The Process for Investigating Fastener Failures

When a fastener fails, it is important to gather as much information about the application and details of the installation as possible as this will not only help determine the root cause of the failure but how further failures may be prevented.

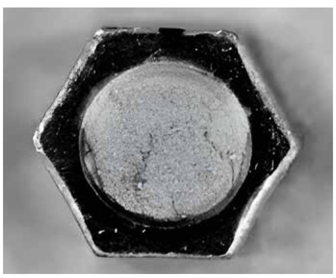

Photo 1. Ductile Fracture

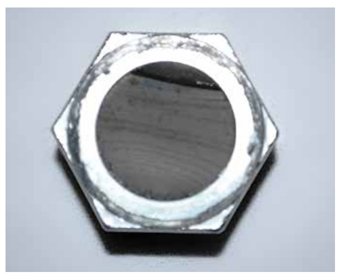

Photo 2. Metal Fatigue

Investigation

This is the time we categorize the data we collected. Sometimes we can tell by the appearance of the samples and fracture surface what may have happened. This will narrow the questions and failure possibilities.

For instance, a ductile fracture (Photo 1) will exhibit dimples with an inclusion, or a cups and cones appearance with a dull colored surface. It will also show some type of distortion, as the material will deform plastically before ultimate failure. However, if the load is applied very rapidly, as in a shock or impact load even while tightening, a ductile material may have the appearance of a brittle fracture. This can happen when using unregulated pneumatic installation tools.

Check the threads of the bolt to determine if there is a change in thread pitch. This will indicate if the bolt was stretched into yield either by service loads or during installation.

A brittle fracture may be flat, similar to metal fatigue but is more shiny, exposing grain boundary cracking, or grain boundary cleaving. Brittle fractures will not show visible signs of distortion. Some fractures may have the characteristic markings of chevron or waterfall patterns, which point to origin of stress initiation.

Metal fatigue (Photo 2) will display the conchoidal or 'beach marks' striations across the fracture surface. These will be a series of bands which may be dark, light or both. The darker bands signify low frequency impacts or vibration, while the lighter bands are indicative of a higher frequency or more rapid impact loads.

Photo 3 is of a metal fatigue fracture of a wheel stud. There are several initiation points in the fracture zone which suggests the wheel stud experienced a rotational load and a bending load in a loose condition.

Typically, fatigue fractures initiate either at the last thread run-out or at the first unengaged thread protruding from the nut.

Basic Questions to Discover:

- What type and grade strength of fastener was used?
    - Did the grade of the nut match the strength of the fastener?
    - Were all of the fasteners used in the connection the same grade or type?
- Was the fastener strength compatible with the joint service loads?
- How was the fastener used?
    - **Was it a static load?**
    - **Was it subject to extreme environmental conditions?**
    - **Was it in a dynamically loaded joint?**
    - **Were there alternating loads?**
    - **Were the loads axial?**
    - **Was the joint subject to vibration or impact loads?**
    - **Was the fastener subject to shear loads?**
- Ancillary components used:
    - Flat washer; type, size, coating.
    - Nut; standard, locking, grade, coating.
- Were there multiple fasteners in the joint?
    - Were the failures adjacent to each other if multiple failures?
- How were the fasteners installed?
    - By hand wrench
    - Pneumatic tool
    - Torque wrench
- Where were the fasteners tightened?
    - Bolt head
    - Nut
    - Both
- What is the condition of the joint surfaces?
    - Rusty or rough
    - Painted or smooth
- What is the condition of the failed parts?
- Where is the location of the fracture?
    - At the head?
    - The thread run-out?
    - First thread outside of the nut?
- What is the condition of the fracture surface?
    - Smooth, dull, bright, rusty?

Photo 3. Metal fatigue fracture of a wheel stud

Photo 4. Flat washers

Photo 5-A. All-metal lock nut

Photo 5-B. All-metal lock nut (inside)

Photo 6. Environment

Ancillary Components Used

This basically means to check the grade strength or property class of the bolt and nut to be sure the nut is compatible with the strength of the bolt. If not, there will be stripped threads and/or fatigue marks on the fracture surface because clamp load was lost.

Clamp load is also lost if a wrought flat washer was used with a Grade 5 (8.8 metric) bolt or higher. If the washers have indentations, clamp load was lost. The washers in Photo 4 have caused a massive loss of clamp load. Metal fatigue from this lost clamp load will cause a rapid bolt failure.

In addition to being too soft to sustain the service loads of the joint, the washer on the left of **Photo 4** has an inside diameter that is too large to fully support the loads under the head of the cap screw. This washer is typically called a USS washer. The washer on the right is an SAE flat washer whose inside diameter will fully support the loads under the head of the cap screw. Washers without indentations are made from hardened steel and will sustain fluctuating loads.

Coatings can make a difference in environments with elevated temperatures. **Photos 5-A** and **5-B** are of an all-metal lock nut that came off a turbocharger. Similar examples have been used in exhaust manifolds or boiler vessels. The inside will look like **Photo B**. The gold colored nuts are cadmium plated and will fail from Liquid Metal Embrittlement at temperatures exceeding 400°F or 204°C. LME is time dependent so failure will take longer at lower temperatures than higher. Zinc plating will also cause LME but at much higher temperatures.

Types of External Loads and Amount of Load

Proper bolt selection depends on knowing what the service loads are. If the bolt is bent, it was not the correct strength or diameter for the application. Heavy vibration and impact loads will cause metal fatigue if the bolts are not properly tightened and maintained. There should also be enough bolts in the connection to carry the load and reduce the individual bolt stress.

Some corrosive environments (**Photo 6**) can lead to stress-corrosion-cracking, where the grain boundaries become under chemical attack. Standing water will set up an electrolytic cell and cause hydrogen embrittlement.

Photo 7. Failed stainless steel

Photo 8. Too much impacting with an air tool can also crack the adjacent area around the nut

Photo 9. Hex corners of a nut

Other times, when there is rust in the fracture zone, it can signify that the failure was not new and had been propagating for some time. This could also cause other stress initiation sites.

Agricultural machines come under heavy chemical attack, even if properly washed down every day. Some have replaced their OE bolts for stainless steel to avoid the frequent replacing of rusty bolts. Unfortunately, in some cases the stainless steel bolts (**Photo 7**) will fail in a bending mode and metal fatigue because they weren't as strong as the OE bolts they replaced.

How was the Fastener Installed?

This makes a huge difference because a fastener can never be evenly tightened by hand with a hand wrench. Thread frictions vary and so does the installer's 'feel'. Sometimes the handle length of standard wrenches does not provide the proper leverage for higher grades of fasteners.

Torque wrenches are fine but not always accurate due to a multitude of variables, mostly including friction.

Pneumatic wrenches are mostly unregulated to output torque. They try to seek a stall point from thread friction. If the threads were lubricated, they would have either stripped the nut threads or stretched the fastener into yield.

Air wrenches are quick. They can cause galling and thread locking of stainless steel fasteners, even if they are of different types of stainless: it is the speed that destroys the fastener. The speed of assembly can also cause an underloaded joint and subsequent metal fatigue because a high compression rate is created as the nut slams into the joint surface. This compressive force has an equal and opposite reaction or recoil which will leave the joint not as tight as expected.

The impact wrench will always leave tell-tale signs of abuse. In **Photo 9**, the hex corners of the nut clearly display markings from the socket on the installation side (right) of the hex corners. There are also markings on the off side (left) which appear not only from removal but from the recoil of the socket as the impact goes forward and instantly recoils back.

With proper investigative techniques, the cause-effect of failures can be determined so that preventive measures can be employed. ■

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