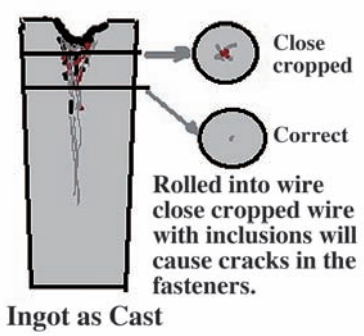
Fastener Hidden Killers

by Thomas Doppke

The title sounds like a murder mystery but it is to attract your attention to numerous small faults and errors that can cause a major catastrophe in an attachment. These can be divided into several areas; material, design, manufacture, and processing. Often overlooked and/or thought of as being of little consequence, they can cause a major failure (fatal to the attachment) down the line.

With cost being today's determining factor in almost everything, the purchase of fastener wire stock of less than optimum quality, regardless of how much money can be saved, will end up costing many times the initial savings. Among the most common wire malfunctions are inclusions caused by 'close cropping' the ingot. As the steel ingot cools the inclusions (slag, dirt, scale, etc.) are pushed towards the center and to the top of the ingot. This area is usually cut off and put into a re-melt pot. To maximize the metal obtainable from a steel ingot the cut off area is often made further up the piece, causing much of the center inclusions to be included and often resulting in seamy stock. As the ingot is rolled down into wire the inclusions remain. There will always be a very small amount of non-metallic in the center of all wire but it should be as minimal as possible.

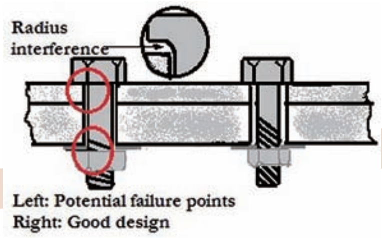


Secondly, unless the chemistry is certified, wire with numerous slag and sulfide stringers (and lead) may be purchased (usually cheaper). While this chemistry (called "free machining quality") is used for product produced by screw machining because of its better cutting properties, it performs poorly in cold heading operations. Thirdly, steel specifications allow variation in chemistry to a certain degree. It has been found by cut rate manufacturers that by classifying a lower chemistry as a higher grade more profit is obtained. Unless the chemistry is known at the beginning, problems in heat treating and manufacturing may result. Four, the proper size wire is extremely important. The received wire is drawn to exact size at the cold heading machine station through a draw die set up. Some fastener manufacturers skip this step, relying upon vendor certifications. The final thread dimensions are dependent upon the diameter of the wire at the outset. Cases are known where the wire is undersized (and a few where oversized wire was submitted), showing either poor attention to quality or perhaps lack of technical competence. Oversized wire will cause a problem with the die draw and may jam the operation. Undersized wire will produce below dimension threads. Finally but by no means the last, improper annealing of the wire by the steel source (too much, too little, spotty areas) will be a killer from the draw die step to the heading operation. Fastener wire must be in a 'soft-as-possible' condition to enable easy and efficient heading. Spotty annealing leaves 'hard' spots and the inconsistent annealing will cause heading difficulties variations when those softer and harder sections are run through the header.

It has been pointed out in numerous articles before that critical fastener design features are notoriously overlooked when it comes into consideration. Fasteners are usually added as a last item on the designer's agenda and rate little attention. However, easily overlooked small mistakes to a fastener's required joint conditions can destroy the best efforts of an attachment. Typically found killers are: designs where the joint plates meet at high stress areas, the thread runout and under the head; off angled attachments; overloaded joints caused by unthought-of factors; and insufficient bolt clearance. There are several more items but these will cover the topic sufficiently.

Almost every handbook on fastening will state that the high stress areas of a joint are where the various fastened plates (parts, etc.) meet. Therefore it is stated widely that the high stress areas of a fastener should not coincide with these areas. Failure to follow this advice will result in possible fatigue and joint failure (a shot to the heart!). As the illustration below shows, a joint where the planes of the joint met at the thread runout will stress the bolt at that point. Since the bolt will be resisting sliding movement the runout area will act as a fulcrum for bending and fatigue failures will occur.

Correct design is to either have the thread runout area inside the joint, as shown, or outside the joint interfaces. Another fault in design is having the clearance hole for the bolt too small. Luckily this does not occur too often but engineers desiring to achieve maximum joint strength think that a tight



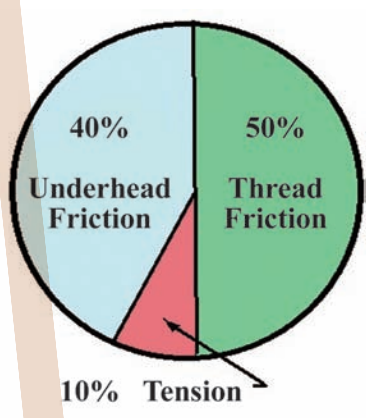
Left: Potential failure points
Right: Good design

hole will prevent possible side slippage and joint loosening. What happens is that the edge of the hole, often left as drilled or punched without a countersunk, stabs into the bolt underhead radius. This creates a fatigue point-enough said!

As an afterthought, little consideration is given to the fastener's seating. As cast surfaces, rough machining and off angled seating planes are never given much notice. A study made a few years ago about off angled tightening showed that a fastener off angled as little as 3-5 degrees would reduce the fatigue life of the joint by almost 20%! The usual standard is that the bolt head cannot exceed 2% angular deviation from the shank longitudinal axis.

In the rush to finish off the design, important factors are often overlooked. Bolts are tension fasteners, and they hold by pulling things together, in tension. Their strength is reduced to as little as 60% if loaded transversely. A large building owned by a company whose identity is confidential, placed large steel letters on the façade, spelling out the company's name. Each weighted several hundred pounds. Several of these fell off, luckily no one was hurt. The bolts were loaded transversely to a force exceeding 60% of their listed tensile strength.

Among other "I didn't think about that" factors are changes in coatings and platings. The coefficient of friction for different platings may change the preload that a joint tightened to a value will actually see. Some coatings are rougher and will result in the joint being underloaded (possible loosening, fatigue or loss of joint) and others are smoother (over torqued to onset of yielding). A major car company lost an entire year of a specialty model when a slippery coating was substituted for a standard one, resulting in a "no build" situation.



As mentioned in previous articles, the amount of tension produced in a joint by torqueing is reduced by 90% by friction. Approximately 50% is lost in thread friction and 40% by underhead friction. This leaves only 10% of the torque actually tightening the joint. It is not much of a mystery to see that small amounts of change to the friction can have major consequences to the loading of the joint. The design that was tested with exemplar hardware from the laboratory's stock was probably never re-evaluated with the production coated parts.

A last item often left off the crime sheet is consideration of the environment in which the fastener will be functioning. Several scenarios come to mind. Recently an article was written about the effects of oils and petro-chemicals upon plastics. ABS and other plastics are sensitive to the oil on fasteners. They will stress crack the plastic. Phosphate and oil coatings are the culprits here. Also the assembly plant often dips bolts and screws into oil to make assembly easier, almost always without permission. Salts from road de–icing increase the chances of stress cracking, especially on higher hardness fasteners. Inadequate drainage from joint areas increase corrosion and such 'wet pockets' are failure sites. Among the typical fluids that a fastener might encounter are; car washing solutions, windshield washer liquid, oil, antifreeze, gasoline/ diesel oil, water, soap and cleaning materials, and probably a few others that I did not think of (like the kid's spilled ice cream).

Luckily there are few dangerous situations that can be directly traced back to the manufacturing process. Things that happen have been covered above. Seams in wire may spilt during heading, undersized threads due to undersized wire may occur if the maker doesn't take steps to check his incoming stock, etc. Quality issues are usually not present with reputable manufacturers but with the constant drive to lower cost many fasteners are coming in from unreliable and suspect sources. That small savings on price will probably cause enormous losses in repair, loss of reputation, and possible legal actions. One often encountered clue in poor fasteners is the overuse of the rolling dies. Expensive to purchase, they have a definite working life. Good companies keep track of how many pieces are produced from a set of dies. They also are aware of contributing factors that shorten the die's productivity such as the hardness of the wire. Many cut-rate companies push the dies to get that extra thousand or more pieces from the rolls, resulting in poorly formed and/or undersized threads. With many end users going to vendor certifications rather than the old, but costly, receiving inspection, these shady companies get their product sold.

The last clue in our mystery of why fasteners die is processing mistakes, omissions, and commissions. Almost all fasteners are heat treated. Again quality work means quality product and cheap prices will probably be representative of poor quality. Overloading the furnaces to reduce cost usually is accomplished by piling fasteners in large piles rather than spreading them to insure even heat (less time in heat, saving $$). The parts in the middle of the pile may see lower temperatures, especially as the heat cycle is not held long enough to evenly heat the entire load. This and short cycle tempering will result in inconsistent hardness throughout the lot. Poor controls of the furnace atmosphere may produce scale and/or decarburization or its opposite-carburization.

Tapping screws require a hardened surface to perform their duty. Again, improper heat treatment will make parts generally unusable. Too little carbon in the atmosphere makes a poor surface, soft and unusable for tapping. Too much makes a surface case which may cause the threads to break off or even strip before tapping.

That seamy stock we discussed above has now made it through to heat treatment. The heading process has cracked the formed part in numerous areas. Small cracks, mostly not visible to casual inspection, open up during heating and quenching cycles (Look up quench cracks on the Internet). If not discovered here the parts will fail in production either instantly or, unfortunately, after an uncertain time period!

The fasteners have now arrived at their final processing step. With the exception of stainless steel and some aluminum fasteners, all parts received some sort of protective covering. Be it platings, paint, or organic coatings, corrosion is a fact of life for fasteners and protection is required. The drive today is to insure that no evidence of corrosion is present lest the customer disapprove and reject the product. Rust was so common in early years that a rusty bolt was not even noticed, but not so today. Paint was used, and still is, on many applications. After the first world war (at the beginning of the 20th century) many plating patents and techniques were utilized to produce a myriad of electroplated coatings. (The German industry had kept them secret and locked up but surrendered the technology as part of the aftermath settlement). As requirements increased over the years the coating thickness attempted to follow suit. Therein lies the problem. There is only a small amount of tolerance allowed for manufacturing variation on fasteners. Also, there is no allowance on internal fasteners, the thought being that any variation would be accommodated on the external side. Many platings exceeded the allowance today. This causes jamming, hard torqueing (which leads to low loading and loosening) and dimensional misfits. Undersizing the threads helps slightly but there is a finite limit to how undersized a thread can be without losing significant strength. Lately high build zinc based coatings have been the answer to high corrosion resistant demands. These are applied by dipping buckets of the parts in a paint-like coating and spinning off the excess rapidly. Exact thickness is impossible to control and threads, especially small diameters, maybe filled to the tips in spots. Recess drives also are filled enough to make driver bits either hard to insert or where a bit cannot be used at all. Designers seldom consider the effects of finishing upon assembly and torque. This problem appears to have no good solution at present. A few new electroplate platings are being tried with moderate success for the high corrosion areas while protection (paint, hidden locations, good drainage, etc.) in design has lessened the problem. Since the problem was not considered at the onset, many of the fixes are 'band-aides' and responses to assembly difficulties. For many applications not subjected to weather or corrosion the standard, thin coatings are sufficient.

Hardened fasteners ae especially vulnerable to a condition known as hydrogen embrittlement. Fasteners which are electroplated (zinc mostly) are saturated with ionic hydrogen (H+) during the plating process. This gas is trapped in the steel part by the impervious zinc (sic) layer. After time the ionic hydrogen collects together in microscopic pockets as hydrogen gas (H2) or combines with carbon to produce methane. Building up pressure until its internal force exceeds the strength of the steel, it ruptures. The gas continues to build up pressure until another rupture occurs, and so on until the final failure-rupture. The failures are often sudden and unexpected. A bolt head may just break off in the middle of the night (so to speak) or under a slight touch. Proper practice is to bake the finished, plated parts immediately after plating (within an hour or less is recommended). Often to save money the plater waits until he has a full oven to bake, which may be as long as several hours). The bake cycle is usually about 4-8 hours. Parts with hardness' over HRC 38 (which includes case hardened tapping screws) are especially vulnerable.

So when a fastener crime has been committed, the fastener detective brings out his magnifying glass and looks at all the clues. Was it a fault with the material? Easy enough to prove. Is the part to specification? All specifications! Rather than relying upon certifications, the crime needs to be investigated personally. Hardness at several locations, chemistry, microscopic examination of structure, surface conditions, evidence of fatigue or other results of external forces acting upon the joint. Dimensional measurements including gaging of dimensions of the threads (if that part was involved). An examination of the crime scene will show if the design contributed to the failure. Joint analysis for loading, proper torque to produce sufficient preload, dimensional study of fit and assembly, effects of coatings and any extraneous lubrications, etc. are a few of the clues gathered. What exactly happened at the time of failure, if it can be determined, will assist in the solution. Was there a heavy impact? Was a cyclic loading a conditions of operation? Is the part necked down indicating overloading or sharply transverse showing an instantaneous fracture? How did the assembly line put the parts together? Often tooling used is easy and quick but extremely harsh on the joint. Impact guns have generally been excluded from most automotive plants today for this reason.

A review of the article above will make a Sherlock Homes of most people who are faced with answering why this fastener failed, and put the criminal away.