# TECH SHEET

## PEM® - REF / THREAD GALLING

**SUBJECT: Root causes and guidelines to promote optimized fastener performance**

**Introduction –** Occasionally, users of our self-clinching fasteners encounter thread binding issues when assembling fasteners made from stainless steel. This problem is typically related to galling. This technical paper is presented to answer many of the typical questions that we receive surrounding this problem.

**Definition –** Galling is the seizing or abrading of threads caused by adhesion between sliding surfaces of the fasteners' mating threads.

**Overview –** Fortunately thread galling is not a widespread problem with threaded fasteners, but when it does occur there can be significant fastener damage and even fastener failures. Even more problematic is the fact that sometimes galling of mating threads goes undetected at assembly and the problem is not found until screws break during removal for service or other reasons. With loose hardware, failed fasteners can be replaced with new fasteners and seldom does the damage extend to the attached parts. However, with self-clinching fasteners, a failed fastener may mean that the panel into which it is installed must also be scrapped. In some cases this can make galling a very expensive problem. For information on repair and replacement of self-clinching fasteners see our Tech Sheet http://www.pemnet.com/design_info/techsheets/Repair_Replacement.pdf.

**Mechanics of Thread Galling –** If we look at the surface of a thread flank under high magnification we see that the surface is not flat, but is composed of high and low spots. The high spots are called asperities. When a thread flank is loaded in straight tension with a tensile testing machine, the asperities yield and compress in height and increase in size until the total contact area is adequate to support the load without further yielding. Figure 1 shows a sectioned view at 1000 X of an internal thread flank of an M5 thread produced with a cut thread tap in UNS S30430 stainless steel. The flank shown in Figure 1 was never loaded. Figure 2 shows a thread flank for another sample that was axially loaded to 1,980 pounds or 90 ksi on the tensile stress area. Notice that the asperities were flattened by the axial load.

Figure 1

Figure 2


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When a threaded joint is tightened by turning one of the members, the asperities are crushed as load increases, but there is also sliding motion between the thread flanks. Many explanations of galling hold that this sliding motion can cause the tips of asperities to shear off. For metals such as stainless steel and aluminum that readily form oxides on their surface, the shearing away of the oxide layer exposes bare metal. With adequate heat from friction and pressure from the induced load, these bare spots can weld together. Welds of this type have been found to be stronger than either base metal. Therefore, with increased torque as the tightening continues the welds themselves will not break, but instead chunks of base metal will be pulled out of the weaker base metal. This is the initiation of galling. As more tightening torque is applied the contact area increases to support the higher induced load. This creates larger, stronger welds which pull out even larger chunks of the weaker base metal. In extreme cases the necessary torque to continue relative rotation of the mating threads can exceed the torsional strength of the external thread and cause it to fail in torsion. Even in less extreme cases, galling significantly increases the coefficient of friction on the galled surface and with the common torque controlled tightening method, preload may be significantly less than required for a reliable joint.

Although the role of heat input in galling is not fully understood, it is known that high heat input increases the chance of galling. The source of heat during tightening of a threaded assembly is friction. Screw threads are very inefficient with only 10 to 15 % of the tightening torque used to induce load, and the rest used to overcome friction. If we assume 12 % efficiency, then 88% of the area under the torque-angle curve (see Figure 3) is the total amount of heat energy produced by friction. Theoretical calculations are given in Table I to demonstrate the effect of soft joints and high speed tightening on localized heating. The calculations highlighted in light blue show that for the ¼-20 thread size the heat energy is only enough to raise the temperature of the entire nut and stud thread within the nut by less than 9˚F (5˚C) for a hard joint and 35˚F (20˚C) for a soft joint. The calculations highlighted in yellow show that when the heat energy from thread friction alone is applied to a thin surface layer on the loaded thread flanks only, the theoretical temperature rise is much higher at 224˚F (124˚C) for a hard joint and 896˚F (498˚C) for a soft joint. All temperatures are increases above ambient.

## Table I

### Theoretical Temperature Rise from Friction Energy

| Parameter Description | Value 1/4-20 | Value 1/4-28 | Units | Source/Comment |
|---|---|---|---|---|
| **Properties of 1/4 -20 Thread Size 300 series stainless steel hardware** | | | | |
| Weight of CLS-0420/28-1 Clinch nut | 0.005826 | 0.005717 | lb/ea. | Finished weight |
| Overall height of CLS-0420-1 | 0.222 | 0.222 | in | Part drawing |
| Weight of 1/4-20/28 stainless ext. thread | 0.010304 | 0.0112 | lb/in | From stud incremental length |
| Area of 1/4-20 stainless external thread | 1.37024 | 1.4268 | $in^2/in$ | From stud area/Sanity check on below |
| Typical screw Major | 0.2449 | 0.2458 | in | Middle of class 2A tolerance |
| Typical nut minor | 0.2043 | 0.2178 | in | 25% of tolerance from 2B max |
| Axial height per flank | 0.01172 | 0.008083 | in | Trig calulation |
| Area of 1/4-20 loaded flanks | 0.330718 | 0.329553 | $in^2/in$ | Cone section area formula |
| Weight of nut and external thread in nut | 0.008114 | 0.008207 | lb | Clculation using above weights |
| Assumed depth of thread surface | 0.001 | 0.001 | in | Assumption |
| Weight of loaded thread flanks | 0.00017 | 0.00018 | lb | Calculation using volume & density |
| Density of UNS S30430 stainless | 0.2833 | 0.2833 | $lb/in^3$ | Literature |
| Specific heat of UNS S30430 stainless | 0.1 | 0.1 | BTU/lb-°F | Literature |
| Tensile stress area of 1/4 -20 thread | 0.03182 | 0.03637 | $in^2$ | Thread standards |
| **Heat Energy Generated by Friction During tightening** | | | | |
| Stress on TSA when tight | 65,000 | 65,000 | $lb/in^2$ | Assumption, 65 % of 100 ksi ultimate |
| Assumed nut factor or "k" value | 0.2 | 0.2 | | Typical value |
| Calculated torque | 103 | 118 | in-lb | Calcultion using load & k value |
| Total revolutions to tighten, hard joint | 0.25 | 0.35 | rev | Assumption for -20, ratioed for -28 |
| Total revolutions to tighten, soft joint | 1.0 | 1.4 | rev | Assumption for -20, ratioed for -28 |
| Total radians to tighten, hard joint | 1.571 | 2.199 | radians | Unit conversion |
| Total radians to tighten, soft joint | 6.283 | 8.796 | radians | Unit conversion |
| Assumed percent efficiency of thread | 12 | 12 | % | Assumption |
| Thread friction as % of total friction | 54 | 54 | % | Assumption |
| Total energy from friction, hard joint | 71.5 | 114.4 | in-lb | Calculation assuming straight line |
| Total energy from friction, hard joint | 0.00715 | 0.01144 | BTU | Unit conversion |
| Total energy from friction, soft joint | 285.9 | 457.5 | in-lb | Calculation assuming straight line |
| Total energy from friction, soft joint | 0.02859 | 0.04575 | BTU | Unit conversion |
| **Temperature Rise from Friction Energy** | | | | |
| Temperature rise of nut and thread, hard | 9 | 14 | °F | Calculation using above values |
| Temperature rise loaded flanks only, hard | 224 | 344 | °F | Calculation using above values |
| Temperature rise of nut and thread, soft | 35 | 56 | °F | Calculation using above values |
| Temperature rise loaded flanks only,soft | 896 | 1377 | °F | Calculation using above values |

**Note:** Above calculations are purely theoretical and are for the purpose of illustraing the potential heating effect from friction. All values are based on what are believed to be reasonable assumptions, but have not been validated by any empirical testing.


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**Factors That Increase the Likelihood of Galling –** The following factors are known to increase the likelihood that some percentage of mating threads will gall when assembled. Each will be examined.

- Soft connection elements
- High speed tightening
- Material and finish combinations
- Fine threads
- Thread damage
- Excessive tightening torque
- Excessive thread length
- Nylon locking elements
- Mating part alignment
- Tightening sequence issues
- Dirty threads
- Fastener quality

**Soft Connection Elements –** In engineering terms, an element is softer when it has lower stiffness. A threaded connection may contain one or more soft elements. Fastener stiffness is generally fixed for a given thread size and material, but does vary with grip length, the longer the grip the lower the stiffness. Also, bolts with reduced shank diameters or bolts made from low modules material such as aluminum will have lower stiffness. Because joints typically have larger cross sectional area than fasteners, they will usually have higher stiffness if made from the same material. However, if the joint contains a low stiffness material such as plastic or fiber, it can have lower stiffness than the fastener. Joints with components designed to be compressed by the fasteners can have very low stiffness. Compressible components include gaskets, viscous sealants, Belleville type washers, and other types of springs. Toothed lock washers and helical spring lock washers also deform during tightening and are therefore soft elements.

The issue with threaded connections with soft elements relative to thread galling is that soft elements require more rotation during tightening. This increases the area under the torque-angle curve (see Figure 3) which means more heat energy input from friction.

**High Speed Tightening –** The discussion above and the calculations in Table I show that the heat energy input from friction is not sufficient to raise the temperature of the entire fastener mass. The issue with high speed tightening is that it can generate locally very high temperatures on the thread flanks before the heat can be dissipated by the rest of the fastener mass. Slower speed allows time for heat dissipation.

Note below that coarse threads are recommended over fine threads. This in part addresses the concern over lower assembly rates with slower tightening speed.


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**Material and Finish Combinations Prone to Galling –** Decades of history on customer complaints of thread galling reveal that both of the threaded components are 300 series stainless steel in the vast majority of complaints. This is supported by the literature on galling studies and research, from which we can find several reasons.

- Materials which form natural protective oxides such as stainless steel, aluminum and titanium have been found to be more prone to galling. One plausible explanation for this is:
  - Because the protective film provides corrosion resistance, fasteners made from these materials usually are not given any plating or other additive finish.
  - These oxides tend to give the surface a higher friction coefficient than plating materials typically used on steel fasteners. This means higher torque is required for a given clamp load which means more area under the torque-angle curve (see Figure 3) and more heat energy input.
  - If the oxide is very thin it will follow the surface roughness on the thread flank and be completely removed when the tip of an asperity is sheared. Pure and very weldable base metal is exposed by this action. This is especially true for stainless steel where the chromium oxide layer is only several Angstroms thick.
  - The abrasive nature of the sheared off oxides may also contribute to thread galling.
- Materials of the same type are generally more prone to galling, possibly because they are more easily welded than dis-similar materials
- Materials of the same hardness are generally more prone to galling. Likely because the breaking down of asperity tips is happening to nearly the same degree on both materials.
- Plated materials are generally less prone to galling.

**Table II** shows the likelihood of galling for selected material and finish combinations.

## Table II

Incidence of Galling for Selected Combinations of Thread Material and Finish

| PEM® Brand Threaded Clinch Fastener Types(1) | Atlas® Brand Blind Threaded Inserts(1) | | Fastener Material | Material and Finish of Mating Thread | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Zinc Plated Steel | | 300 Series Stainless Steel | | Hardened PH Stainless |
| | MaxTite® Inserts | SpinTite® Inserts | | Alum. | Not Hardened | Hardened | Machined | Forged | |
| CLA, CHA, FHA, BSOA & SOA | AEA | | Aluminum | | | | | | |
| HN & HNL | AES, AECH | AEKS, AELS, AEHS | Zinc/cadmium pated steel | | | | | | |
| AS, B, FH, TFH, HFH, HFE, S, BSO & SO | | | Zinc pated hardened steel | | | | | | |
| PF30, PF50, PFHV | | | Nickel plated hardened steel | | | | | | |
| KF2, KFE, SMTSO | | | Tin plated steel | | | | | | |
| AC, BS, F, FEX, KFS2, KFSE, BSOS & SOS | | | 300 Series Stainless Steel (2) | | | | | Note 4 | |
| CLS, FHS, HFHS, TFHS, SMPS | AENM & AENMTR | AETHC, AELC, AEHC | 300 Series Stainless Steel(3) | | | | Note 4 | | |
| | AESS | | Ferritic stainless steel | | | | | | |
| A4, F4, FH4, BSO4, SO4 & TSO4 | | | Hardened 400 series stainless | | | | | | |
| FHP, SP, SFP & SMPP | | | Hardened PH stainless | | | | | | |

Typically there are no galling issues

Low incidence of galling issues

Higher incidence of galling issues

**Notes:** 1. Not all threaded fastener types are listed. Listed types are most popular.
2. Parts on this row are machined from a machineable grade of 300 series
3. Parts on this row are forged from a forgeable grade of 300 series
4. When 300 series threads are mated, there is slightly less chance of galling with different alloys


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**Fine Threads –** It is generally agreed that fine threads are more prone to galling than coarse threads. The following points may explain why:

- Fine threads are more prone to nicks or other damage from handling. Thread nicks can contribute to galling as discussed below
- Fine threads require more rotation and higher torque for the same stress on the larger tensile stress area during tightening, hence more area under the torque angle curve and more heat energy input
- Although there are more fine threads in a given nut height, the total flank area is essentially the same as coarse thread. The higher heat energy applied to essentially the same volume of metal results in higher theoretical temperature increases. See light red highlights in Table I

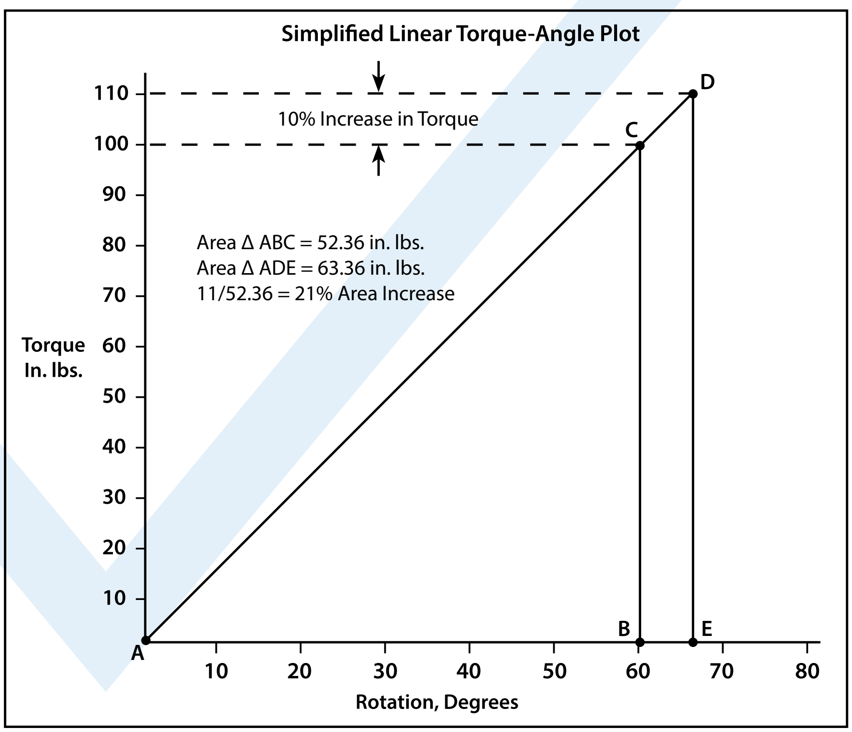
**Thread Damage –** Threads with significant nicks or other damage which prevents acceptance of the Go gage are more prone to galling, likely for the reasons below:

- If there is interference between the mating threads there will be some level of prevailing torque during the entire tightening process. This will add a "tail" to the front of the torque-angle curve at a low torque value but continuing for multiple turns. This will add to the area under the torque-angle curve.
- In some cases the geometry of the damaged area may be such that it initiates galling in the immediate vicinity of the damage.

**Excessive Tightening Torque –** Proper tightening torque is essential to develop the needed preload in the fastener and preload is essential to prevent vibration loosening. Tightening torque should never be reduced below the proper value for the sake of galling prevention. However, tightening torque can contribute to galling in two ways:

- Higher tightening torque adds significantly to the area under the torque-angle curve. As shown in Figure 3, a 10% increase in the tightening torque causes a 21% increase in the area under the curve.
- Higher tightening torque increases the risk that some fasteners will start to yield and yielding will create a large increase in angle adding significantly to the area under the torque-angle curve.

**Figure 3**





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**Excessive Thread Length –** The recognized rule of thumb is to design for a minimum of two screw threads extending above the top of the nut in the fully assembled condition. It is understood that this is not always possible given standard screw length increments and this is not a problem. Even lengths above those dictated by screw length are not a problem unless there is another factor present that causes some axial load during the entire tightening process. Such factors include:

- Use of a locknut with a nylon locking element causes axial load, especially on the first installation cycle of a new nut because there is no thread in the nylon and axial force is needed to drive the mating screw through the nylon.
- Use of a drive type, such as Phillips Recess that requires axial load for high torque transmission in conjunction with the operator or assembly machine applying axial force at the start of the tightening process

The net result of the combined long length and axial load is a significant tail added to the front of the torque-angle curve and hence greater area under the curve.

**Nylon Element Locknuts –** As explained above, nylon locking elements usually generate some amount of axial load beginning when the screw first contacts the nylon. The load is typically low and it is usually only a cause for galling with stainless steel hardware. Although all-metal deformed thread stainless steel locknuts are usually supplied with a lubricant, many believe that a lubricant is not needed for a stainless steel locknut using a nylon element. This may not be entirely true, because these locknuts sometimes gall.

**Mating Part Alignment –** mating parts should be lined up as well as possible before final assembly. This will reduce the amount that the fastener has to be turned during tightening. Otherwise thread galling can occur since:

- There will be prevailing torque during the entire tightening process adding a tail-to the front of the torque-angle curve, as previously explained this means more heat input.
- The flank to flank contact when the screw is on an angle is restricted to two small areas, a small arc on one side of the nut and another small arc 180 degrees away on the other side of the nut. These small areas can easily be heated to damaging temperatures by the heat energy of friction.

For more on the positional tolerance of the threads in installed self-clinching fasteners see our Tech Sheet http://www.pemnet.com/design_info/techsheets/ThreadPosition.pdf

**Tightening Sequence Issues –** There are two ways the tightening sequence can contribute to thread galling. First, even if the tolerance scheme recommended above is used, it can be effectively negated with a wrong tightening sequence. If one fastener is tightened to enough clamp load to keep the pieces from moving before all of the other fasteners are started, some clearance holes, although large enough in diameter, may not be in the proper position, causing screws to enter on an angle. This is the same issue as screws entering on angle mentioned immediately above.


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Second, conditions in which tightening on one side causes the components to gap on the opposite side. The fasteners on the gapped side will need to draw the gapped components together and are essentially a soft joint. A better approach is start in the middle and progressively tighten fasteners on alternate sides of center, finishing at the far ends.

**Dirty Threads –** Abrasive dirt or grit allowed to accumulate on the threads may also contribute to thread galling, but the mechanism does not appear to have been well studied. Aside from galling concerns, threads should be kept clean in order to have a consistent friction value so that when tightened with torque control there is also reasonable control of clamp load. Clamp load is of primary importance to fastener function.

**Low Quality/Inconsistent Quality Fasteners –** In addition to the numerous design and assembly issues discussed above, poor and or inconsistent fastener quality can contribute to thread galling in the following ways.

- Threads not perpendicular to the bearing face of nuts can create the same galling issues as screws entering on an angle because of hole size/position problems
- Threads that do not gage can create the same galling issues as nicked or damaged threads
- Inconsistent yield strength can lead to the issues that arise when some fasteners yield discussed above in the section on excessive tightening torque

**Methods to Reduce the Likelihood of Galling –** There are two major ways to prevent galling. The first way is to simply eliminate or reduce the factors known to contribute to galling. These were mentioned above and are referred to as design and assembly methods.

The second way is to employ methods for the sole purpose of reducing the likelihood of galling. These will be referred to as additive methods.

**Additive Methods –** To this point there has been an assumption that standard fasteners, available from stock will be used and that a lubricant will not be applied at the assembly step. Although this is the preferred route, there will be situations in which design features prone to galling simply cannot be eliminated. The next line of defense against galling is the assembly techniques, but even with the best assembly practices there may be applications in which there is still some galling. When this happens it may be necessary to consider one or more of the following additive methods. They are listed in recommended order of consideration, so those listed first will typically have the least additional cost and/or shortest additional lead time.

**Adding a Lubricant at Assembly –** Although they are generally considered a nuisance to apply, there are many different lubricants and anti-seize compounds available. Some, such as USP grade castor oil are very safe and still provide excellent lubrication. The IFI recommends FastLube AG, as an anti-seize compound for stainless threads.


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**Specifying Fasteners with a Lubricant –** It is common to specify dry film lubricants on all-metal, prevailing torque locknuts, but these same dry film lubricants can be applied to non-locking fasteners as well. Typically only one of the mating threads needs to have a lubricant to prevent galling. When possible it is preferable to apply the dry film lubricant to the external thread because it is easier to get good, complete coverage on external threads.

**Specifying Fasteners with Anti-Galling Plating –** Some metals which can be electroplated have inherent lubrication properties. See the list below of the more common metals used.

- Cadmium – excellent lubricity but not RoHS compliant and a REACH SVHC
- Hard Chrome – effective to prevent galling of stainless steel, even at low thickness
- Tin – good lubricity and not restricted for environmental concerns
- Zinc – effective to prevent galling with enough thickness and does not have a negative impact on corrosion resistance of most stainless steels. Not recommended for stainless steels for high temperature service. Thick zinc plating proven effective at significantly reducing galling is available as finish designation suffix P114.

The major cost and lead time issue with using a plating to combat galling is usually not the cost of the plating, but the fact that most stainless steel and aluminum fastener threads are not produced with an allowance to accommodate the thickness of the plating. This usually means that existing parts cannot simply be taken from stock and plated, but parts need to be specially made with the needed thread allowance.

As with lubricants, typically only one of the mating threads needs to have a plating to prevent galling. Most electroplating process can achieve good coverage in internal threads so the decision of which component to plate can be made on the basis of cost by selecting the lighter weight or lower surface area component.

**Re-evaluate the Tightening Torque –** Adding a lubricant or changing the plating changes the torque-tension relationship. Lubricants will reduce the tightening torque required to achieve the desired pre-load. When these types of changes are made the specified tightening torque must be re-evaluated.


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**Specifying Fasteners made from Anti-Galling Materials –** This option is listed last because it typically will require fasteners made to order with high cost and long lead time. However, it can be viable option, especially for high volume, long product life applications. There are a number of proprietary material chemistries available. See Table III for a summary of the properties of 4 common choices. Note that these alloys retain higher yield strength at the elevated temperature of 800˚F than type 304 which is included in Table III as a point of reference for 300 series stainless alloys typically used for fasteners. Although the role of increased metal temperature from the heat energy of friction is not fully understood, it is known that materials with higher resistance to deformation at elevated temperature are less likely to gall.

## Table III

Chemical Composition and Mechanical Properties of Four Common Anti-Galling Alloys

| Material | Chemical Composition, % by Weight | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cr | Ni | C | Mn | P | S | Si | N | Mo | Fe |
| Gall-Tough® [1] | 15.00/18.00 | 4.00/6.00 | 0.15 max | 4.00/6.00 | 0.040 max | 0.040 max | 3.00/4.00 | 0.08/0.20 | | Balance |
| Gall-Tough PLUS® [1] | 16.50/21.00 | 6.00/10.00 | 0.15 max | 4.00/8.00 | 0.040 max | 0.040 max | 2.50/4.50 | 0.05/0.25 | 0.50/2.50 | Balance |
| Nitronic® 60 [2] | 16.00/18.00 | 8.00/9.00 | 0.10 max | 7.00/9.00 | 0.060 max | 0.030 max | 3.50/4.50 | 0.10/0.18 | | Balance |
| Nitronic® 50 | 20.50/23.50 | 11.5/13.5 | 0.06 max | 4.00/6.00 | 0.045 max | 0.030 max | 1.00 max | 0.20/0.40 | 1.50/3.00 | Balance [3] |
| Type 304 [4] | 18.00/20.00 | 8.00/10.50 | 0.08 max | 2,00 max | 0.045 max | 0.030 max | 1.00 max | | | Balance |

| Material | At Maximum Strength | | | Annealed Cond. At Room Temp. | | | Annealed Cond. At 800 F | | |
|---|---|---|---|---|---|---|---|---|---|
| | Condition of Maximum Strength | Tensile ksi | Yield ksi | Tensile ksi | Yield ksi | Elong. % | Tensile ksi | Yield ksi | Elong. % |
| Gall-Tough® | 20 % Cold Worked | 223 | 107 | 161 | 60 | 63 | 79 | 29 | 62 |
| Gall-Tough PLUS® | 30 % Cold Worked | 200 | 140 | 113 | 61 | 59 | 87 | 30 | 58 |
| Nitronic® 60 | 70 % Cold Drawn | 263 | 217 | 103 | 60 | 64 | 78 | 29 | 56 |
| Nitronic® 50 | 75 % Cold Drawn | 246 | 234 | 117 | 60 | 45 | 89 | 34 | 43 |
| Type 304 | 9 % Cold Drawn | 103 | 74 | 85 | 35 | 60 | 61 | 21 | 37 |

Notes:
1. Gall-Tough and Gall-Tough PLUS are registered trademarks of Carpenter Technolgy Corporation
2. Nitronic is a registered trademark of AK Steel (formerly Armco)
3. Nitronic 50 also contains intentional Nb and V, both at 0.10 to 0.30 %
4. Type 304 is not an anti-galling alloy, but is included as a reference point typical of 300 series

<u>**Summary**</u> **–** The above are general guidelines to prevent thread galling. Not all possible scenarios can be covered in this forum. If you have questions about thread galling or any other technical issue, please e-mail your questions to #techsupport@pemnet.com


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