THE CAUSE AND PREVENTION OF FASTENER FATIGUE FAILURE

A white paper from Unbrako N.A.

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Executive summary

Most industrial fastener failures—an estimated 85%—are caused by fatigue. New federal law mandates compliance to a number of industry quality specifications, but it does not call for fatigue failure safeguards. This paper traces design and material steps U.S. manufacturers are taking to prevent fastener fatigue failure, and encourages end users to consider including fatigue requirements in their specifications.

The failure of fasteners in industrial and aerospace applications costs U.S. industry—and the public—billions of dollars every year in downtime and lost production. Injuries and even deaths have resulted. More than 60 aircraft accidents have been attributed to fastener failure. While recent legislation has mandated that suppliers meet industry standards for these critical components, no existing regulation for industrial fasteners specifically addresses the cause of an estimated 85% of all fastener failures—fatigue.

What *is* fastener fatigue?

A typical industrial fastener, say, a socket head cap screw, looks absolutely rigid, but in fact it is—it must be—quite flexible. Due to such factors as design, material, method of manufacture and heat treatment, a cap screw will "stretch" when subjected to mechanical and/or thermal pressure. Such cap screws constantly stretch and return to their original shape. (If they are subject to excessive stress, of course, they permanently deform and eventually destruct.) These stretch-and-return actions are called cycles. A socket head cap screw can be subject to perhaps 240 cycles a day (e.g., in an 800-ton press) all the way up to 1 million cycles a day (e.g., in an ultrasonic horn).

As this peak-to-peak cycling occurs, the fastener is subject to stress. Eventually a crack will occur, just as it does when you rapidly flex a paper clip back and forth. The crack occurs at the fastener's most vulnerable point, referred to by engineers as the "maximum stress concentration area." The crack spreads and fastener fatigue failure has occurred.

The art of manufacturing industrial fasteners is a constant search for these various Achilles' heels and an ongoing development of design and manufacturing methods for overcoming them. The paradox of that quest is that, once you've "cured" one area of vulnerability, you have, in truth, created another. If not replaced, most dynamically loaded fasteners will suffer fatigue failure eventually; the only question is *when* they will fail. The fastener designer's objective becomes one of extending the number of cycles to failure at a given dynamic load.

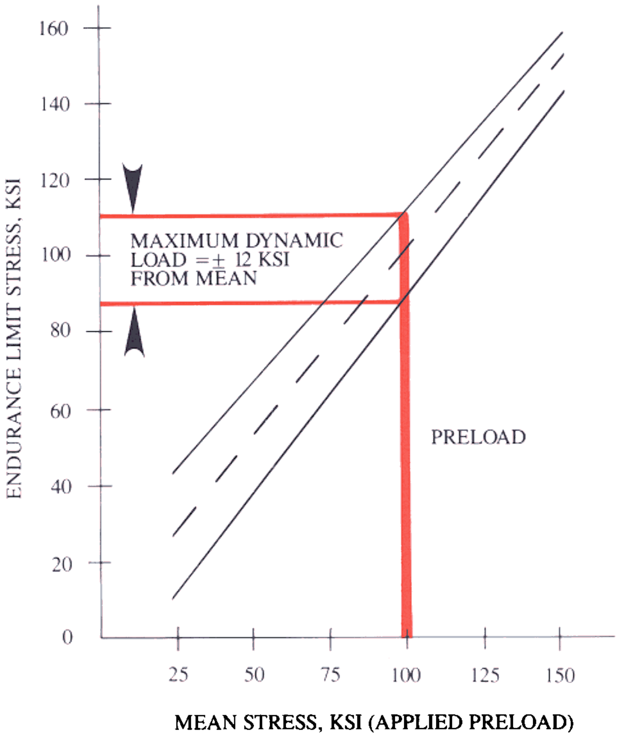
Where does fatigue failure occur?

The most common locations for fatigue failure include the joint interface (i.e., first "loaded" thread), the fillet, the threads, and the thread expiration or "run-out." As the industry has developed better materials and production methods to improve fatigue strength, the threads have become the weakest point of the fastener and currently account for the highest number of fatigue failures.

How is fatigue strength measured?

The number of variables involved and their interdependence in fastener performance have made setting standards for fatigue strength a difficult task. Currently, the number of "cycles to failure" is used to determine a relative strength for a series of fasteners. This complex measurement offers a standard of performance that encompasses all the variables of the fastener, which will finally fail at its weakest link.

Modified Goodman Diagram
Socket Head Cap Screws, Rolled Threads.
Stress based on the area at the basic thread minor diameter.



Modified Goodman diagrams help designers predict fastener performance. The broken diagonal line depicts the mean of the alternating load for a screw with a 90% probability of enduring 10 million cycles. The diagonal solid lines show that the maximum deviation of dynamic load from the mean stress is ±12 ksi when the screw is preloaded to 100 ksi.

Does the new Fastener Quality Act protect against fatigue failure?

In response to a great deal of media coverage and resultant public outcry, the United States Congress has passed Public Law 101-592. The Federal Fastener Quality Act mandates conformance to a variety of existing industry standards for fasteners. For instance, it closes the door to the millions of counterfeit fasteners that have flooded the U.S. market in recent years.

However, and importantly, the new Fastener Quality Act does not change the end user's protection against the cost and danger of failure caused by fatigue. Only through a complete program of design, production, quality control, and testing developed in conjunction with the supplier can the end user be assured of reliable fastener performance.

Thus, while the new law is extremely valuable to all users of fasteners, it does not mean that all fasteners will now be of uniform quality. There will still be vast differences among the fasteners offered by individual manufacturers. Many of those differences influence the crucial area of fatigue.

Guarding against failure

Clearly, design, purchasing and other industrial specifiers concerned with fasteners must take their own precautions to guard against fatigue failure. In this endeavor, responsible manufacturers of fasteners are constantly seeking out and shoring up the points of vulnerability referred to earlier.

The ultimate goal is to increase the number of "cycles to failure." Here are some stages along the trail to that goal.

Head Construction: ASTM standards require heads to be forged rather than machined. This precludes the planes of weakness caused by machining and increases the head fatigue strength. In addition, head height, socket depth and width, and wall thickness must all fall within strict tolerances in order to ensure proper key engagement. This allows the socket head cap screw to be tightened to a high preload, thereby minimizing the cyclic loads felt by the fastener. It should be noted that limited hex key engagement and/or oversize sockets can lead to screw failure at low wrenching torques.

Fillet Design: A smooth fillet with the correct radius for the application will help to reduce fatigue failure by blending the sharp profile where the head meets the shank. An elliptical radius will provide better distribution of stress and decrease the possibility of fatigue crack initiation.

Threads: A generous radius in the root of the thread reduces the concentration of stress caused by a "flat root" profile. Equally important is the proper radius in the thread run-out. Again, this lessens stress by reducing sharp corners and improves fatigue strength. Note that this radiused run-out is not mandated by common socket screw specifications.

ASTM standards require that threads be formed by rolling rather than cutting or grinding. Threads formed by rolling will ensure that the grain flow follows the thread contour. If the rolling is done after heat treatment the fatigue life can be increased by several hundred percent, due to the residual compressive stresses induced by the process. Rolled threads provide a smooth finish, reducing the susceptibility to a fatigue failure that could propagate from a surface imperfection. ASTM standards define acceptance criteria for thread laps that can initiate a fatigue crack. These standards appear to be the most commonly violated. Although often overlooked, they are critical to the fatigue life of the fastener.

Heat Treating: While heat treatment is used to produce stronger parts, improper treatment can result in conditions that will greatly reduce the fatigue strength of the fastener. Carburization (increase in surface carbon making the surface harder than the core) and decarburization (surface softer than the core) will reduce fatigue performance. Microstructural changes and cracks can be caused by insufficient temperature control. The wrong quenching media or procedure may not produce parts hardened throughout and can also cause cracking.

Surface Finish: ASTM standards specify surface finishes for different parts of a fastener. A rough surface finish on the screw threads or body or even a slight deformation in the fillet area represent potential initiation sites for a fatigue failure.

Some conclusions

The Fastener Quality Act, as well as a full range of ASTM, ANSI, and military specifications, offers limited protection from fatigue failure by providing guidelines for individual fastener parameters. In order to protect the end user and the public, designers and specifiers must go beyond these regulations to ensure the synergistic match of all facets of fastener production and supply.

Preventing fatigue failure includes starting with proper design, working with a qualified supplier, taking advantage of the most modern materials and production capabilities, and drawing on the manufacturer's extensive application and engineering experience.

The manufacture of fasteners must be implemented in a carefully controlled process, taking into account all the physical, mechanical, and chemical issues raised above. Perhaps most important is a thorough process control and assurance program, designed with the end user's application and tolerances in mind, to guarantee adequate testing, both in-process and after completion.

Considering the high incidence of fatigue failure and the possible associated catastrophic costs, end users should consider using fatigue requirements in their specifications for critical fasteners. A qualified manufacturer can build these criteria into the production process and conduct tests for process verification.

As the future brings even lighter parts, even fewer fasteners in critical applications, and even more exacting part specifications, the designers and specifiers of these parts must be even more aware of the role of fatigue in fastener failure. By working closely with an experienced, qualified supplier, designers and specifiers can help to reduce the incidence—and the cost—of fastener fatigue failure.

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