast-cleaned steel substrates.
3. ISO 8502 - Tests for assessment of surface cleanliness before coating.
4. ISO 4624 - Pull-off test for adhesion of coatings.
5. ASTM D4541 - Pull-off strength of coatings using portable adhesion testers.
6. ISO 12944-4 - Types of surface and surface-preparation methods for protective paint systems.
7. Roberge, P. R., Handbook of Corrosion Engineering, McGraw-Hill.
8. Schweitzer, P. A., Paint and Coatings: Applications and Corrosion Resistance, CRC Press.