

Fastener Failures Due to Stress Corrosion Cracking

by:

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Fasteners are susceptible to many forms of embrittlement, with stress corrosion cracking generally considered to be the most complex failure mechanism.

Fasteners are susceptible to many forms of embrittlement. These forms include the following:

- Environmentally induced cracking.
- Stress corrosion cracking.
- Hydrogen embrittlement.
- Corrosion fatigue.
- Liquid metal embrittlement.

Of these, stress corrosion cracking (SCC) is generally considered the most complex. Stress corrosion cracking is a failure mechanism that is caused by environment, susceptible material and tensile stress (**Figure 1**). Stress corrosion cracking can be in the form of:

- Sulfide stress cracking.
- Chloride induced SCC.
- Caustic induced SCC.
- Hydrogen induced SCC.



Fig. 1 — Factors contributing to stress corrosion cracking.

Many factors affect stress corrosion cracking phenomena such as stress level, alloy composition, microstructure, concentration of corrosive species, surface finish, micro-environmental surface effects, temperature, electrochemical potential, etc. Further complications are initiation and propagation phases, and the observation that in some cases cracks initiate at the base of corrosion pits.

Stress corrosion cracking is cracking induced from the combined influence of all three conditions seen in **Figure 1**. Cracks can be transgranular or intergranular in nature. The stress must be in the form of tensile stress above some minimum value (i.e., threshold level) usually below the yield stress of the material in the presence of a corrosive environment. Temperature is a significant environmental factor affecting cracking. Pitting is also commonly associated with stress corrosion cracking phenomena. In addition, catastrophic failure can occur without significant deformation or obvious deterioration of the component.

Mechanisms

Mechanisms proposed for stress corrosion cracking include the following:

- **Active Path:** Localized preferential corrosion (dissolution) at the crack tip, along a susceptible path, with the bulk of the material remaining in a more passive state. The rate of metal dissolution can be several orders of magnitude higher when an alloy is in its active state, compared to its passive condition.
- **Hydrogen Embrittlement:** It has been postulated that harmful hydrogen concentrates in highly stressed regions associated with the crack tip or other notches, leading to localized embrittlement.
- **Brittle Film-Induced Cleavage:** Cracks initiated in a brittle surface film may propagate (over a microscopic distance) into underlying more ductile material, before being arrested by ductile blunting of the crack tip. If the brittle film reforms over the blunted crack tip (under the influence of corrosion processes), such a process can be repeated over and over again.

Negating the Effects of Stress Corrosion Cracking

Corrosion can be controlled effectively by a combination of good design, correct selection of SCC resistant materials, environment management, maintenance and inspection. Stresses to consider include the following.

- Operational conditions:
 - Applied (tensile) stresses.
- Thermally induced factors:
 - Temperature gradients.
 - Differential thermal forces (expansion and contraction).
- Build-up of corrosion products:
 - Volumetric dependent.
- Assembly issues:
 - Poor fit up (tolerance problems).
 - Tightening/torqueing.
 - Press and shrink fits.
 - Fastener interference.
 - Joining.
- Residual stresses from the manufacturing processes:
 - Joining (welding, brazing, soldering).
 - Forging or casting.
 - Surface treatment (plating, mechanical cleaning, etc.).
 - Heat treatment (e.g., quenching, phase changes).
 - Forming and shaping.

- Machining.
- Cutting and shearing.

Choosing the proper fastener alloy is one of the most important considerations to negate the effects of stress corrosion cracking. It is relatively simple to choose a fastener with adequate strength and good (general) corrosion resistance. However, knowing the particular type of stress corrosion cracking issues that may be at work in the application is an important step in achieving a resistant fastener material. In certain environments, it may be necessary to choose a material that will experience some general corrosion since general corrosion is visually evident and, with proper preventative maintenance, general corrosion can be seen and fasteners replaced as necessary. On the other hand, stress corrosion cracking is rarely visually apparent and often occurs without warning. When it does, a catastrophic failure may occur.

Other methods include removing the corrosive environment or changing the manufacturing process or design to reduce the (tensile stresses). Corrosion can be effectively controlled by a combination of good design, careful selection of stress corrosion-resistant grades (e.g., stainless steel) and effective management, including maintenance and inspection. Specific steps can be taken to prevent the onset of SCC and minimize its consequences when it does occur by:

1. Consideration of the potential for SCC during the design and fabrication of components.
2. Selection of appropriate material grades.
3. Maintaining a chemical balance of the environment.
4. Ensuring that the potential for (organic or inorganic) contamination is minimized.
5. Maintaining proper environmental conditions (e.g. air quality).
6. Regular inspections of components for signs of corrosion and SCC.

Examples

In many applications, austenitic stainless steel fasteners (e.g., *ASTM A193 grade B8*) of 304 and 316 stainless steels provide good general corrosion resistance and are commonly requested. However, if the environment contains chlorides, fluorides or other halogens, these can act as a catalyst for chloride SCC. As an example, in marine environments, carbon steels are subject to corrosion so stainless steel fasteners might seem like a logical choice. However, in marine environments or other chloride containing services, alloy steel fasteners are preferred.

In order to reduce their susceptibility to general corrosion, alloy steel fasteners like grade B7 are usually provided with some type of protective coating such as zinc or cadmium plating. Unfortunately, this can lead to another form of environmental stress cracking known as liquid metal embrittlement (LME), or a related failure mode, solid metal induced embrittlement (SMIE) so appropriate cautions must be taken.

Symptoms of Stress Corrosion Cracking

Stress corrosion cracking is a type of localized corrosion characterized by fine cracks (as seen in the two photographs in **Figure 2**) that propagate quite rapidly leading to failure of the component and potentially the associated structure.

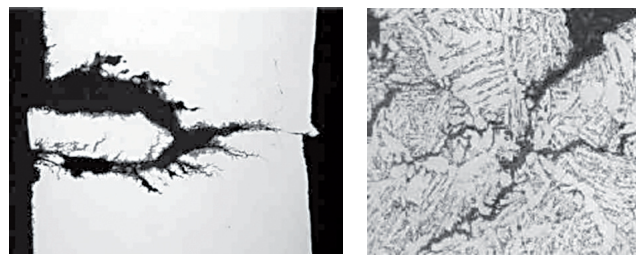


Fig. 2¹ — Typical appearance of stress corrosion cracking failure.

Other Fastener Failure Mechanisms

Fastener failures are not limited to just fatigue, hydrogen embrittlement, stress corrosion cracking and overload that must be dealt with by fastener makers. Other failure mechanisms include conversion of retained austenite (**Figure 3**), inclusions (**Figure 4**) and forming/forging defects, for example poor grain flow (**Figure 5** on next page).

Further Information

ASTM STP 1487 (Structural Integrity of Fasteners Including the Effects of Environmental and Stress Corrosion Cracking, 3rd Volume) contains 11 peer-reviewed papers that provide information on the structural integrity of fasteners

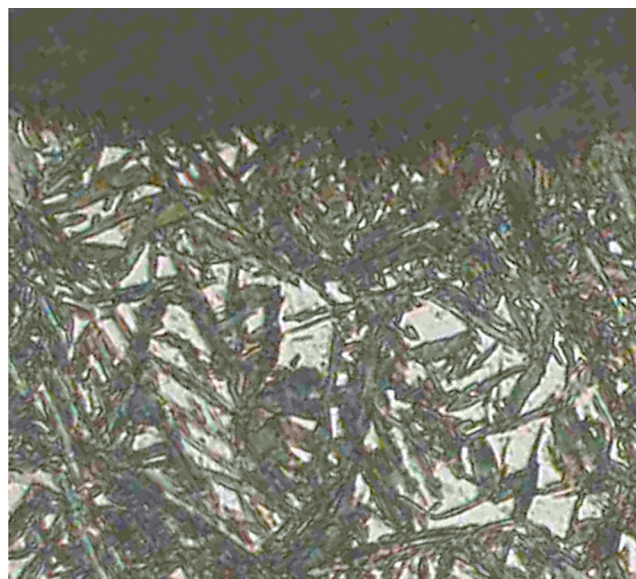


Fig. 3³ — Retained austenite (white areas are retained austenite).

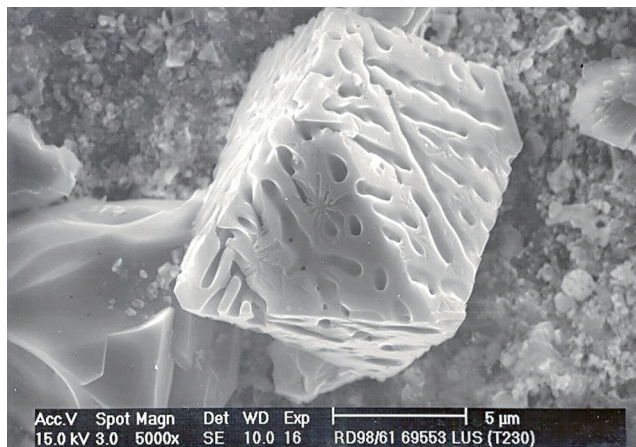


Fig. 4⁴ — Typical inclusion in steel.

Fastener Failures Due to Stress Corrosion Cracking ...continued

including the effects of environmental and stress corrosion cracking. The four sections cover:

- **Fatigue and Crack Growth Experimental Techniques**—

Three papers cover the development of a fastener structural element test for certifying navy fasteners material; experimental crack growth behavior for aerospace application; and influence of cold rolling threads before and after heat treatment on the fatigue resistance of high strength coarse thread bolts for multiple preload conditions.

- **Design/Environmental Effects**—Two papers examine the relationship between the tightening speed with friction and clamped-load; and the optimum thread rolling process that improves stress corrosion cracking (SCC) resistance to improve quality of design.

- **Fatigue and Crack Growth Analytical Techniques**—Three papers describe current analytical techniques for fatigue and crack growth evaluations of fasteners; a numerical crack growth model using the finite element analysis generated stress field; and the resistance of high strength, fine thread bolts for multiple preload conditions.

- **Design Consideration**—Three papers focus on the comprehensive, nonlinear three-dimensional (3-D) finite element model to simulate a displacement controlled for riveted structure; state-of-the-art fatigue crack growth analysis techniques that are used in various industries to evaluate damage tolerance evaluation of structures; the material stress state within the thread of the bolt; and on each parameter affecting the structural integrity of a bolted joint.

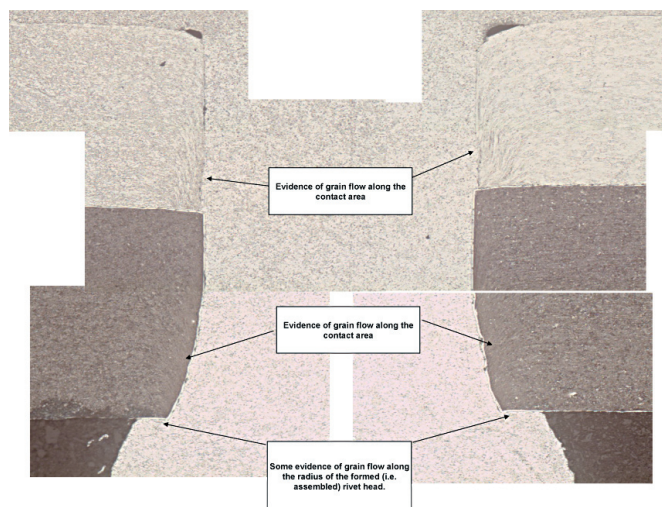


Fig. 5 — Rivet exhibiting poor grain flow and premature failure.

In Conclusion...

Stress corrosion cracking in fastener applications can be minimized by careful consideration of the factors indicated above and by taking the time to understand how and where the fastener will be used in service. www.heat-treat-doctor.com

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