The Minefield of Automotive Lug Nuts

By Ed Fisher

From time-to-time, people wonder about the aluminum lug nuts that Porsche used for so many years and whether they are safe on the street or the track. They also wonder about what torque to use and whether or not to lubricate the threads.

A friend asked me a related question. He had just purchased titanium lug nuts for his 993 and wondered what torque to use and whether to lubricate. I had to think about it for a while and do some research. That effort is what led to this article.

When I ran my 944 in autocross and my previous 944S2 and a few other cars on the track, I ditched the aluminum or closed steel for open steel lug nuts. I think open lug nuts were actually required for the PCA track days I went to, but I'm not sure if aluminum was allowed, even if open. In any case, here is where my thinking is these days. Full disclosure: I was a mechanical engineer and designed and analyzed bolted joints for a living on occasion.

First let's look at the ultimate tensile strengths for some lug nut materials out in the market today. I'm going to assume that all lug nuts are the same standard size, shape and 14x1.5 thread. Unfortunately, I have not been able to determine the exact material used historically in Porsche aluminum lug nuts. Almost nobody wants to reveal what material they're using except for the titanium guys! Ever heard of Pexalloy? Me neither, until doing research for this article, but some of the more expensive lug nuts and bolts around are made from it. It may be really great stuff, but there's no way to know what it really is if the seller won't tell you.

Aluminum.......... 7075-T6..…83 Ksi
Stainless Steel….T304H........91 Ksi
Titanium ……   6AL-4V.....120 Ksi
Steel………..Grade 8/10.9…150 Ksi
Chromed steel…1080?……..176 Ksi

(Editor's note: Ksi is a measure of Ultimate Tensile Strength, tensile strength being the amount of axial stress a material can take before breaking.)

Some people are making lug nuts from 6061-T6 aluminum. This alloy has an ultimate tensile strength of 45 Ksi. Personally, I wouldn't use them, especially since you can do so much better.

The better aluminum lug nuts these days are claimed to be made from 7075-T6. Aside from it being relatively weak compared to the other materials in the list above, the main problem I have with any aluminum is that when it gets hot, like from hot brakes on a track day, the strength goes down fast. At 212F 7075-T6 is down to 70 Ksi. At 300F it's down to 31 Ksi. I do not know for sure what temperature the lug nuts can actually become on a track day, but I've seen 300F quoted in print for wheels on a race track. So, I just say no. I don't think aluminum is a proper material in this application that combines abuse (lots of tire changing, running over curbs, etc.) with unusual heat, even if you always use a torque wrench, know that you have proper thread engagement and know that your lug nuts have never been assaulted by Bubba and his impact gun. (Porsche always warned against letting Bubba the tire changer and his impact wrench anywhere near your aluminum lug nuts.)

Historically the Porsche torque callout in most applications was 130 N-m which equals 96 lb-ft. (Editor's note: Porsche now stipulates 96 lb-ft. for 2008 and older vehicles and 118 lb-ft. for 2009 and newer vehicles.) However, the torque callout was only correct if you lubricated the threads and the shoulders with assembly paste. Optimoly HT (Optimol PASTE HT) was called out historically but may have been discontinued. More recently Porsche calls for Optimol PASTE TA. *Pelican Parts* sells TA, but it is not based on silver like they claim. (It would be a lot more expensive if it was!) Only the color is silver, guys. It consists primarily of aluminum and zinc powders in a thickened petroleum base.

Here is the key point: No torque for any bolted joint is correct unless a friction condition is specified, i.e., clean and dry or lubricated with something or the other. With lug nuts, there is the lubrication of the shoulder that contacts the wheel to take into account as well as the threads. The lubrication is desirable for 3 reasons: 1) to prevent galling (failure at the surface) of threads and shoulders, 2) to increase the joint clamp-up level and accuracy for a given applied torque, and 3) to prevent long-term corrosion. #1 is, I think, obvious. #2 is often not recognized. 96lb-ft of torque does not produce as much clamp and elastic deformation within the joint if the threads are clean and dry, for instance, as if they have been lubricated. #3 is especially important with aluminum which can corrode badly under certain conditions.

Some modern Porsches use higher torques but with no lubrication. Some use higher torques <u>and</u> lubrication. The lug bolts supplied now, which I think are all steel, have rotating collars of aluminum that contact the wheel and are intended to spin on the bolt shank, not at the wheel. Therefore, they can't gall on the wheel so they need no lubrication at that interface but Porsche may require them to be lubricated at the bolt to collar interface and on the threads. Find out what Porsche says for your specific model and year and do that! Don't listen to unqualified opinions on the internet.

If you have aluminum lug nuts on your street-driven Porsche I would do two things: 1) if in any doubt about your present hardware, either what they're made of or their torquing history, buy new lug nuts that you know are made from 7075-T6, and 2) be sure to always lubricate and set the torque with a wrench as directed by Porsche. I wish I could tell you that OEM Porsche lug nuts, either new or back in the day, are 7075-T6 aluminum but I can't. I've been unable to find out. I have some that are over 30 years old. Whatever they are made of, Porsche thought they were fine when new so that counts for a lot.

Clamp-up

We need to digress and talk further about clamp-up before going into the other lug nut materials.

Clamp-up, or more technically correct *pre-load,* is the name of the game in bolted joint design. In an automotive application it is the clamp-up that 1) prevents the wheel from separating from the hub flange under load, and 2) vastly reduces the repetitive loading that would normally cause the components to quickly fail from fatigue. The welcome and necessary side-effect of 1 plus 2 is that the nut is prevented from backing off.

If, under a momentary high load, the wheel separates from the hub flange or even comes close to separating, then the load in the threads can momentarily drop precipitously on the rebound. That variation in load can allow the nut to back off. No separation equals low load variation at the threads equals no nut backoff, all assured by proper torque.

The clamp-up does something else very important in this application: it prevents the studs from seeing shear and bending loads. It’s not the job of the studs to directly prevent the wheel from turning on the flange. It is the friction between the wheel and the hub that does that. That frictional resistance to the wheel turning is dependent upon, yep, you guessed it, the clamp-up load, i.e., the tensile load within the stud threads that pulls the wheel against the flange. Preloading the studs and nuts is what maintains a high frictional resistance to the wheel turning on the flange. If the wheel turns on the flange it will damage both the studs and the wheel. It may even simply cut the studs off.

Some Porsche engineer way back when, let's call him Hans, either analyzed the wheel bolt joint, tested it, or did a combination of both. Probably more than once over the years. The main purpose of the analysis was to figure out what torque to specify to create the proper amount of joint clamp-up. He had to make sure the materials weren't overloaded, but the bigger worry is that the materials will fail early from fatigue without proper clamp up. The trick is to assure enough clamp-up to prevent fatigue failure while not driving any of the joint materials beyond their yield strength during installation.

Very few people really understand how preloading the joint reduces reversing loads and thus prevents fatigue failure. For the sake of brevity, let's just take it on faith that it does. It doesn't eliminate all reversing loads, as some people think (even some engineers) but they become quite small as long as the external loads on the joint remain well below the preload.

The analysis that Hans performed also looked at the over-torque limit. Over-torquing your lug nuts or bolts is every bit as bad as under-torquing them. In spite of the studs (or lug bolts) being steel, the threads can be damaged very easily by an air gun set too high or any type of impact wrench or even an owner with simple hand tools and no torque wrench who thinks tighter must be better.

I read a paper that analyzed wheel separations on pickup trucks in the mining industry. The investigators found that over-torquing weekly(!) in the field was found to be the primary cause of numerous wheel separation incidents. Too much torque caused permanent deformation of the threads (in both stud and nut) which in turn promoted crack formation in the studs. The preload was lost and fatigue failure resulted. The threads were 12mmx1.5mm, made from SAE 5140 steel with a tensile strength in the 82 Ksi range. They found that permanent deformation occurred at <u>any</u> torque above the manufacturer’s recommended value of 123 lb-ft. In this particular case the specified torque value was actually too high. (Hans had not been available.) The investigators recommended better steel for the studs and nuts that upped the tensile strength of both to 120 Ksi.

Now that we understand how important the clamp-up is we can explain why lubrication is important. Many people think intuitively that lubricant must make it easier for the nut to loosen. This intuition is wrong. The situation is actually that the friction in the joint soaks up a large percentage of the torque that you apply with your torque wrench. Lubricated threads and shoulders soak up less torque than unlubricated threads. So, if you do a fantastic job of cleaning all the threads, maybe with a strong degreaser, and really get any residual oil, grease, dirt, pollen or whatever out of the threads and don’t lubricate you've changed the situation for old Hans. He thought the nut factor was going to be 0.1, for instance (nut factor is basically a measure of friction) and you just increased it to 0.25 by threading super-clean aluminum onto super-clean steel. Now, 25% of the torque you applied, 2.5 times the 10% it should have been, went into overcoming friction instead of producing clamp-up. You may have just created a condition where the preload can be lost due to a very small loosening of one nut. Soon after that one studs fails in fatigue and then the rest all go at once like dominoes. You’re left looking at a hub with 5 broken-off studs and the wheel is nowhere to be found.

Another big factor: unlubricated threads create more uncertainty in knowing how much torque was applied. Even though your torque wrench was set to 96 and it went click, Hans doesn't really believe it. Hans isn’t allowed to believe it. He knows that the actual applied torque can vary by 25% in either direction. So, Hans applied a factor of + or - 25% to the applied torque of 96 lb-ft in his clamp-up analysis, if he followed standard practice, and made sure everything was fine at both extremes. But, if Hans knew that some internet-obsessed American was going to super clean the threads first and then torque the lug nuts dry because someone he doesn't even know told him to, he would have been obligated to apply + or - 35% to the torque value in his analysis. Hans never really sleeps well. He always worries about this, especially since lubrication wasn't always mentioned in the owners' manuals and was even hit or miss in the shop manuals.

One last thing about proper torquing: the situation is not quite as perfect as I've described. When the nuts are being torqued there are generally loads on the wheel, i.e., the car is sitting on the wheels. For this and other reasons such as temperature changes, material creep and loading beyond yield (over-torquing) a perfectly pre-loaded joint is often not realized or maintained long-term. Tests have shown a 10% loss of clamp-up in aluminum wheels within 24hrs of torquing just from material creep alone. This is why you should always retorque every nut on every newly mounted wheel relatively soon after first use. On the street this means after an hour of driving time and then periodically, say every 3 to 6 months, thereafter. The faster you put miles on the car the more often you should slap a torque wrench on it. At the track, where big temperature changes and very high loads can play havoc with theoretical perfection, that means after every session after you let it cool down. If your lug nuts seem to always be getting loose, replace them immediately. This is not normal. They're probably damaged or badly worn.

This quote is from *meaforensic.com*, a Canadian legal firm specializing in forensic accident investigations: "The most common reason for a wheel to separate is failure of the fasteners, where wheel nuts fall off and/or wheel studs break and release one or two wheels from the vehicle. These failures generally occur 175 to 3000 miles and one to fifteen weeks after a wheel was taken off and put back on during some service, such as a tire installation." The site goes on to say that these unfortunate events can be almost totally eliminated by retorquing soon after installation.

Stainless Steel

These days you can buy lug nuts made from stainless steel, which was rather shocking news to me because the world of “stainless” steel contains some very shady characters. Most of the lug nuts I found in stainless claim to be made from T304, which at best is only slightly stronger than 7075-T6 aluminum. T304 can be anywhere from 71 Ksi to 91 Ksi, depending upon the exact grade, which never seems to be revealed. Personally, I would avoid T304 lug nuts like the plague. Maybe I'm prejudiced by a career in aerospace structures. We don't use it much. We especially never use it for safety-critical fasteners. It corrodes too easily! There are other stainless steels that are very good, but they are $$$. I doubt anyone makes lug nuts out of 17-4PH but if they do I bet they’ll tell you and that would be fine. And if you see some A286 lug nuts buy them. Not for nothin’ is A286 called a superalloy.

Titanium

6AL-4V (also called Grade 5) is a high-strength, tightly controlled, Ti alloy (6% aluminum and 4% vanadium) with an ultimate tensile strength of 120Ksi. All the Ti lug nuts and bolts I’ve seen claim to be made from it. So, Ti lug nuts (or bolts) are significantly stronger than 7075-T6 or T304. Since weaker aluminums basically work, we can infer that 6AL-4V is plenty strong in this application. It also has good fatigue resistance. It is only 120/176 = 68% as strong as some high-carbon steel lug nuts, however. So, manufacturers who say, like one maker of 6AL-4V Ti lug nuts advertises, "Titanium is 50% lighter than steel, yet considerably stronger…” are blowing smoke at you. In the first place it’s only 45% lighter than steel. (I warned you that I was an engineer.) Secondly, sure, 6AL-4V is stronger than some types of steel, like what was produced in the Middle Ages, but it is not stronger than the steel used in many steel lug nuts. No matter the advertisement hype, I'd be fine with Ti lug nuts or bolts if I was confident they were 6AL-4V and didn’t mind the price.

Some people have claimed that a Ti lug nut should be torqued higher than an aluminum one due to the difference in elastic modulus. I think this is wrong, possibly even dangerous, depending on how much extra torque you want to advocate. The difference in modulus between 7075-T6 and 6AL-4V is a whopping

53%. Do you want to increase the torque by 53% to 147 lb-ft? I didn’t think so. Steel nuts have an elastic modulus almost three times aluminum. Do we increase the torque for them? Nope. Last thing you want to do is warp your 50-year-old Fuchs. Have you seen what those go for lately?

The big thing for me is that Ti looks at the heat from a track day and just laughs. 6AL-4V retains most of its strength at some pretty high temperatures. I recommended to my friend with the 993 to torque to 100 lb-ft (assuming that that's the new Porsche number) and lubricate just like aluminum for exactly the same reasons.

We don't have to worry about 6AL-4V corrosion. Not gonna happen. What we might worry about is the Ti corroding the steel stud or the aluminum wheel due to galvanic effects. I think you want to keep using the paste to separate the dissimilar metals microscopically even if the Ti nuts come with a surface coating.

By the way, don't use regular anti-seize as the lubricant even though 100 people on the internet will say it’s fine. You want the paste Porsche calls out or something you know is really very similar. Why? 1) Paste stays put better. Regular anti-seize migrates all over the place, especially when it gets warm. You don't want it to get between the back side of the wheel and the flange. You know why if you read the earlier section on keeping the wheel from rotating on the flange. You really don't want it to get on your brake disk, either. And 2) use the paste so the joint friction is what Hans expects. Think of Hans. Be kind to Hans. He’s not getting any sleep!

Steel

Grade 8 and grade 10.9 steels are 150 Ksi and the best of the forged steel lug nuts are made from these materials or something similar. Febi-Bilstein in Germany may be the modern OEM supplier to Porsche of steel lug nuts and steel lug bolts. What they sell are Grade 8 for the nuts and Grade 10.9 for the bolts. Interestingly, they have a phosphate conversion coating. Such a coating is primarily for corrosion resistance but it can also be modified to produce a lubrication layer. It is conceivable that Porsche specifies a modified coating to eliminate the need for additional lubrication at installation in some cases.

Lesser steel lug nuts and studs may be hot forged from cheaper low-carbon steel with strengths only in the low 80 Ksi range, like the ones in the mining industry pickup trucks. They will have about the same strength or somewhat higher than 7075-T6 and T304 but be harder, tougher and have better fatigue properties. Open-ended forged lug nuts are what I have always used, but I didn't know exactly what they were made of. Going forward I won't buy anything from anyone who won't tell me exactly what it's made from. Also, most any steel will get along well with aluminum wheels galvanically. If your steel lug nuts do start to corrode after a few winters on salted roads, well, you can easily see it and replace them.

Some steel lug nuts are made from material even stronger than grade 8, I've seen claims of 176Ksi, which indicates something like forged 1080 high-carbon steel. Such steel is not expensive. High strength stuff like that is relatively brittle and not good for corrosion, which is why the nuts are always chrome plated. How smart is that? Dress up a cheap material with a shiny surface that not only makes it look good but makes it acceptable for the purpose and jack the price. (I once knew a man who invented a process for plating gold very thinly onto plastic to make cheap jewelry. He got rich.) The chrome plate, which on the lower-priced units is probably very thin, can crack or flake and then the material underneath can rapidly corrode. You may not be able to see it. The last thing you want is unseen crevice corrosion in a brittle material. If you have high-quality chrome-plated lug nuts and don't change the wheels very often they are probably fine for many years. In any case, I'd closely inspect them at intervals, like whenever new tires are being fitted, and immediately replace any with the slightest evidence of chrome cracking or flaking.

Summary

The landscape of automotive lug nuts has become a minefield with a dizzying array of types, materials, colors, and price points. I hope you've now learned enough to be careful when you buy. Beyond that, follow Porsche's guidelines, get a good torque wrench, use it often and don't be slow to replace any components (studs, nuts or bolts) if they show any signs of not being in tip-top condition.