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Bolt failures - Case histories from the Norwegian petroleum industry

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In the petroleum industry bolts are widely used in different kind of equipment as critical load transferring components. Despite the importance with respect to integrity and safety, little attention has been paid to the correct use of bolts and bolting materials.

Several aspects need thorough consideration to avoid failure for specific bolt grades:

(i) Mechanical properties: Proof or tensile strength, shear strength, tensile ductility, hardness, impact toughness, creep and stress relaxation, fatigue properties etc.

(ii) Physical properties: Thermal expansion, magnetic properties, elastic modulus etc.

(iii) Corrosion or environmental properties: General corrosion, hydrogen embrittlement, stress corrosion cracking, crevice corrosion and pitting, corrosion fatigue, high temperature corrosion, liquid metal embrittlement etc.

In addition, correct installation procedures for bolt tensioning are essential: Correct preload/torque level, manual tightening for non-critical applications, torque wrenching which is much dependant on thread lubricants, thread fit, tightening speed, surface finish, plating as well as galling behaviour, 'turn-on-nut method', measurement of bolt elongation and use of strain gauges.

Several incidents at Statoil operated petroleum fields and installations in the North Sea have in many cases been directly attributed to bolt failures. The present paper describes four of these failures, the different failure mechanisms involved, and the characteristic features as evidenced by visual examination, light optical microscopy and scanning electron microscopy:

(i) Fatigue failure: ASTM B7 low alloyed steel bolt grade. Fracture initiation along threads with typical and pronounced beach marks (i.e. cyclic fracture propagation) and transgranular fracture mode. See Fig.1.

(ii) Hydrogen embrittlement failure: ISO 10.9 low alloyed steel bolt grade. Multiple fracture initiation along bolt head transition with intergranular fracture morphology and heavy secondary cracking. Hydrogen source suggested from manufacturing (pickling stage) and/or cathodic hydrogen charging due to anodic Zn coating. See Fig.2.

(iii) Ductile torsional overload failure: ISO 12.9 low alloyed steel bolt grade. Smooth and flat fracture initiated from threads and with ductile dimpled fracture mode. See Fig.3.

(iv) Liquid Metal Embrittlement (LME) failure: ISO 8.8 low alloyed steel bolt grade with Cd coating used at higher temperature than recommended, i.e. above 230°C. Intergranular fracture mode with Cd penetration along the grain boundaries as evidenced by XRD analysis. See Fig.4.

Fig. 1 High cycle fatigue; beach marks and transgranular fracture morphology.

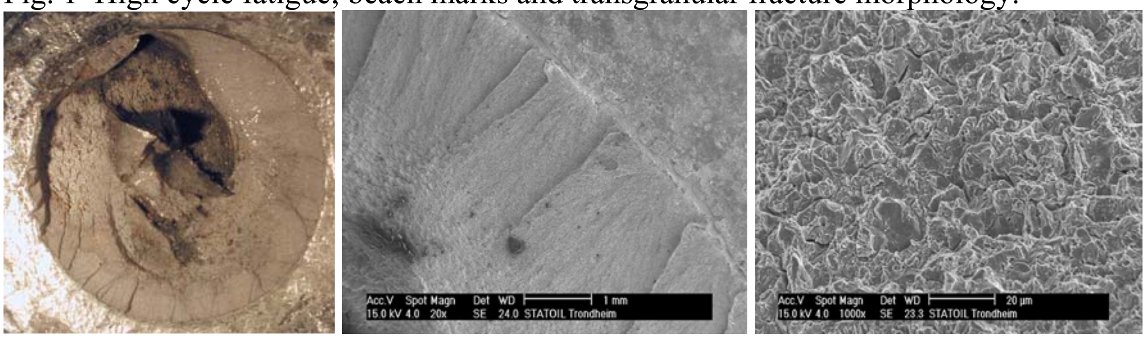

Fig. 2 Hydrogen induced failure; multiple initiations, intergranular fracture and secondary cracks.

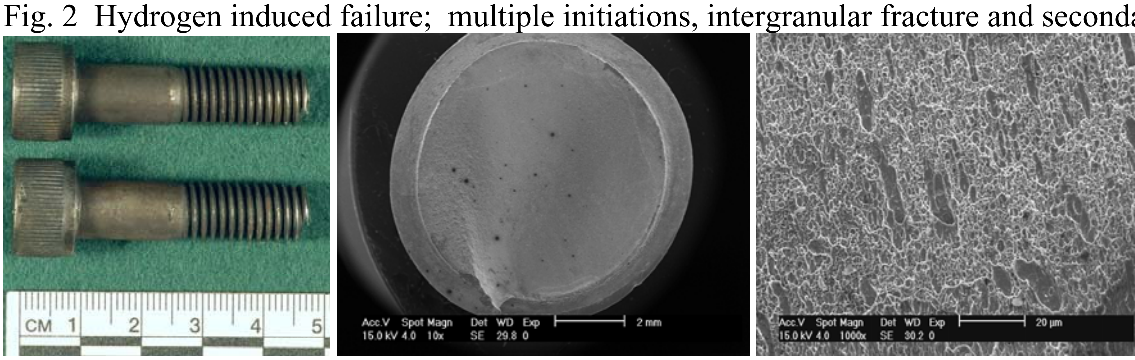

Fig. 3 Ductile torsional overload failure; smooth fracture with ductile dimple fracture mode.

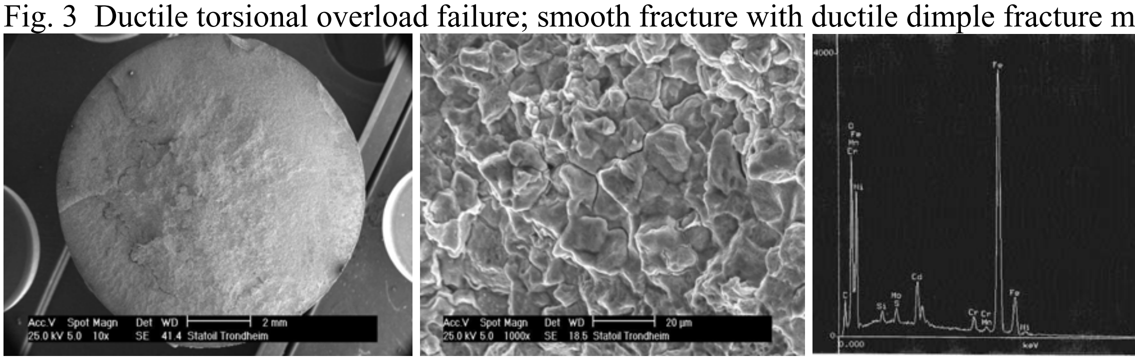

Fig. 4 Liquid metal embrittlement (LME) failure. Intergranular failure mode with Cd penetration along the grain boundaries.

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