Fastener Failures: Liquid Metal EMBRITTLEMENT

by Guy Avellon

Many fastener failures we encounter are basic; metal fatigue, over tightening, thread stripping, etc. Some failures are more complex involving multiple causes for the failure. Then, there is the failure mechanism you rarely see but in an entirely different application, as we shall see here.

The failure presented here is of a wheel stud made for auto racing. The shape is unlike standard wheel studs because instead of a straight shank between the threaded portions, this area is barrel shaped, like a brass air brake compression sleeve. The purpose is for better seating and absorbing load stress. The end of the wheel stud has an internal hex for tightening it into the wheel hub. The nut is standard hex with a conical end to seat into the wheel.

The vehicle is a sedan manufactured in Europe and was used for club racing. Normally, these vehicles would have stud bolts that thread directly into the wheel hub. However, these were changed out for ease of tire removals. The wheel studs are hardened and tempered steel, Property Class 10.9, 1040 MPa (150 ksi), M12x1.5 with a black zinc plating. Stated maximum torque (to induce yield) is 180 Nm (133 lb-ft); recommended torque is 108 Nm (80 lb-ft), OEM recommendation is 119 Nm (88 lb-ft).

First, the thread pitch of all samples was measured with a metric pitch gauge. It was found that all used samples exhibited yield; i.e., they had been stretched beyond their elastic limit. This was not gross overloading but was very slight, just enough to lose clamp load. An electric impact gun was used to change from street tires to racing tires.

The following photograph **(Photo 1)** will illustrate the change in thread pitch which is indicative of material yielding. There should be no gap between the threads of the wheel stud and the thread gauge.

All materials will stretch; soft or heat treated and strong steel alloys. It is the elastic ability of the metal to want to return to its original shape that produces clamp force. However, if that material is stretched past its yield point, the material no longer returns to its original dimensions and assumes a new permanent length. Since the threads have the smallest cross-section, they will change first. Further stretching produces a more pronounced 'necked-out' shape, also called a 'dog-bone'.

A perfect thread match should leave no air gaps between the threads. However, when measuring, the threads must be measured in the grip area; i.e., the area between the end of the nut and the last thread of the fastener. This is the area that stretches. If the threads were measured where the nut's position was on the threads of the fastener, those threads would be standard, no change.

If there is no thread pitch gauge available, the second photograph (**Photo 2**) illustrates another way to identify if the fastener in question has been stretched into yield. Simply place a new fastener along the entire length of the threads of the other fastener as in **Photo 2**. If the threads do not match, then the fastener in question has been stretched into yield, even if you could thread a nut all the way along the threads.

The recommended torque for these wheel studs was lower than standard torque values because these wheel studs were plated and OEM wheel studs are not plated. Typically, common passenger vehicles require a torque of 150 Nm (110 lb-ft). The plating reduces the coefficient of friction between the mating surfaces which requires the torque to be lowered to 108 Nm (80 lb.-ft.). DeWalt makes cordless impact wrenches that range from 197-406 Nm (145-300 lb-ft) of torque. This clearly exceeds the wheel stud's physical yield strength properties, with or without the plated surfaces.

The **Photograph 3** of the wheel nut indicates the severe impacting that occurred by the rounding of the hexagonal corners of the nut.

The wheel studs were obviously over-stressed and metal fatigue was initiated. However, an examination of the fracture surface indicates another source of failure: liquid metal embrittlement (LME).

In the following **Photograph 4**, there are 'chatter' markings between the 10 to 12 o'clock positions. This is from joint loosening and from the impact wrench. Metal fatigue is indicated by fine striation bands, which can be seen propagating from the 4 o'clock position. The mass of white with dark carbon deposit is indicative of LME.

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Steels are embrittled by zinc at temperatures exceeding 400° C (752° F). Zinc melts at 419° C (786° F). When stresses are present the zinc diffuses into the steel, generating crack nucleation and a fast rate of crack propagation. Ductility is lost and the stealthy fracture is total and quick.

This type of fracture is rarely seen with zinc plated parts. Presumably because many go unreported as the failure mode was not easily determined or was attributed to metal fatigue.

For comparison, **Photograph 5** is of an LME on a cadmium plated nut, used to tighten an exhaust manifold. It cracked within 5 minutes. The fractures are similar, with the white area surrounding a carbon deposit. Cadmium melts at 321° C (610° F), much lower than zinc.

The nut in **Photograph 6** was also cadmium plated. It was a top deflected prevailing torque-type lock nut that was used on a flange on studs in a heat exchanger. Here, both the nut and bolt fractured. The same characteristics of black deposits with white metal were prevalent.

Studies of other LME failures have indicated that the failures are time, temperature and size related. That is, the higher the temperature, the faster the LME fracture occurs. The fractures will occur faster with smaller diameter products than larger fasteners, due to their mass. Lower temperatures, slightly above the ‘critical’ temperature of 400° C (752° F), take longer to fail, as was the case with the sample in **Photograph 6.**

Conclusion

There were multiple causes for failure in this wheel stud example, but the primary damage to the wheel studs was caused from using an unregulated impact gun, coupled with the multiple reuse of wheel nuts that induced the stresses that allowed the LME to occur. There were no material defects indicated.

Because zinc has a higher melting point than cadmium, zinc plating is safer to use with more elevated temperature applications. Even though racing brake temperatures may exceed 649° C (1200° F), common wheel studs do not normally experience this temperature since they are threaded into the wheel hub, which acts as a heat sink. However, these wheel studs experienced temperatures over 343° C (650° F), at which point the zinc caused LME.

This also leads to a word of caution for distributors and users who purchase B7 threaded rods, also known as A193-B7. This material and designation ‘B7’ is commonly used for high temperature, heat exchangers and high pressure vessel applications, up to 594° C (1100° F). Many times this product is plated with zinc for appearance and corrosion resistance and is not suitable in high temperature applications, as it will fail from LME.