Stress Failures in Fasteners

Article by Guy Avellon

There are many different ways a fastener can fail and the most common is metal fatigue, however, many stress failures can be attributed to being environmentally assisted. These are premature failures that are under the influences of tensile stress and some type of chemical or harmful environment. **The predictive failure mechanisms are predicated on the types of affected bolt material employed and the environment, or corrosive media, subjected to the bolt and joint.**

Stress Corrosion Cracking

Stress Corrosion Cracking (SCC) is one form of failure to fasteners and bolted joints whose crack propagation occurs unnoticed until the final catastrophic failure. As the name implies, this phenomenon occurs under the combined conditions of tensile stress and a corrosive environment.

SCC occurs under the combined conditions of tensile stress and a corrosive environment.

The environment is of critical importance as it only takes very small amounts of highly active chemicals to produce the initiation of cracking sites. These chemicals include nitrates, alkalis (hydroxides) and sulfides or ammonia. During the action of SCC, many times the exterior surface of the fastener material is relatively unaffected. The corrosive media will attack stress initiation sites and any corrosion pitting sites. SCC is basically an anodic cracking mechanism.

Stress concentrations initiate crevice loading due to high tensile stresses or residual internal stresses from cold working. Fine cracks, which may be either intergranular or transgranular, will propagate perpendicular to the applied stress.

A brittle fracture occurs without any plastic deformation and normally ductile materials will sustain a brittle fracture at lower stress levels when subjected to SCC. This is especially true of Body-Centered-Cubic (BCC) metals which are less densely packed than Face-Centered-Cubic (FCC) materials.

Typically, your BCC metals include ferritic steels, alpha irons, chromium and tungsten. The FCC common metals include aluminum, copper and austenitic steels. Alloy steels are more susceptible to SCC than just the base metal and will propagate more rapidly, as these fasteners will generally be stressed to higher limits.

Other examples would include copper alloys and bronze which have a tendency to adversely react to ammonia. Since many pipe fittings and valves are made of these materials, it is best to avoid their usage on tanks containing ammonia and some farm implements.

Grade 8 fasteners on a cement mixing truck were found failing due to SCC. Typically, cement trucks are washed down with muriatic acid, which is 70% diluted hydrochloric acid. The trucks are rinsed off with water, however the fasteners were located in an area that did not receive a full neutralizing water rinse and which retained some liquid in the area which initiated the pitting and subsequent failure.

Stress corrosion cracking may also be found around elevated temperature applications, such as heat exchangers. Heat and some gases will cause SCC on many steels.

Austenitic stainless steels are quite susceptible to chloride SCC. As an example, a water park used type 304 fasteners for assembly of the rides and base water containers. The fasteners failed from chloride SCC due to the chlorine added to the water for health safety. The fasteners had residual stresses from cold working when the wire was cold drawn and formed. The solution was to use type 316 stainless steel.

Hydrogen Embrittlement

Hydrogen embrittlement (HEMB), or hydrogen assisted cracking, is where the presence of ionic hydrogen makes a steel brittle and susceptible to subcritical crack growth under stress. Typically, this affects high strength steels and alloy steels whose hardness exceeds 36 RC and material strength is 150 ksi and greater.

Hydrogen may be absorbed into a fastener from chemical processing the steel and by welding steel with electrodes that may contain moisture. Typical chemical processing methods include caustic cleaning, pickling, phosphating and during electroplating with the chromic acid post treatments.

All of these chemical processes generate hydrogen in their chemical reaction, which makes HEMB a cathodic cracking mechanism. Decades ago, cyanide zinc and cadmium plating were replaced with more highly efficient acid or alkaline plating solutions which reduced the evolution of hydrogen from the work surface. However, baking is still recommended for high strength alloys.

For hydrogen damage to occur, the fastener must be tensioned. Fractures occurring during installation tightening are not due to HEMB. Depending upon the amount of hydrogen absorption, material hardness and tensile loading, the threshold stress intensity increases the crack growth velocity of the hydrogen as it diffuses through the grain boundaries to ultimate fracture within 24 hours.

Fastener fractures will generally occur at the fillet, or junction of the fastener head and body. This is the area of the greatest single stress concentration. Cracks which originate at the thread roots are generally the result of metal fatigue, but when subjected to tensile stresses of a static or inherent nature while in contact with a mildly corrosive solution, hydrogen is generated and cracking begins at the grain boundaries.

Sulfide stress cracking is another form of HEMB. This type of failure is predominately associated with oil and gas pipelines.

Liquid Metal Embrittlement

Liquid metal embrittlement (LME), or solid metal embrittlement, is when one of the metals is brought close to its melting point, under stress, at high operating temperatures. With some metals, it may be time dependent at lower temperatures. The greater the stresses the less time it will take for crack nucleation and propagation.

Cadmium plated metal locking nuts (Class B and C) are very susceptible to elevated temperatures. Though the cadmium plating has been banned by the EPA and RoHS, the military still uses cadmium plating as well as some imported products. Since zinc and cadmium both appear silver in color, it was traditional to apply a yellow dichromate post treatment to the cadmium plated parts to distinguish the two.

The problem with the cadmium plated lock nuts is that when exposed to elevated temperatures in excess of 400°F (204°C) the cadmium diffuses into the grain boundaries of the steel to cause intergranular cracking, even though the melting point of cadmium is 610°F (321°C). The fracture may initiate with either the bolt or the nut. In some cases, both may experience fractures.

A classic example is when an exhaust pipe to muffler was repaired on a school bus using cadmium plated lock nuts. The pipe and flange heated sufficiently to cause the bolt to fail from LME before the bus left the maintenance yard.

Large grain sizes are more severely embrittled and the fracture stresses vary inversely with the grain diameter. Brittle to ductile transition temperatures are increased by increasing the grain size. Therefore, to avoid any type of metal induced embrittlement with high strength fasteners, make sure the heat treatment produces a fine grain structure.

Zinc, lead, cadmium and tin can embrittle steel at temperatures below each metal's melting point. Zinc can cause LME above temperatures of 650°F (343°C). In fact, many steels will experience loss of ductility and cracking during hot dip galvanizing.

Corrosion Fatigue

Corrosion fatigue is metal fatigue failure in a corrosive environment. This is a mechanical degradation of the fastener under the combined action of corrosion and cyclic loading. Unlike stress corrosion cracking, where corrosive pitting leads to the development of brittle cracks, the only requirement for corrosion fatigue is that the material is under tensile stress.

Corrosion fatigue is metal fatigue failure in a corrosive environment. This is a mechanical degradation of the fastener under the combined action of corrosion and cyclic loading.

Corrosion fatigue may be mitigated by the addition of alloys, cathodic protection, nitriding, plating and shot peening.

In Conclusion

Be aware of the environment for the application and the fastener materials used for compatibility. High stresses are likely to nucleate a crack in corrosive environments.