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Hydrogen embrittlement in high-strength fasteners

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A high-strength bolt that fails hours or days after installation, with no overload and no visible corrosion, is usually a hydrogen embrittlement failure. The delay is the characteristic feature and the reason it is so often misdiagnosed as a supply problem.

Three conditions, all required

- A susceptible microstructure. Risk rises steeply above roughly 1000 MPa tensile strength, or about 39 HRC. Property class 8.8 fasteners are generally tolerant; 10.9 needs care; 12.9 is genuinely vulnerable.
- A source of atomic hydrogen. Acid pickling before plating, the electroplating bath itself, cathodic protection, and corrosion in service all generate atomic hydrogen at the steel surface.
- Sustained tensile stress. The preload is normally sufficient on its own; residual stresses from forming add to it.

Remove any one and cracking does not occur. In practice the strength is fixed by the design and the stress is the point of the fastener, so control is exercised over the hydrogen.

Internal and environmental embrittlement

Internal hydrogen embrittlement comes from hydrogen introduced during manufacture, chiefly pickling and electroplating. It is the mechanism behind failures in the first hours or days after tightening, and it is preventable by process control. Environmental hydrogen embrittlement comes from hydrogen generated in service, by a corrosion reaction on the fastener or by an over-driven cathodic protection system.

Baking

Baking drives absorbed hydrogen back out before it can concentrate at stressed regions. Timing matters: baking must begin as soon as practicable after plating, within a few hours at most. Typical conditions are 190 to 230 C for between 4 and 24 hours depending on strength, section and coating. Higher-strength parts need longer, not hotter, since the temperature is limited by the tempering temperature of the steel.

Baking is a mitigation, not a guarantee. Zinc plating forms a relatively impermeable barrier that slows hydrogen egress, which is one reason electroplated high-strength fasteners remain a managed risk even when baked correctly.

Avoiding the hydrogen instead

- Zinc flake coatings applied by dip-spin and cured, with no acid pickling and no electrolytic step. This is the usual answer for property class 10.9 and above.
- Mechanical zinc plating, which deposits zinc by peening rather than electrochemically.
- Hot-dip galvanising, subject to its own constraints on thread fit and maximum property class.

If a fastener is property class 10.9 or above and the drawing calls for electroplating, treat it as a question to be answered rather than a detail to be procured.

Recognising it after the fact

Hydrogen embrittlement failures are brittle, with little or no plastic deformation, and they initiate at the head-to-shank radius or the first engaged thread root. Fracture surfaces are typically intergranular near the origin, changing to a ductile mode as the remaining section overloads. That intergranular origin requires scanning electron microscopy to see, which is why fracture surfaces should not be cleaned or handled before examination.

Standards and further reading

1. ISO 4042 — Fasteners: electroplated coating systems and embrittlement relief.
2. ISO 15330 — Preloading test for the detection of hydrogen embrittlement.
3. ASTM F1940 — Process control verification to prevent hydrogen embrittlement.
4. ASTM B850 — Post-coating treatments for reducing risk of hydrogen embrittlement.
5. ISO 10683 — Non-electrolytically applied zinc flake coating systems.