The Study and Prevention of
Fastener Fatigue Failure

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In the industrial and aerospace applications, the failure of fasteners costs US the loss of billions of US dollars every year, and even results in aircraft damages and deaths. More than 60 aircraft accidents have been caused by fastener failure. American government mandated that manufacturers of these important components meet industrial standards in its legislation, yet current regulations of industrial fasteners only emphasize the 85% of causes of all fastener fatigue failures.

What is Fastener Fatigue?

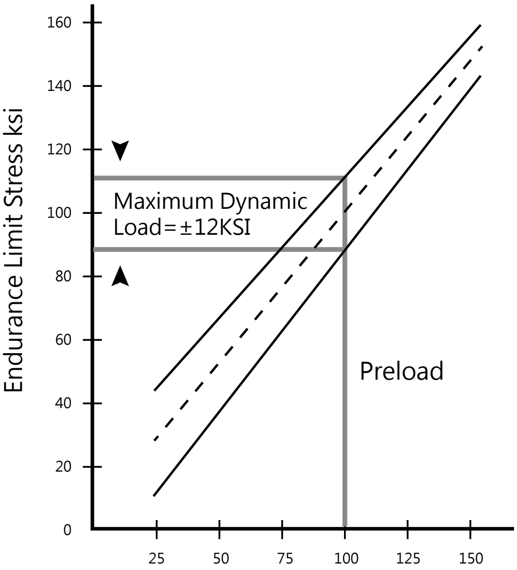
The typical socket head cap screw looks very rigid, but in fact it is quite flexible. Due to factors, including materials, design, manufacturing methods and heat treatment, the cap screw will stretch when the screw is subject to mechanical or thermal pressure. Such a cap screw constantly stretches and returns to its original shape. If a cap screw is subject to excessive stress, it will permanently deform and eventually be destructed. The stretch and return actions are called cycles. 800-ton press is applied to a cap screw for 240 cycles a day and up to 1 million cycles a day for the ultrasonic horn. When this "peak-to-peak" occurs cyclingly, the fastener is subject to stress, and eventually a crack will occur at the most vulnerable point, of the fastener i.e. "the maximum concentration area". The crack spreads to result in fastener fatigue failure.

Fastener manufacturers are constantly searching for the development of design and manufacturing technology to overcome fatigue failure. The incidents often occur. Once you have solved the vulnerability at one point, another one will occur at another point. If most dynamically loaded fasteners are not replaced, the fasteners will suffer fatigue failure eventually; thus the only question is when they will fail. The objective of a fastener designer is to extend the number of cycles to failure at a given dynamic load. The most common locations of fatigue failure are the joint interface (the first loaded thread), the flange, the threads, and the end of thread (run-out). When the industry has developed better materials and manufacturing methods to improve fatigue strength, the threads become the weakest point of the fastener and the common location of fatigue failure.

How is Fatigue Strength Measured?

The number of variables involved and their inter-relation in fastener performance have made setting standards for fatigue strength a difficult mission. Currently, the number of cycles to failure is used to determine a relative strength of fasteners. This complicated measurement offers a standard performance that includes all variables of the fasteners which will eventually fail at the weakest link.

Modified Goodman diagram assists designers to predict fastener performance. The broken diagonal line describes the means of the alternating load for a screw with 90% probability of enduring 10 million cycles. The diagonal solid lines indicate that the maximum deviation of dynamic load from the means stress is ±12Ksi when the screw is preloaded to 100Ksi.



Prevention of Fastener Failure

Those who concern about design, purchase and other industrial specifications of fasteners must take action to prevent fatigue failure. The responsible fastener manufacturers are constantly searching for the protective measures for the points of vulnerability. The ultimate objective is to increase the number of cycles to failure. The following methods can achieve these objectives:

Head Structure: ASTM standards demand heads be forged instead of machined that includes the weak planes caused by machining and increases the head fatigue strength. Additionally, head height, socket depth and width, and wall thickness must fall within strict tolerance to ensure ideal key engagement. This allows the socket head cap screw to be tightened to a high preload, therefore decreasing the cyclic loads on the fastener. The limited hex key engagement and oversized sockets can lead to screw failure at low wrenching torque.

Flange Design: A smooth flange with the correct radius for the application will help decrease fatigue failure by bending the sharp profile and head shank. An elliptical radius will provide better stress distribution and decrease the possibility of fatigue crack in the initial stage.

Threads: A wide root of the thread decreases the concentration of stress caused by a flat root profile. The ideal radius in the thread run-out is also important. This can decrease stress by reducing sharp corners and change fatigue strength. This radius run-out cannot be mandated by socket screw specifications. ASTM standards demand that threads be formed by rolling instead of cutting or grinding. Threads formed by rolling will ensure that grain flow follows the thread profile. If the rolling is made after heat treatment, the fatigue life can be increased by few times due to the residual compressive stress induced by the manufacturing process. Rolled thread provides a smooth finish, decreases the possibility to a fatigue failure that could propagate from a surface imperfection. ASTM standards define acceptable criteria for thread laps that can initiate a fatigue crack. These standards are usually not easy to achieve. Though they are often neglected, they are critical to the fatigue life of the fastener.

Heat Treatment: Heat treatment can enhance the performance of components, while improper heat treatment can tremendously decrease the fatigue strength of the fastener. Carburization increases carbon on the surface, making the surface harder than the core, and decreases fatigue performance. Microstructural changes and cracks can be caused by insufficient temperature control. The wrong quenching medium or procedure may not produce the part hardened throughout and can also cause cracking.

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

Conclusions

The Fastener Quality Act, and a full range of ASTM, ANSI and military specifications provide protection from fatigue failure by offering guidelines for individual fastener parameters. To protect the end users and the general public, designers and specifiers must meet the requirements of specifications to ensure the collaboration of all aspects for fastener production and supply.

Prevention of fatigue failure includes starting with ideal design, operating of a qualified supplier, taking advantage of the advanced materials and manufacturing capabilities, and making use of manufacturer's extensive application and engineering experience. The fastener manufacturer must carefully control the process, and take all the physical, mechanical, and OEM issues into consideration. The most important is a strict process control and quality assurance program, considering design with the end user's application and tolerances to guarantee adequate testing both in process and after completion.

Considering the high cost of fatigue failure and the possible disaster, the end users should consider using fatigue requirements in the specifications for important fasteners. A qualified manufacturer can put these criteria into the production process and conduct tests for process certification.

In the future, lighter fasteners are possibly used. In important applications, and even more exact part specifications, The designers and specifiers of these parts should be aware of the role of fatigue in fastener failure. By working closely with experienced, and qualified suppliers, designers and specifiers can assist in decreasing the cost of fastener fatigue failure.

References

White paper from Unbrako N. A. ■