Fastener Failure Analysis

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Procedures

When determining the root cause of any failure, there must be some guidelines to follow and questions to ask. The first major part of the investigation is to gather as much information as possible about the application of the fastener:

- How it was installed; by hand, pneumatic tool, torque wrench?
- Ancillary components used: flat washer, type; nut, grade, finish, coating?
- Type of external loads subjected on the joint: heavy impacting; vibrating; rotating; static; axial; transverse?
- Amount of load?
- Environment?
- Were there multiple fasteners in the joint?
- How were the multiple fasteners tightened: by cross-pattern; incremental loading; one after another?
- Where were the fasteners tightened: on the head; by the nut; alternating?
- What is the condition of the joint: rusty; painted surfaces; rough; smooth; lubricated?
- What is the condition of the failed parts: painted; rusty; greasy; heat scorched?
- What is the location of the fracture: head; thread run-out; just outside the nut; external cracking?
- What is the condition of the fracture surface: smooth; dull; shiny; rusty?
- Are there any chemical, mechanical test results of the fastener lot?

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 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.

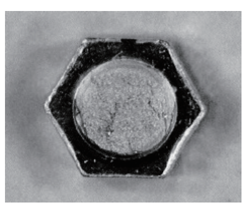

Fig. 1. Ductile fracture

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 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 signifying low frequency impacts or vibration, while the lighter bands are indicative of a higher frequency or more rapid impact loads.

Fig. 2. Metal fatigue fracture

The following photograph 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.

Fig. 3. Multiple fatigue initiation sites

Coatings can make a difference in environments with elevated temperatures. If there is an all-metal lock nut (**Fig. 4**) that came off a turbocharger, exhaust manifold or boiler vessel, the inside will look like **Fig. 5**. 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.


Fig. 4

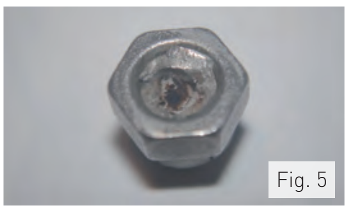
Fig. 5

Analysis

How was the fastener installed?

This makes a huge difference because a fastener can never be evenly tightened by hand. Thread frictions vary and so does the installer's 'feel'. Sometimes the 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 include 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 will 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.


Fig. 6. Impact wrench effect on a nut

The impact wrench will always leave tell-tale signs of abuse. In the photograph above, the hex corners of the nut clearly displays 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.

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 the following photograph have caused a massive loss of clamp load. Metal fatigue from this lost clamp load will cause a rapid bolt failure.


Fig. 7

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.

Environment


Fig. 8

Some corrosive environments 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.

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 will fail in a bending mode and metal fatigue because they weren't as strong as the OE bolts they replaced.

Fig. 9. Failed stainless steel

Multiple bolts

Load distribution in a joint with several bolts can be a problem if not evenly tightened. When this occurs, the entire joint begins to lose clamp load and the least tightened fastener is subjected to metal fatigue stresses. Then, because of the loss of the overall load capability of the joint, the adjacent bolts are exposed to extra stresses to compensate and a domino effect occurs.

Fig. 10

The fracture surfaces will indicate which bolt failed first and last by the progression of the fatigue crack. The first to be exposed will have the crack propagate through the most area, and then the second will not be as advanced and so forth, until the last failure(s) could be in ductile tension, (third socket screw from the right).

Also note areas of rust in the fracture area. This will indicate age by its progression. The rust will be a significant indicator in some instances to prove prior or existing damage to the bolt if that bolt was recently reused or tightened with another nut and then suddenly failed in an application.

Condition of the joint surfaces

The surfaces will indicate if there is any torque scatter to be considered. Painted and oily surfaces will reduce friction as well as promote shear forces. Burrs around the edge of holes will damage the fillet area under the bolt head and cause separation. The burr can also provide a barrier to prevent a solid connection, similar to rust forming a cushion. Non-parallel surfaces will mean that extra force was needed to bring the joint together, not to create clamp load.

The smoking gun

Sometimes one encounters problems for which there is no logical solution with the information provided. There is a piece of the puzzle missing and searching for this I call "looking for the smoking gun".

Case #1

When the boom on a lift truck was fully extended lengthwise to the truck chassis, the bolts holding the bull-ring gear towards the truck cab fractured. It was assured that the assembly was performed correctly: tightening the bolts in increments and criss-crossing by quadrants. Upon further questioning, it was found that the nuts were torqued onto the bolts per procedure.

However, when they tightened the bolts towards the cab, the structures were too close together to tighten the nuts with the torque wrench, so they tightened the bolt heads instead. There can be as much as a 20% decrease in clamp load from tightening the bolt head due to torsional unloading.

Case #2

The nuts were cracking on a hydraulic assembly. It was insisted that the proper torque of 109 Nm +10, -0 was employed as usual. The failure point of the assembly and materials was 136 Nm. After further discussion, it was learned that on this particular application, a crow's foot extension was used on the torque wrench. A small 6" extension would elevate the applied torque to 145 Nm and at +10, the applied torque is increased to 160 Nm. Both clearly beyond the failure torque of 136 Nm. There was also a low viscosity hydraulic fluid present which would further affect the torque on the assembly.

Case #3

A large agricultural spraying tractor had several failed stainless steel bolts. All exhibited some form of bending. The fracture surfaces were typical of metal fatigue. The customer replaced his corroded bolts with stainless steel to avoid frequent replacement. No further information was provided.

Not knowing what the original fasteners were, the parts catalog for the manufacturer of the farm implement was downloaded. It was discovered that many of the OE parts were flanged head bolts and nuts. The nuts were Grade C, which meant these were lock nuts with a proof load of 180 ksi. The stainless steel used had a tensile strength of 100 ksi, but the yield strength was only 60 ksi. Clearly not as strong as the recommended OE fasteners. ■