Failure Investigation Report - hhhuukk

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Case details

- Component: sdfsdf
- Material: not stated
- Mode: standard
- Description: The dam thing broke when it was loaded for the first time, probably because it was designed by claude code.

Methodology

Structured claim-based investigation. Claims were admitted per the evidence status model; the deterministic diagnostic engine matched claims to pack indicators; confidence per the documented model (S, K, C, M, B dimensions). At Diagnose, adaptive questioning selected the next most-discriminating indicator until a mode reached high confidence or candidates were exhausted.

Evidence claims used in this run

- [C1] (Description / narrative - EV-DESC, user_entered, status: user_entered_fact) The dam thing broke when it was loaded for the first time, probably because it was designed by claude code.
- [C2] (Service history - EV-SERVICE, ai_extracted, status: approved) The component broke when it was loaded for the first time.
- [C3] (Design data - EV-DESIGN, ai_extracted, status: approved) The failure is attributed to it being designed by claude code.
- [C4] (Material specification - EV-MATSPEC, user_entered, status: user_entered_fact) Material specification and certification status? - Answer: steel
- [C5] (Design data - EV-DESIGN, user_entered, status: user_entered_fact) Design loads and duty cycle vs actual service loads? - Answer: 140% of the design load
- [C6] (Manufacturing records - EV-MFGREC, user_entered, status: user_entered_fact) Manufacturing route incl. welding, plating, heat treatment records? - Answer: Rolling
- [C7] (Loading & stress - EV-LOAD, user_entered, status: user_entered_fact) Loading character: steady/cyclic/impact; known vibration? - Answer: Dropped
- [C8] (Maintenance & lubrication - EV-MAINT, user_entered, status: user_entered_fact) Maintenance and inspection history incl. lubrication? - Answer: None it was new
- [C9] (Macro / visual examination - EV-MACRO, user_entered, status: user_entered_fact) Macro fracture description: deformation, zones, origin location? - Answer: One large crack running the entire length with no evidnce of plastic deformation
- [C10] (Fracture-surface examination (fractography) - EV-FRACTO, user_entered, status: user_entered_fact) Fracture surface features: beach marks, chevrons, dimples, facets? - Answer: smooth

sharp fracture surfaces

- [C11] (Corrosion products / deposits - EV-CORRPROD, user_entered, status: user_entered_fact) Corrosion: pits, products, thinning measurements? - Answer: no

- [C12] (Dimensional measurements - EV-DIM, user_entered, status: user_entered_fact) Wear: scoring, debris, dimensional loss at contacts? - Answer: no

- [C13] (Microscopy / metallography - EV-MICRO, user_entered, status: user_entered_fact) Secondary cracking present? Branched? - Answer: no

- [C14] (Chemical composition - EV-CHEM, user_entered, status: user_entered_fact) Lab results: chemistry, hardness, microstructure vs spec? - Answer: steel contained Mn and S

Candidate failure modes

Confidence is evidence support for this mode - NOT a probability.

Thermal-mechanical fatigue - Confidence 80.0/100 (High)

Supporting evidence present:

- Network or surface cracks (claims: C10)
- crack orientation related to thermal stress (claims: C9, C13)
- service temperature cycles (claims: C5)

Evidence missing:

- oxide-filled cracks (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)

Fretting fatigue cracking - Confidence 80.0/100 (High)

Supporting evidence present:

- Dark fretting debris (claims: C12)
- contact scar (claims: C12)
- crack at contact edge (claims: C9, C12, C13)

Evidence missing:

- multiple shallow origins (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Bending fatigue - Confidence 75.0/100 (High)

Supporting evidence present:

- Semi-elliptical surface origin (claims: C9, C10)
- crack front marks (claims: C9, C10, C13)

Evidence missing:

- final overload opposite origin (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Ammonia SCC - Confidence 75.0/100 (High)

Supporting evidence present:

- Intergranular/transgranular cracking (claims: C13)
- blue/green corrosion products possible (claims: C11)

Evidence missing:

- residual stress source (would come from Service environment)

Suggested test / examination to raise certainty:

- Service-environment chemistry review or sampling

Polythionic acid SCC - Confidence 75.0/100 (High)

Supporting evidence present:

- Intergranular cracking in sensitised HAZ/base metal (claims: C13)
- refinery shutdown history (claims: C8)

Evidence missing:

- sulphide/acid conditions (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)

Scuffing / scoring - Confidence 75.0/100 (High)

Supporting evidence present:

- Longitudinal score marks (claims: C10)
- smeared/overheated surfaces (claims: C10)

Evidence missing:

- rapid damage onset (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Galling - Confidence 73.3/100 (High)

Supporting evidence present:

- Severe torn surfaces (claims: C10)
- seizure marks (claims: C10)
- high friction history (claims: C8)

Evidence missing:

- transfer lumps (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

VHCF - Confidence 66.7/100 (Moderate)

Supporting evidence present:

- Internal fish-eye origin (claims: C9)
- little surface initiation (claims: C10)

Evidence missing:

- fine granular area (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Creep crack initiation/growth - Confidence 66.7/100 (Moderate)

Supporting evidence present:

- Intergranular cracking (claims: C13)
- time-dependent crack extension (claims: C9, C13)

Evidence missing:

- creep cavities ahead of crack (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Metallographic sectioning and microscopy

LME - Confidence 66.7/100 (Moderate)

Supporting evidence present:

- Intergranular or brittle crack path (claims: C9, C13)
- rapid cracking during contact (claims: C12, C13)

Evidence missing:

- liquid metal residue (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Low-cycle fatigue - Confidence 65.0/100 (Moderate)

Supporting evidence present:

- Multiple crack origins (claims: C9, C13)
- plastic strain marks (claims: C10)
- transgranular cracking (claims: C13)
- rapid crack growth after cyclic plasticity (claims: C9, C13)

Contradicting evidence:

- Very high cycle count with elastic stress only (claims: C5)

Wear (adhesive/abrasive) - Confidence 65.0/100 (Moderate)

Supporting evidence present:

- Surface material loss, scoring, grooves, galling or polishing at contact surfaces (claims: C12)
- Wear debris in lubricant or assembly (claims: C12)
- Lubrication deficiency (starvation, degradation, wrong lubricant, dry running) (claims: C8)

Evidence missing:

- Dimensional loss at contact surfaces beyond tolerance (would come from Dimensional measurements)
- Abrasive contamination present (sand, dust, grit) (would come from Service environment)

Suggested test / examination to raise certainty:

- Dimensional / wall-thickness survey
- Service-environment chemistry review or sampling
- Surface examination
- Dimensional survey
- Lubricant/debris analysis
- Hardness

Fretting wear - Confidence 60.0/100 (Moderate)

Supporting evidence present:

- Dark oxide debris (claims: C12)
- polished/rough contact scar (claims: C12)

Evidence missing:

- shallow pits (would come from Macro / visual examination)
- stick-slip boundary (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Plating-induced hydrogen embrittlement - Confidence 60.0/100 (Moderate)

Supporting evidence present:

- Delayed brittle fracture after plating (claims: C9, C10)

- intergranular/quasi-cleavage features (claims: C10)
- high hardness (claims: C14)
- plating history (claims: C6, C8)

Evidence missing:

- Delayed brittle fracture after plating (would come from Coating / protection records)

Suggested test / examination to raise certainty:

- Coating / protection system review

Torsional shear fracture - Confidence 53.3/100 (Moderate)

Supporting evidence present:

- Spiral fracture (claims: C9, C10)
- dimpled shear features (claims: C10)

Evidence missing:

- shear lips (would come from Macro / visual examination)
- plastic twisting (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

High-temperature hydrogen attack - Confidence 53.3/100 (Moderate)

Supporting evidence present:

- Decarburised zones (claims: C9)
- intergranular cracking/blisters (claims: C13)

Evidence missing:

- methane fissures (would come from Macro / visual examination)
- loss of strength (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Alpha-prime embrittlement - Confidence 48.0/100 (Moderate)

Supporting evidence present:

- Hardness/toughness change (claims: C14)
- brittle fracture (claims: C9, C10)
- thermal exposure record (claims: C6)

Evidence missing:

- Hardness/toughness change (would come from Hardness)
- phase decomposition evidence (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Hardness survey across the section
- Metallographic sectioning and microscopy

Weld-toe fatigue - Confidence 45.0/100 (Moderate)

Supporting evidence present:

- Crack at weld toe/root (claims: C9, C13)
- beach marks (claims: C10)

Evidence missing:

- Crack at weld toe/root (would come from Welding records)
- lack-of-fusion or undercut as initiator (would come from Welding records)

Suggested test / examination to raise certainty:

- Welding record review

Coating cracking - Confidence 45.0/100 (Moderate)

Supporting evidence present:

- Crack network in coating (claims: C9, C13)
- substrate corrosion at cracks (claims: C11)

Evidence missing:

- Crack network in coating (would come from Coating / protection records)
- thermal mismatch pattern (would come from Operating conditions)

Suggested test / examination to raise certainty:

- Coating / protection system review
- Operating-condition data review

Ratcheting - Confidence 44.4/100 (Moderate)

Supporting evidence present:

- Incremental dimensional growth (claims: C12)
- local thinning (claims: C11)

Evidence missing:

- ovalisation (would come from Macro / visual examination)
- bulging (would come from Macro / visual examination)
- fatigue may follow (would come from Loading & stress)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Loading / stress review or analysis

Plastic collapse - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Gross deformation before rupture (claims: C9)

Evidence missing:

- hinge lines (would come from Macro / visual examination)
- collapse shape consistent with limit load (would come from Loading & stress)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Loading / stress review or analysis

Intergranular brittle fracture - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Faceted grain-boundary surface (claims: C10)

Evidence missing:

- rock-candy morphology (would come from Macro / visual examination)
- grain-boundary precipitates or cavities (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Metallographic sectioning and microscopy

Torsional fatigue - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Helical or 45-degree crack path (claims: C9, C13)

Evidence missing:

- shear-mode initiation (would come from Macro / visual examination)
- final torsional overload zone (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Chloride SCC - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Branched transgranular cracks in austenitic stainless steels (claims: C13)

Evidence missing:

- chloride deposits (would come from Corrosion products / deposits)
- heat-transfer concentration sites (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)
- Macro / visual examination of the fracture and component

Droplet impingement erosion - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Impact pits (claims: C7)

Evidence missing:

- leading-edge roughening (would come from Macro / visual examination)
- directional erosion pattern (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Tribocorrosion - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Wear scar with corrosion products (claims: C11)

Evidence missing:

- repassivation damage (would come from Macro / visual examination)
- accelerated loss versus wear/corrosion alone (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Type II hot corrosion - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Pitting-like hot corrosion (claims: C11)

Evidence missing:

- sulphate deposits (would come from Corrosion products / deposits)
- attack at temperature/deposit-prone zones (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)

Nitridation / chlorination - Confidence 41.7/100 (Moderate)

Supporting evidence present:

- Nitride/halide products (claims: C11)

Evidence missing:

- internal attack (would come from Macro / visual examination)
- embrittlement or accelerated wastage (would come from Dimensional measurements)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Dimensional / wall-thickness survey

Corrosion (general/pitting/crevice) - Confidence 34.4/100 (Low)

Supporting evidence present:

- General wall thinning or measurable metal loss (claims: C11)
- Pitting or crevice attack on surfaces (claims: C11)

Evidence missing:

- Corrosive service environment (chlorides, acids, moisture, seawater) (would come from Service environment)
- Corrosion products/deposits present (rust, scale, oxide) (would come from Corrosion products / deposits)
- Protective coating or cathodic protection breakdown (would come from Coating / protection records)

Suggested test / examination to raise certainty:

- Service-environment chemistry review or sampling
- Corrosion-product / deposit analysis (EDS / XRD)
- Coating / protection system review
- Corrosion product analysis
- Dimensional/thickness survey
- Environment chemistry

Slurry erosion - Confidence 30.0/100 (Low)

Supporting evidence present:

- Thinning/grooving at flow changes (claims: C11)
- particle impact features (claims: C7, C10)
- corrosion products if synergistic (claims: C11)

Contradicting evidence:

- Stagnant corrosion under deposit without erosive flow (claims: C11)

Hot tearing - Confidence 30.0/100 (Low)

Supporting evidence present:

- Interdendritic crack surfaces (claims: C9, C10, C13)
- oxidised crack surfaces (claims: C9, C10, C13)
- location at constrained sections (claims: C9)

Contradicting evidence:

- Service fatigue crack with beach marks (claims: C5, C10)

Necking - Confidence 29.2/100 (Low)

Supporting evidence present:

- cup-and-cone fracture association (claims: C9, C10)
- dimples if fractured (claims: C10)

Evidence missing:

- Local area reduction (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Resonance-induced fatigue - Confidence 29.2/100 (Low)

Supporting evidence present:

- fatigue beach marks (claims: C10)
- service vibration history (claims: C5, C7, C8)

Evidence missing:

- Multiple origins at high-stress points (would come from Loading & stress)

Suggested test / examination to raise certainty:

- Loading / stress review or analysis

Stress-oriented HIC - Confidence 29.2/100 (Low)

Supporting evidence present:

- crack orientation stress-related (claims: C9, C13)
- sour-service history (claims: C8)

Evidence missing:

- Array of small cracks linking through wall (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Strain-age embrittlement - Confidence 29.2/100 (Low)

Supporting evidence present:

- brittle fracture tendency (claims: C9, C10)
- strain-age thermal history (claims: C8)

Evidence missing:

- Increased yield/ductility loss (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Fatigue - Confidence 27.8/100 (Low)

Supporting evidence present:

- Beach marks (crack arrest lines) on fracture surface (claims: C10)
- Cyclic/vibratory/rotating service loading (claims: C7)

Evidence missing:

- Fatigue striations visible under SEM (would come from Fracture-surface examination (fractography))
- Ratchet marks indicating multiple initiation sites (would come from Fracture-surface examination (fractography))
- Initiation at stress concentration (fillet, keyway, thread, hole, weld toe, notch) (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- SEM fractography of the fracture surface
- Macro / visual examination of the fracture and component
- SEM fractography
- Macro examination of origin
- Stress analysis
- Hardness

Uniform corrosion - Confidence 23.3/100 (Low)

Supporting evidence present:

- corrosion products (claims: C11)
- predictable corrosion allowance consumption (claims: C11)

Evidence missing:

- Relatively even wall loss (would come from Dimensional measurements)
- thickness reduction (would come from Dimensional measurements)

Suggested test / examination to raise certainty:

- Dimensional / wall-thickness survey

Two-body abrasive wear - Confidence 23.3/100 (Low)

Supporting evidence present:

- cutting/ploughing marks (claims: C10)
- wear debris (claims: C12)

Evidence missing:

- Parallel grooves (would come from Macro / visual examination)
- directionality (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Quench cracking - Confidence 22.0/100 (Low)

Supporting evidence present:

- Cracks at sharp corners/section changes (claims: C10)
- high hardness (claims: C14)
- no service crack-growth marks (claims: C5, C10)

Contradicting evidence:

- Fatigue striations from service cycles (claims: C5)

Evidence missing:

- brittle appearance (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Corrosion-fatigue cracking - Confidence 21.7/100 (Low)

Supporting evidence present:

- Fatigue features with corrosion products (claims: C10, C11)

Contradicting evidence:

- Dry inert service (claims: C5)

Evidence missing:

- multiple origins at pits (would come from Macro / visual examination)
- reduced life versus air (would come from Macro / visual examination)
- branching may occur (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Dynamic overload fracture - Confidence 20.0/100 (Low)

Supporting evidence present:

- Deformation pattern aligned with impact (claims: C9)
- sudden overload features (claims: C10)

Contradicting evidence:

- Service crack-growth evidence predating the impact (claims: C5)

Evidence missing:

- local denting (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Temper embrittlement - Confidence 20.0/100 (Low)

Supporting evidence present:

- Intergranular brittle fracture (claims: C9, C10)
- service heat-treatment history (claims: C5, C8)

Contradicting evidence:

- Ductile fracture (claims: C9, C10)
- no embrittling thermal history (claims: C8)

Evidence missing:

- upward shift in transition temperature (would come from Operating conditions)

Suggested test / examination to raise certainty:

- Operating-condition data review

Coating delamination - Confidence 20.0/100 (Low)

Supporting evidence present:

- interfacial fracture (claims: C9, C10)
- corrosion products under coating (claims: C11)
- poor surface profile/contamination (claims: C10)

Evidence missing:

- Lifted coating (would come from Coating / protection records)

Suggested test / examination to raise certainty:

- Coating / protection system review

Grinding burn - Confidence 19.4/100 (Low)

Supporting evidence present:

- hardness gradient (claims: C14)
- surface cracks (claims: C10)

Evidence missing:

- Temper colour (would come from Macro / visual examination)
- retempered/rehardened layer (would come from Hardness)
- residual stress (would come from Loading & stress)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Hardness survey across the section
- Loading / stress review or analysis

Solidification cracking - Confidence 18.0/100 (Low)

Supporting evidence present:

- Centreline/interdendritic weld crack (claims: C9, C13)
- oxidised/segregated surfaces (claims: C10)
- no service striations (claims: C5)

Contradicting evidence:

- Hydrogen cold crack in HAZ after cooling (claims: C9, C13)

Evidence missing:

- Centreline/interdendritic weld crack (would come from Welding records)

Suggested test / examination to raise certainty:

- Welding record review

Thermal bowing - Confidence 17.5/100 (Low)

Supporting evidence present:

- distortion without cracking (claims: C13)
- thermal gradients in service history (claims: C5)

Evidence missing:

- Repeatable bowing with temperature (would come from Operating conditions)

Suggested test / examination to raise certainty:

- Operating-condition data review

Ductile overload - Confidence 17.5/100 (Low)

Supporting evidence present:

- Dimpled (microvoid coalescence) fracture surface under SEM; cup-and-cone profile (claims: C10)
- Documented single overload, impact or pressure surge event (claims: C7)

Contradicting evidence:

- Beach marks or fatigue striations present (claims: C10)

Evidence missing:

- Gross plastic deformation, necking, bending or bulging adjacent to fracture (would come from Macro / visual examination)
- Shear lips at fracture edges; fracture at ~45 degrees to load (would come from Fracture-surface examination (fractography))
- Inclusions or second-phase particles at the bases of dimples (microvoid nucleation sites) under SEM (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- SEM fractography of the fracture surface
- Metallographic sectioning and microscopy
- Visual/macro
- SEM fractography
- Tensile test

Seam / lamination - Confidence 17.5/100 (Low)

Supporting evidence present:

- orientation parallel to rolling direction (claims: C6)
- inclusion-lined surfaces (claims: C10)

Evidence missing:

- Planar internal indication (would come from Non-destructive testing)

Suggested test / examination to raise certainty:

- Non-destructive testing (UT / RT / MPI / PT)

Quench/heat-treatment distortion - Confidence 16.7/100 (Low)

Supporting evidence present:

- out-of-tolerance dimension (claims: C12)
- hardness/microstructure gradients (claims: C14)

Evidence missing:

- Warping (would come from Macro / visual examination)
- bowing (would come from Macro / visual examination)
- twist (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Axial fatigue - Confidence 16.7/100 (Low)

Supporting evidence present:

- beach marks (claims: C10)

Evidence missing:

- Planar crack growth normal to axial stress (would come from Loading & stress)
- final overload (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Loading / stress review or analysis
- Macro / visual examination of the fracture and component

Primary creep / secondary creep deformation - Confidence 16.7/100 (Low)

Supporting evidence present:

- creep strain record (claims: C6)

Evidence missing:

- Permanent elongation/sagging/bulging (would come from Macro / visual examination)
- grain-boundary cavities may begin (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Metallographic sectioning and microscopy

Crevice corrosion - Confidence 16.7/100 (Low)

Supporting evidence present:

- sharp boundary between exposed (claims: C10)

Evidence missing:

- Attack under gasket/deposit/lap joint (would come from Corrosion products / deposits)
- crevice area (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)
- Macro / visual examination of the fracture and component

Chromium carbide sensitisation - Confidence 16.7/100 (Low)

Supporting evidence present:

- intergranular corrosion/SCC (claims: C11)

Evidence missing:

- Grain-boundary carbide/depleted zones (would come from Microscopy / metallography)
- HAZ association (would come from Welding records)

Suggested test / examination to raise certainty:

- Metallographic sectioning and microscopy

- Welding record review

Subsurface rolling-contact fatigue - Confidence 16.0/100 (Low)

Supporting evidence present:

- Subsurface origin (claims: C9)
- inclusion-associated crack (claims: C9, C13)

Contradicting evidence:

- Surface corrosion/wear origin only (claims: C10, C11)

Evidence missing:

- spall (would come from Fracture-surface examination (fractography))
- butterfly morphology (would come from Fracture-surface examination (fractography))

Suggested test / examination to raise certainty:

- SEM fractography of the fracture surface

Sigma phase formation - Confidence 16.0/100 (Low)

Supporting evidence present:

- Brittle fracture (claims: C9, C10)
- hardness changes (claims: C14)

Contradicting evidence:

- No sigma phase in microstructure (claims: C14)
- ductile fracture (claims: C9, C10)

Evidence missing:

- reduced toughness (would come from Macro / visual examination)
- metallographic sigma phase (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Metallographic sectioning and microscopy

Sulfide stress cracking - Confidence 15.2/100 (Low)

Supporting evidence present:

- high hardness/strength (claims: C14)
- often little corrosion loss (claims: C11)

Contradicting evidence:

- low-strength qualified material (claims: C4)

Evidence missing:

- Brittle cracks (would come from Macro / visual examination)
- H2S/sour-service exposure (would come from Service environment)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Service-environment chemistry review or sampling

Hydrogen embrittlement - Confidence 14.3/100 (Low)

Supporting evidence present:

- Hydrogen source: plating, pickling, cathodic protection, H2S/sour service (claims: C6)

Evidence missing:

- Hydrogen source: plating, pickling, cathodic protection, H2S/sour service (would come from Service environment)

- High-strength/high-hardness steel (susceptible grade) (would come from Material specification)
- Intergranular or quasi-cleavage fracture morphology (would come from Fracture-surface examination (fractography))
- Delayed failure under static load (hours-weeks after installation) (would come from Service history)

Suggested test / examination to raise certainty:

- Service-environment chemistry review or sampling
- Material specification & certification review
- SEM fractography of the fracture surface
- Service-history record review
- Fractography (intergranular)
- Hardness

Surface-initiated rolling-contact fatigue - Confidence 13.3/100 (Low)

Supporting evidence present:

- surface cracks (claims: C10)

Evidence missing:

- Micropitting (would come from Macro / visual examination)
- grey staining (would come from Macro / visual examination)
- shallow spalls (would come from Fracture-surface examination (fractography))

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- SEM fractography of the fracture surface

Bimetallic corrosion - Confidence 12.5/100 (Low)

Supporting evidence present:

- location tied to couple (claims: C9)

Evidence missing:

- Preferential attack of one metal near joint/contact (would come from Loading & stress)
- noble metal protected (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Loading / stress review or analysis
- Macro / visual examination of the fracture and component

Cavitation erosion - Confidence 12.5/100 (Low)

Supporting evidence present:

- little corrosion product initially (claims: C11)

Evidence missing:

- Honeycomb/pitted roughness (would come from Macro / visual examination)
- damage at low-pressure/high turbulence zones (would come from Loading & stress)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Loading / stress review or analysis

Metal dusting corrosion - Confidence 12.5/100 (Low)

Supporting evidence present:

- carburised zones (claims: C9)

Evidence missing:

- Pits/grooves filled with carbonaceous dust (would come from Macro / visual examination)
- rapid local wastage (would come from Dimensional measurements)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Dimensional / wall-thickness survey

Scale/coating spallation - Confidence 12.5/100 (Low)

Supporting evidence present:

- exposed substrate hot corrosion/oxidation (claims: C11)

Evidence missing:

- Spalled scale patches (would come from Fracture-surface examination (fractography))
- repeated scale layers (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- SEM fractography of the fracture surface
- Corrosion-product / deposit analysis (EDS / XRD)

Stress rupture - Confidence 11.1/100 (Low)

Supporting evidence present:

- intergranular cracking (claims: C13)

Evidence missing:

- Creep cavities (would come from Microscopy / metallography)
- necking or bulging (would come from Macro / visual examination)
- oxide-filled cracks (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- Metallographic sectioning and microscopy
- Macro / visual examination of the fracture and component
- Corrosion-product / deposit analysis (EDS / XRD)

Pressure burst - Confidence 10.0/100 (Low)

Supporting evidence present:

- wall thinning if corrosion-assisted (claims: C11)

Evidence missing:

- Fish-mouth opening (would come from Macro / visual examination)
- ductile tearing (would come from Macro / visual examination)
- hoop-stress orientation (would come from Loading & stress)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Loading / stress review or analysis

Creep-fatigue interaction - Confidence 10.0/100 (Low)

Supporting evidence present:

- cavities plus fatigue features (claims: C10)

Evidence missing:

- Mixed transgranular/intergranular cracking (would come from Fracture-surface examination (fractography))
- oxide-filled cracks (would come from Corrosion products / deposits)
- dwell sensitivity (would come from Service history)

Suggested test / examination to raise certainty:

- SEM fractography of the fracture surface
- Corrosion-product / deposit analysis (EDS / XRD)
- Service-history record review

Relaxation failure - Confidence 10.0/100 (Low)

Supporting evidence present:

- little visible cracking (claims: C13)

Evidence missing:

- Loss of bolt preload (would come from Loading & stress)
- gasket leakage (would come from Macro / visual examination)
- relaxed spring force (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Loading / stress review or analysis
- Macro / visual examination of the fracture and component

Under-deposit corrosion - Confidence 10.0/100 (Low)

Supporting evidence present:

- chemistry gradient evidence (claims: C14)

Evidence missing:

- Attack under scale/sludge/deposit (would come from Corrosion products / deposits)
- tubercles (would come from Corrosion products / deposits)
- pit clusters (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)
- Macro / visual examination of the fracture and component

High-temperature sulfidation - Confidence 10.0/100 (Low)

Supporting evidence present:

- sulphur-rich corrosion products (claims: C11)

Evidence missing:

- Sulphide scale (would come from Corrosion products / deposits)
- metal loss (would come from Dimensional measurements)
- carburisation/sulfidation interactions possible (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)
- Dimensional / wall-thickness survey
- Macro / visual examination of the fracture and component

Graphitisation of carbon steel - Confidence 10.0/100 (Low)

Supporting evidence present:

- service temperature history (claims: C5, C8)

Evidence missing:

- Graphite nodules/planes (would come from Microscopy / metallography)
- reduced strength (would come from Macro / visual examination)
- intergranular/planar weakness (would come from Fracture-surface examination (fractography))

Suggested test / examination to raise certainty:

- Metallographic sectioning and microscopy
- Macro / visual examination of the fracture and component
- SEM fractography of the fracture surface

Coating blistering - Confidence 10.0/100 (Low)

Supporting evidence present:

- fluid/corrosion products beneath (claims: C11)

Evidence missing:

- Dome-shaped blisters (would come from Coating / protection records)
- loss of adhesion (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Coating / protection system review
- Macro / visual examination of the fracture and component

Stress corrosion cracking - Confidence 9.8/100 (Low)

Supporting evidence present:

- Branched cracking in metallographic section (claims: C13)

Contradicting evidence:

- Fully ductile dimpled fracture (claims: C10)

Evidence missing:

- Susceptible alloy-environment combination present (would come from Service environment)
- Sustained static tensile stress incl. residual stress (welding, forming) (would come from Loading & stress)
- Inter- or transgranular cracking with little plastic deformation (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Service-environment chemistry review or sampling
- Loading / stress review or analysis
- Metallographic sectioning and microscopy
- Metallography (branching)
- SEM
- Environment chemistry

Brittle fracture - Confidence 9.5/100 (Low)

Supporting evidence present:

- Chevron (herringbone) marks pointing back to origin (claims: C10)
- Impact or high strain-rate loading (claims: C7)

Contradicting evidence:

- Dimpled ductile fracture surface (claims: C10)

Evidence missing:

- Little or no plastic deformation; flat fracture normal to stress (would come from Macro / visual examination)
- Bright granular/crystalline or cleavage fracture surface (would come from Fracture-surface examination (fractography))
- Low service/ambient temperature at failure (would come from Operating conditions)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- SEM fractography of the fracture surface
- Operating-condition data review

- Charpy impact
- SEM fractography
- Hardness

Solid-particle erosion - Confidence 8.7/100 (Low)

Supporting evidence present:

- impact craters/cutting lips (claims: C7)
- thinning at elbows/nozzles (claims: C11)

Contradicting evidence:

- Electrochemical corrosion without particle impact pattern (claims: C11)

Evidence missing:

- Directional wastage (would come from Dimensional measurements)

Suggested test / examination to raise certainty:

- Dimensional / wall-thickness survey

Carbide spheroidisation - Confidence 8.7/100 (Low)

Supporting evidence present:

- reduced hardness/strength (claims: C14)
- creep deformation association (claims: C9)

Contradicting evidence:

- As-manufactured microstructure (claims: C14)
- hardness within specification (claims: C4, C14)

Evidence missing:

- Spheroidised carbides (would come from Microscopy / metallography)

Suggested test / examination to raise certainty:

- Metallographic sectioning and microscopy

Caustic SCC - Confidence 8.1/100 (Low)

Supporting evidence present:

- boiler/alkali service history (claims: C5)

Contradicting evidence:

- fatigue-only crack growth (claims: C9, C13)

Evidence missing:

- Intergranular or branched cracks near caustic concentration areas (would come from Fracture-surface examination (fractography))
- deposits (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- SEM fractography of the fracture surface
- Corrosion-product / deposit analysis (EDS / XRD)

Incomplete penetration - Confidence 7.5/100 (Low)

Supporting evidence present:

- fatigue/fracture origin at root (claims: C9, C10)

Evidence missing:

- Root planar indication (would come from Non-destructive testing)
- notch-like root defect (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Non-destructive testing (UT / RT / MPI / PT)
- Macro / visual examination of the fracture and component

Carburisation attack - Confidence 7.0/100 (Low)

Supporting evidence present:

- increased hardness (claims: C14)
- dimensional/microstructural changes (claims: C12)

Contradicting evidence:

- Surface decarburisation or general oxidation only (claims: C10)

Evidence missing:

- Carbide networks (would come from Microscopy / metallography)
- reduced ductility (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Metallographic sectioning and microscopy
- Macro / visual examination of the fracture and component

Rolling-contact fatigue - Confidence 6.5/100 (Low)

Supporting evidence present:

- subsurface or surface-initiated crack networks (claims: C9, C13)

Contradicting evidence:

- corrosion pits alone (claims: C11)

Evidence missing:

- Pitting (would come from Macro / visual examination)
- spalling (would come from Fracture-surface examination (fractography))
- butterfly cracks (would come from Fracture-surface examination (fractography))

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- SEM fractography of the fracture surface

Hydrogen blistering - Confidence 6.0/100 (Low)

Supporting evidence present:

- hydrogen/sour/corrosion history (claims: C8, C11)

Evidence missing:

- Raised blisters (would come from Coating / protection records)
- internal laminations (would come from Macro / visual examination)
- step cracks (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Coating / protection system review
- Macro / visual examination of the fracture and component

Elastic buckling - Confidence 5.4/100 (Low)

Supporting evidence present:

- often little fracture at initiation (claims: C9, C10)

Contradicting evidence:

- tensile fracture as primary event (claims: C9, C10)

Evidence missing:

- Global or local out-of-plane deformation (would come from Macro / visual examination)

- wrinkles (would come from Macro / visual examination)
- lobes (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

General yielding - Confidence 4.6/100 (Low)

Supporting evidence present:

- no progressive beach marks (claims: C10)

Contradicting evidence:

- No permanent dimensional change (claims: C12)

Evidence missing:

- Permanent bend (would come from Macro / visual examination)
- necking (would come from Macro / visual examination)
- local plastic flow (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Lap / fold - Confidence 3.8/100 (Low)

Supporting evidence present:

- fatigue crack from lap (claims: C9, C13)

Contradicting evidence:

- Open service crack with no oxide/fold interface (claims: C5)

Evidence missing:

- Folded oxide-containing seam (would come from Corrosion products / deposits)
- surface-breaking linear indication (would come from Non-destructive testing)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)
- Non-destructive testing (UT / RT / MPI / PT)

Irradiation embrittlement / swelling - Confidence 2.5/100 (Low)

Supporting evidence present:

- service dose record (claims: C5, C6)

Contradicting evidence:

- No radiation service or dose record (claims: C5, C6)

Evidence missing:

- Toughness shift (would come from Macro / visual examination)
- hardening (would come from Hardness)
- swelling (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Hardness survey across the section

Hydrogen-assisted cold cracking - Confidence 2.0/100 (Low)

Supporting evidence present:

- high hardness (claims: C14)

Contradicting evidence:

- Solidification crack morphology during hot stage (claims: C9, C13)

- no hardness/hydrogen risk (claims: C14)

Evidence missing:

- HAZ or weld toe/root cracks (would come from Welding records)
- delayed occurrence (would come from Service history)
- hydrogen source (would come from Service environment)

Suggested test / examination to raise certainty:

- Welding record review
- Service-history record review
- Service-environment chemistry review or sampling

Brinelling - Confidence 0.0/100 (Low)

Contradicting evidence:

- Fretting marks without plastic indentation (claims: C10)

Evidence missing:

- Indentations matching rolling elements or contact asperities (would come from Loading & stress)
- spacing related to geometry (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Loading / stress review or analysis
- Macro / visual examination of the fracture and component

Stable ductile tearing - Confidence 0.0/100 (Low)

Contradicting evidence:

- No pre-existing crack (claims: C9, C13)
- all fracture surface instantaneous (claims: C9, C10)

Evidence missing:

- Stretched zone (would come from Macro / visual examination)
- stable tearing region (would come from Macro / visual examination)
- final overload zone (would come from Macro / visual examination)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component

Atmospheric rusting/corrosion - Confidence 0.0/100 (Low)

Contradicting evidence:

- Submerged-only corrosion or high-temperature dry oxidation only (claims: C11)

Evidence missing:

- Rust/oxide scale (would come from Corrosion products / deposits)
- preferential attack at water traps (would come from Macro / visual examination)
- chloride/sulphur deposits (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- Corrosion-product / deposit analysis (EDS / XRD)
- Macro / visual examination of the fracture and component

Hydrogen-induced cracking - Confidence 0.0/100 (Low)

Contradicting evidence:

- no internal cracking (claims: C13)

Evidence missing:

- Stepwise internal cracks parallel to surface/rolling plane (would come from Macro / visual examination)

- blister association (would come from Coating / protection records)
- sulphide exposure (would come from Corrosion products / deposits)

Suggested test / examination to raise certainty:

- Macro / visual examination of the fracture and component
- Coating / protection system review
- Corrosion-product / deposit analysis (EDS / XRD)

Lack of fusion - Confidence 0.0/100 (Low)

Contradicting evidence:

- Service crack through fully fused material (claims: C5)

Evidence missing:

- Planar weld indication (would come from Non-destructive testing)
- unfused interface (would come from Macro / visual examination)
- crack/fatigue origin at weld sidewall or between passes (would come from Welding records)

Suggested test / examination to raise certainty:

- Non-destructive testing (UT / RT / MPI / PT)
- Macro / visual examination of the fracture and component
- Welding record review

Candidate root causes

- **Design issue** - Confidence 64.0/100 (Moderate), via MECH-FM-MET-FAT-006. Typical for fatigue and cyclic cracking
- **Design issue** - Confidence 64.0/100 (Moderate), via MECH-FM-MET-FAT-010. Typical for fatigue and cyclic cracking
- **Design issue** - Confidence 60.0/100 (Moderate), via MECH-FM-MET-FAT-003. Typical for fatigue and cyclic cracking
- **Material selection issue** - Confidence 60.0/100 (Moderate), via MECH-FM-MET-EAC-004. Typical for environmentally assisted cracking and hydrogen damage
- **Material selection issue** - Confidence 60.0/100 (Moderate), via MECH-FM-MET-EAC-005. Typical for environmentally assisted cracking and hydrogen damage
- **Maintenance/inspection issue** - Confidence 60.0/100 (Moderate), via MECH-FM-MET-WEAR-005. Typical for tribology / wear / erosion
- **Maintenance/inspection issue** - Confidence 58.6/100 (Moderate), via MECH-FM-MET-WEAR-004. Typical for tribology / wear / erosion
- **Design issue** - Confidence 53.4/100 (Moderate), via MECH-FM-MET-FAT-013. Typical for fatigue and cyclic cracking

Limitations

- Knowledge pack status is 'ai_generated_draft'; conclusions inherit that status.
- Scores reflect only admitted claims; unreviewed or rejected material is excluded.
- Keyword/tag matching may miss or mis-map evidence; review the evidence table above.
- Confidence is evidence support for a mode, not a probability or a finding of fact.

Liability declaration (DRAFT)

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Audit

Run #1 executed 2026-06-20 13:29:43.170194 with claims snapshot as listed; full trail available in the application audit log.