BakerRisk Technical Brief

This Technical Brief is intended to provide lessons learned from materials, structure and equipment failures, prevent costly failures, and maintain equipment reliability and integrity.

Avoiding Bolt Failures

Bolts, fasteners, and studs are commonly used to secure rotating components, to flange two pipes together, or to join multiple structural items such as in aircraft wing skins or I-beams on a high-rise structure. Although bolts and fasteners may be the smallest items in a design, this does not minimize their importance. Bolt failures have resulted in fires, fatal accidents, crashes, catastrophic ruptures, foreign object damage in gas turbines, and leaks of hydrocarbon products that have exploded. An accident attributed to bolt failure occurred in 1979 when Flight 191 from Chicago's O'Hare Airport tragically crashed 30 seconds after take-off. The NTSB concluded that the engine tore loose due to a missing pylon attach bolt.

One of the most common failure mechanisms for bolts is fatigue. Fatigue is the phenomenon that occurs in bolt materials as the result of cyclic variations of the applied stress. A fatigue fracture of a bolt is shown in Figure 1. The fatigue fracture will typically have some characteristic features such as ratchet marks at the initiation location, a relatively smooth surface, and often distinct crack propagation patterns of "clam shells" or "beach marks" on the surface.

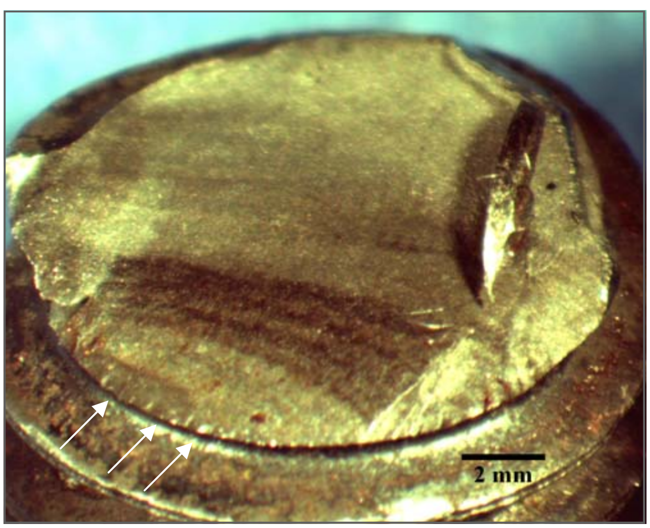

Figure 1. Fatigue Fracture Surface on a Bolt Showing Crack Initiation at the First-engaged Thread Root

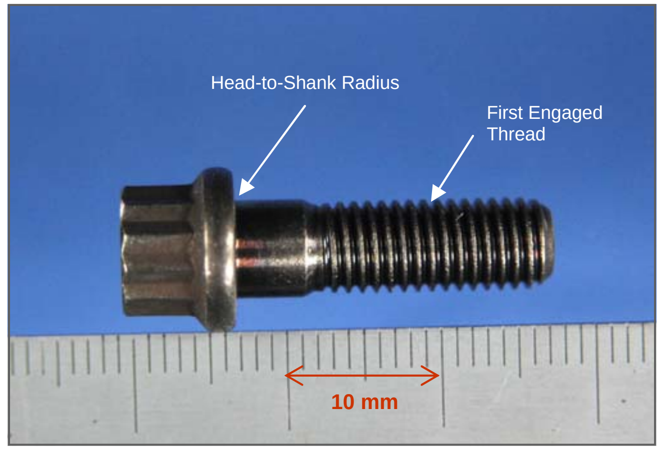

Figure 2. Common Locations for Fatigue Crack Initiation in a Bolt

A bolt fatigue failure involves three stages of damage: 1) initial crack initiation at a thread root, radius or material defect; 2) progressive cyclic fatigue growth; and 3) final sudden failure of the remaining cross section of the bolt. Fatigue failures of bolts are often found at the first-engaged threads, which have the highest stress, or at the head-to-shank fillet radius. Figures 2 and 3 show a fatigue crack that initiated at the head-to-shank radius of a bolt.

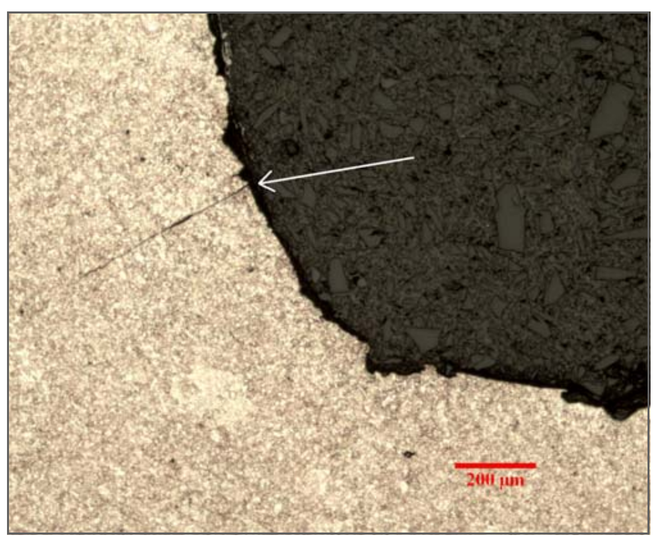

Figure 3. Photomicrograph of a Fatigue Crack at the Bolt Head-to-Shank Radius

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BAKER ENGINEERING AND RISK CONSULTANTS, INC.

Corporate Office
3330 Oakwell Court, Suite 100
San Antonio, TX 78218-3024
210.824.5960 tel
210.824.5964 fax

Houston Office
11000 Richmond Ave., Suite 350
Houston, TX 77042-6702
281.822.3100 tel

Washington DC Office
1050 17th St. NW, Suite 600
Washington, DC 20036
202.496.1295 tel

Canada Office
466 Speers Rd. 3rd Floor
Oakville, Ontario L6K 3W9
905.338.6292 tel

About BakerRisk

Baker Engineering and Risk Consultants, Inc. is one of the world's leading explosion analysis, structural design, and risk engineering companies. BakerRisk provides comprehensive consulting, engineering, laboratory and range testing services to government agencies and private companies involved with dangerous, highly hazardous, reactive, or explosive materials.

For more information on material engineering services, failure analyses, or lab testing, contact:

Daniel J. Benac, P.E.
(210) 824-5960
DBenac@BakerRisk.com

www.BakerRisk.com

Most materials and structure have a fatigue endurance limit. That is, if the stress is below the fatigue endurance limit, failure will not occur, even with many load cycles. Figure 4 illustrates a Stress vs. Cycles curve for a low alloy steel with a 150,000 pounds per square inch ultimate tensile strength and a stress concentration factor K_t=3.3. If a bolt is subjected to reverse bending (stress ratio (R) = Maximum Stress/Minimum Stress) R = -1) and the stress is below 30,000 pounds per square inch, then a fatigue crack should not initiate. To keep the stress below the fatigue endurance limit, bolts are tightened with a pre-determined torque value based upon the yield strength of the bolt and diameter. This clamp load, also called *pre-load*, is a percentage of the bolt yield stress. In a cyclic condition, if the cyclic stress does not exceed the pre-load stress, then the mean fatigue stress is reduced and the probability for a fatigue failure is also reduced. However, if the preload is not adequate, then the bolt could fail in a low number of cycles.

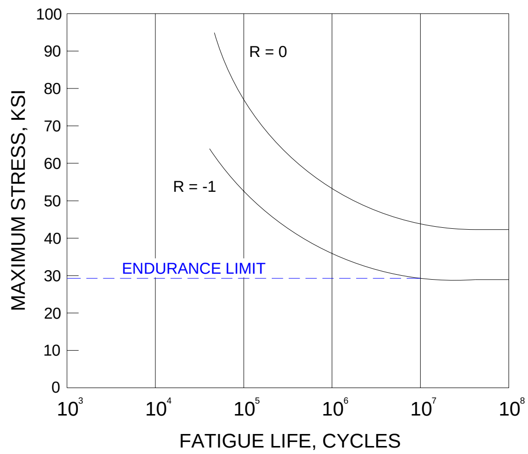

Figure 4. Stress vs. Cycles Curves for an Alloy Steel Bolt at a Stress Ratio of R=0 and R= -1

Avoiding Bolt Failure

Bolts that are torqued may fail due to fatigue in the following situations:

- The initial pre-load torque value for the bolt is too low
- The pre-load torque value is above the yield stress of the bolt
- The yield stress of the bolt material is too low
- Elevated temperatures, causing bolt relaxation
- Equipment vibrations, causing the bolt to loosen
- Higher stress amplitudes above the endurance limit

To reduce the probability of a bolt fatigue failure, each bolted-joint design should be individually evaluated and the following should be considered:

- Verify that engineering drawing torque value is appropriate for the specific bolt alloy and diameter
- Select the proper strength and toughness material for the bolt
- Use proper torque wrenches for the given application
- Use rolled threads, which induces compressive stresses, instead of cut threads
- Assure that the fastener hole is free from dirt or corrosion to avoid higher and incorrect torque readings
- Reduce operating stresses and vibrations of equipment by using additional supports
- Consider the use of a safety wire or tack welding the head in high-vibration conditions
- Check and re-torque bolts that may have become loose

Fatigue failures of bolts and fasteners can be avoided through good design practices, proper installation, and routine inspection practices.