# Fretting Failures

by Thomas Doppke

**While vibration and the other mechanisms of joint failure have been explored in great detail and rightly deserve consideration, there is another factor that is little known or discussed. In fact, it is rarely even correctly identified. Known as fretting and its result, fretting corrosion; it has become a more common occurrence now that Aluminum is being used with great frequency. Aluminum is especially susceptible to fretting failure although it occurs in all metals. Fretting is defined as a form of damage, which arises when two surfaces, in contact and nominally at rest with respect to each other, experience slight periodic relative movement. The rubbing between the two parts under the slight movement produces a metal debris which can; increase the wear rate; can cause other problems chemically; and it may simply fall into adjacent components, impairing function or causing damage. This slight movement, slippage, is very small, undetectable in most cases, with relative movements of as little as 150 mm per year being claimed in some failures. The wear products being abrasive in the main, further contribute to damage by increasing the wear between the surfaces. Reduction of the surface under a clamped load reduces the tension and ultimately results in a fatigue type failure; the condition to which many fretting failures have been wrongly assigned to as the primary cause/origin.**

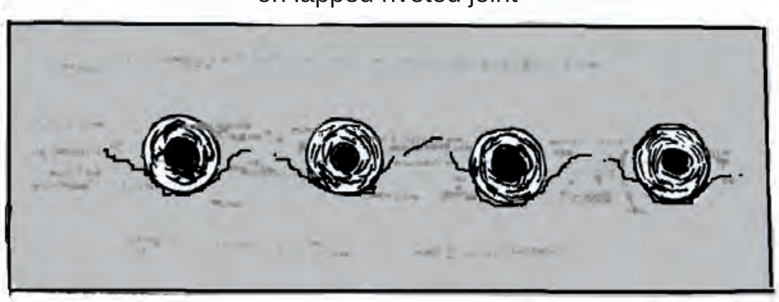
Situations where surfaces are in clamped contact and are subjected to varying stresses or vibration are possibilities for the generation of slight relative movements and the occurrence of fretting. These situations can be divided into two general classes of joining. Those where the design is such that no relative movement between the elements is intended and those where some movement may occur part of the time. This first class includes shrink fits, riveted joints, bolted joints, keyed fits and soon. The second class includes bearings, couplings, wire cables, cams, and such. Since we are most interested in fastened joints, these shall be the focus of this article.

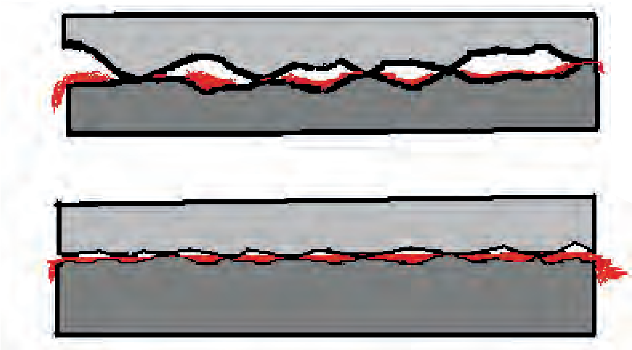
Fretting occurs in joints where the fit is usually tight, that is, where there is no possible relative movement as in riveted and pinned joints (where the holes are completely filled). But it can occur in bolted joints as well. Since the surfaces are never brought out of contact with each other the fretted material has no opportunity to escape. The appearance of the expelled material is the best indicator of a fretting condition. When fretting occurs between ferrous materials the dross is usually reddish in appearance, often called **"rust dust"** and between aluminum surfaces the expelled material is black whereas the usual corrosion products of aluminum that occur are white. In cases where fretting has been operating for sometime, the presence of fatigue cracks is a further indication.

Fatigue fractures caused by fretting have a characteristic shape and location. **Examination will show that the cracks usually start at the edge of the wear pattern, not the hole, as the illustration shows.**

Often the fatigue cracks will form a sine wave-like pattern. An example is a riveted section where the fatigue cracks went from

Illustration of typical sine wave-like pattern from fretting damage on lapped riveted joint






Rough vs. Smooth Surfaces

around one wear pattern circle, traveling downwards in a curve and curving up to the next wear pattern, giving the appearance of the aforementioned sine wave. The loss of clamp load leads to a greater movement of the parts, the greater relative movement makes the problem worse, causing increased progress of the failure.

**Surface roughness plays a large factor in how fast the fretting progresses. A rougher surface retards the fretting by; one, allowing more deformation of the asperities and two, having hollows for the dust to collect in.** This reduces the abrasive action of the dross. The debris is composed of removed metal, for the most part, oxides of the metals. Acting as sandpaper, these particles scour the surfaces. The generated dust increases frictional resistance to movement on one hand but also acts as an abrasive to increase the wear between the two surfaces. A smooth surface keeps the metal grit between the surfaces, effectively scouring the two contacted faces.

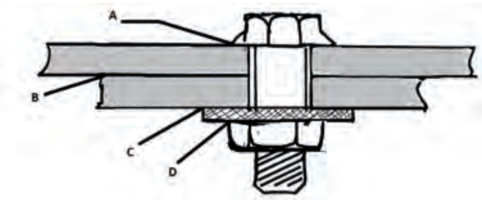
At what point can it be said that the wear is from fretting and what is considered normal wear conditions? First of all, fretting occurs at very low velocities. Whereas some wear occurs in normal conditions at speeds as low as, for example, 0.25nmm per second; fretting can occur, as mentioned before, at speeds as low as 150mm per year. Secondly, fretting occurs when the two surfaces are in constant contact with each other, depriving the abrasive residue from any means of escape from between the two surfaces save at the edges of sheet sections.

The effects of fretting are varied and can produce failures ranging from annoying to fatal. Wire rope attacked by fretting, forms oxides. Oxides are almost always larger in volume than their parent metals. The oxides generated force apart the wire strands, allowing for the further intrusion of moisture, which further increases the oxidation and abrasion. Perhaps bringing down a suspension bridge or the failure of a lifting crane. A well-documented example is the failure of a surgical implant (bone splint) in which the attaching screws fretted and caused a septic condition. Metals, regardless of how 'un-reactive' they are thought to be, are partially soluble and the presence of metallic ions in the local area 'poisoned' the tissue, retarding healing.

Abrasive particles may fall into adjacent components, causing electrical shorts and electronic malfunctions of devices, especially those which function with small amounts of current flow. Look at any modern electrical device; cell phone, iPod, computer, etc., the miniaturization trend leaves very little room between circuits for particle rain. Entrapped particles in operating mechanisms can cause seizure and jamming of the moving parts, a serious matter if the part is a safety value or solenoid.

As the illustration of the failed rivet hole shows, joints, which are tight (clearance interspaces are fully filled) as are riveted joints, are especially susceptible to fretting. Reverse bending moments or vibrations, even if they do not exceed the clamping load, can institute fretting action. The fretting can occur at the rivet head to base metal junction, between the two sheets being held together, or between the shank and the hole wall.

In the case of bolted joints, while there is clearance space in the shank to hole wall area, the head bearing surface against the surface of the component being joined and the nut face on the other side are subject to fretting. While the engineer will answer that clamp load (pre-load) keeps the joint tight and prevents any movement, what is not accounted for is the fact that the joint will see loads that exceed design parameters. These will only occur for microseconds and are usually not cyclic on a regular basis. Typical of these events are hitting a curb with




Areas of fretting on a bolted joint
A - Bolt underface to surface
B - Contact faces between sheets
C - Washer face to surface
D - Nut face to washer
Note: No fretting will occur between bolt shank and bolt hole wall.

Lubrication of wire cables prevents fretting and oxide expansion corrosion

a tire, a shock load when starting up a motor, even slamming a door. **Thermal expansion and cooling causes movement of items as varied a computers to light bulbs.** The latter item not being of much concern as far as fretting is concerned although the use of the new fluorescent bulbs with their very long life as shown some black "soot" deposits when being replaced (complaint from service maintenance company for large building; "employees complain of black soot on hands, dirtying things they touch".)

Prevention of fretting may be approached from several directions. Lubrication is usually given a first look. In the case of aluminum fretting, a grease or oil lube between the two parts is often enough to lower the coefficient of friction to decrease the scouring action. Where further processing is done, this idea does not work well. Many companies utilize racks, which keep the parts separated. Others use sheets of paper between the sheet metal.

Wire rope is lubed but the selection of the lubrication agent is critical. Too thick and it will not penetrate to the coat the internal surfaces completely, too thin and it will flow out of the strand bundles.

While there is some theoretical knowledge written on the nature of fretting and how is forms, these articles are long out of print and are of little value to any but the expert in physical and material science. Dealing with the mathematics of fretting would give a good understanding for how it happens, but most readers would rather know what to look for in case of a failure.

Is it fretting or normal fatigue? In addition to the formation of the debris, the second most noticeable fretting characteristic is the local pitting of the surface. There appear to be two types that show up regularly; a shallow dish-like pit and a deep pit, usually with a rim. The shallow pit is formed when the debris can escape the formation area and begin to start the sandpapering action. The deep pit forms when the removed material is trapped. Since this material is greater in volume that the area of the pit, the great pressure it is under causes the deformation of surrounding metal and raises a rim around the pit circumference.

**The fretting fatigue cracks can be found at right angles to the fretting direction, that is, in the direction of movement which is the direction of alternating stresses.** The crack starts at an oblique angle at the fretted point and turns to travel at right angles to the fretting direction when the crack has traveled beyond the effects of the fretting. A typical fretting fatigue failure crack face may show a tongue of material on one face and a mating chip out of the other crack face as a result of this faction. This and the fretting damage are the best indications that the failure is due to fretting.

One question often asked is what happens at the exact moment that fretting begins. It has been postulated that the surface asperities contact each other, are under great pressure (the clamping load is concentrated in the touch points which may exceed the tensile strength of the material), and the relative movement (slippage) erodes away the forming protective film (usually oxides). This pressure "welds" the two surfaces together. When there is enough time between movement the welds are easily separated as the forces that join them are weaker than the elastic effect of the two sliding surfaces and the mount of weld surface has been reduced by the forming oxide layer. When the frequency of movement is greater the oxide films do not form fully and metal-to-metal bonding occurs. Subsequent movement breaks these welds, producing a galled surface, which further welds on the next contact. This increases, rapidly with rapid cycling and slowly with sporadic movement, until the formation of debris is formed. This debris acts as a scouring agent to further abrade the surfaces.

The ways to prevent fretting damage begin with design. Surfaces are joined to produce a higher normal pressure to prevent any oscillatory movement is a goal, However, since most joints will be subjected to some movement, fretting will probably occur. The design should strive to make the stress points occur in areas where fretting will not. This will probably not be easy as the two are often interlinked. Some common solutions to some standard joints are listed below.

Press fits (hubs, shafts, motor shaft into bearings, etc.) the reduction of the high stress area (usually at the shaft to mounting hole) by reducing the shaft diameter is an easy solution if possible. The formation of a groove at that area is also another solution. Again, surface finish, hardness, frequency of the vibration all may have some effect.

**Pinned joints show that a close fitted joint shows the lowest fretting occurrence. As interference increases so does the fretting damage.**

Riveted and bolted joints, if repeatedly flexed or subjected to varying tensile stresses, show fretting occurring in the area of the holes (see illustration above). The best design practice is to use plates of equal thickness and as many and as thick (largest diameters) of fasteners as possible. This is not easy today with demands for reduction of metal weight and part size.

Lubrication has been touched upon slightly before but in general a lubricant that offers the lowest coefficient of fiction will allow relative movement that will occur anyways but will reduce the abrasive action in the contact areas.

Metallic coatings have been used as a friction reducer between metal surfaces. Cadmium, now banned in most countries, was considered a great friction coating as it did not work harden nor did it lend itself to intermetallic welding to any great extent.

Using a material of higher fatigue strength does not always solve the fretting problem. Experiments have shown that this is not always the case. Results have been varied, but some facts were determined. Cast surfaces were higher in fretting fatigue strength than those in the forged condition although the cast material had a lower fatigue strength listed to begin with.