KEEPING IT TOGETHER

THE NUTS AND BOLTS OF FASTENERS

Presented by Jim Rowe
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We take fasteners and the complex system we have for identifying them by type and usage for granted. Here is some information that may help you in choosing the proper fastener for all your repair/replacement needs.

Starting at the beginning, the invention of the screw thread is attributed to Archimedes in the 3rd century BC. The *Archimedes Screw* consisted of a cylinder with an internal continuous screw thread. When the lower end was placed into water and the cylinder rotated, water was raised to a higher level. The principle was also applied for handling light, loose materials such as grain, sand and ashes. The screws that we have today use the same technique in that a mating threaded component, rather than water, is moved through the cylinder. Sir Joseph Whitworth, a British mechanical engineer, became known for his work on engineering standards. In 1841 he proposed the introduction of standard fastener sizes to the Institution of Civil Engineers. These comprised a universal set of specifications for the angle and pitch of screw threads, the Whitworth thread became the first standard thread system in the world. Threaded fasteners are classified by shape, material and finish, which are specified by industry standards. In the United States, the American Society for Testing Materials (ASTM) sets the standards. In Europe, the International Standards Organization (ISO) sets the standards.

Types of Fasteners

Unified National Coarse Threads (UNC)
UNC threads are the most common general fastener thread. Their fit is deeper and more generic than that of a fine thread, allowing for easy removal. Generally, they have a higher tolerance for manufacturing and plating, and do not need cross threading to assemble.

Unified National Fine Threads (UNF)
UNF threads have better torque-locking and load-carrying ability than UNC threads because of their larger minor diameter. Because of their more specific fit, they have tighter tolerances, finer tension adjustment, and can carry heavier loads. They are most commonly found in the aerospace industry.

United National Extra Fine Threads (UNEF)
UNEF threads are finer than UNF threads; they are used in applications with tapped holes in hard material, thin threaded walls, and tapped holes in thin material. As with UNF threads, UNEF threads are common in the aerospace industry.

UNJC and UNJF Threads
There are two types of "J" threads: external and internal. External UNJC and UNJF threads have a larger root radius than the corresponding part (either UNC, UNR, UNK, or UNF threads). The larger root radius results in a larger tensile area than the corresponding thread, and smaller stress concentration—bolts that carry heavy loads usually use "J" threads.

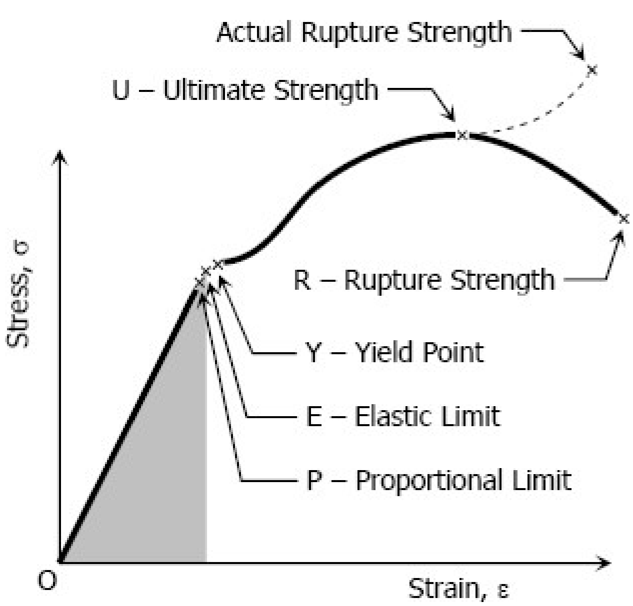
UNR and UNK Threads
A UNR external thread is the same as a UNC thread, only the root radius is rounded. There is no internal UNR thread. UNK threads resemble UNR threads, but the root radius and minor diameter require inspection.

Constant-Pitch Threads
These threads come in a variety of diameters to fit a given application—bolts with diameters of 1 in. and above commonly use pitches of 8, 12, or 16 threads per inch.

CHARACTERISTICS OF BOLTS

How Strong is it? One important consideration in applying a bolt is its strength. The bolt material strength is determined by the alloy and processing method (for example, cold working and heat treating.) The two important material properties are the tensile strength and yield strength. The tensile strength, sometimes called the ultimate strength, is the stress level where the material breaks. The yield strength is the stress level where the material yields or permanently deforms. When operating under any normal load fasteners should be below the yield stress. The tensile strength is always higher than the yield strength. Materials with a large difference between the yield and tensile strength are considered ductile, meaning they will stretch substantially before breaking. The load a fastener carries is calculated by multiplying the material strength by the nominal cross-section area of the thread. For inch-size fasteners, the material strength is specified by the "grade." A grade 8 bolt is stronger than a grade 5, which is stronger than a grade 2. The grade is indicated by a series of marks on the bolt's head. For metric fasteners, the term "property class" is used and is stamped directly on the head. The property class for steel fasteners is given in the form X.Y, where X is 1/100 of the nominal tensile strength in newtons/mm^2, and Y is 10 times the ratio between the yield strength and tensile strength. The multiplication of these two numbers gives 1/10 of the yield strength in newtons/mm2 . For example, a fastener with a property class of 8.8 has a nominal tensile strength of 800 newtons/mm^2 (116,000 psi) and a yield strength of 640 newtons/mm^2 (93,000 psi).

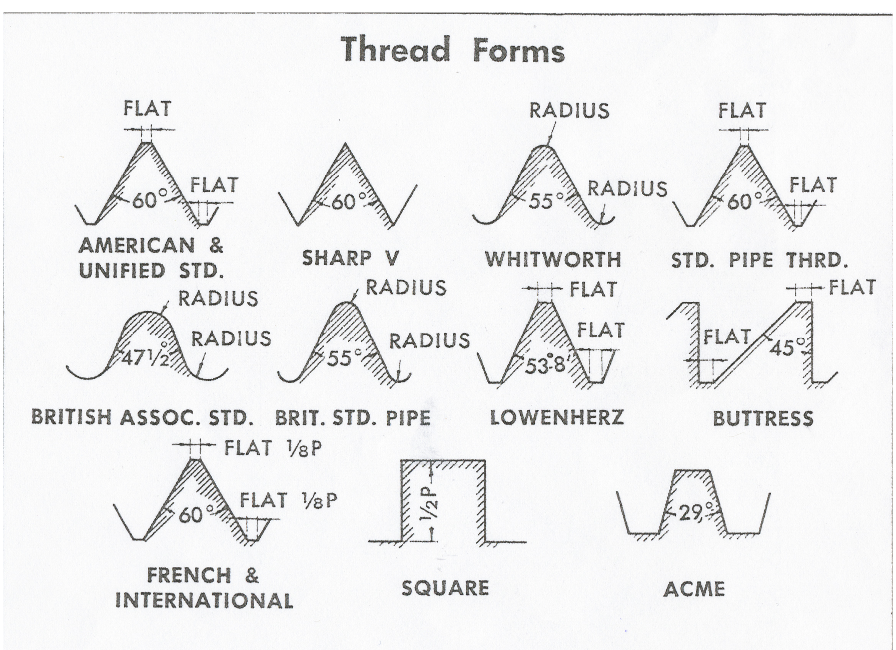
Suppose that a metal specimen be placed in tension-compression-testing machine. As the axial load is gradually increased in increments, the total elongation over the gauge length is measured at each increment of the load and this is continued until failure of the specimen takes place. Knowing the original cross-sectional area and length of the specimen, the normal stress σ and the strain ε can be obtained. The graph of these quantities with the stress σ along the y-axis and the strain ε along the x-axis is called the stress-strain diagram. The **stress-strain diagram** differs in form for various materials. The diagram shown below is that for a medium-carbon structural steel.



There are two common types of stainless steel fasteners: corrosion-resistant stainless steel, ASTM 304 (a.k.a. 18-8) or DIN/ISO A2, and acid-resistant stainless steel, ASTM 316 or DIN/ISO A4. A2 is by far the most prevalent material, and is what is normally supplied for stainless metric fasteners. There are three typical property classes (strengths) for in the metric system: 50, 70, and 80. The class equals the tensile strength divided by 10. The metric property class is a dash (-) number after the alloy designator. For example, a screw marked A2-70 is a 304 stainless steel screw with a 700 N/mm2 tensile strength. Both alloys come in all property classes, but A2-70 and A4-80 are the most common.

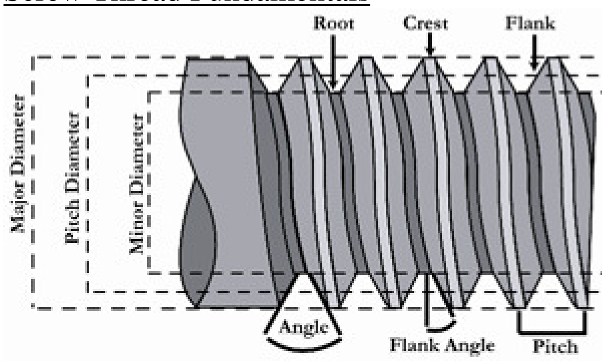
Fastener Property Comparison Note that the strength class specifies much more than the strength of the fastener and includes properties like the alloy, manufacturing method, hardness, and heat treatment

Inch Grade	Marks on Head	Material	Tensile Strength		Yield Strength	
			N/mm^2	psi	N/mm^2	psi
2	none	Steel	510	74,000	393	57,000
5	3	Steel	827	120,000	634	92,000
8	6	Alloy Steel	1030	150,000	896	130,000
SHCS	none	Alloy Steel	1240	180,000	965	140,000
18-8	none	302 Stainless	690	100,000	448	65,000
316	none	316 Stainless	690	100,000	448	65,000
Metric Class	**Marks on Head**	**Material**	**Tensile Strength**		**Yield Strength**	
			N/mm^2	**psi**	**N/mm^2**	**psi**
8.8	8.8	Steel	800	116,000	640	93,000
10.9	10.9	Steel	1040	151,000	940	136,000
12.9	12.9	Alloy Steel	1220	177,000	1100	160,000
A2-70	A2-70	302 Stainless	700	102,000	450	65,000
A4-80	A4-80	316 Stainless	800	116,000	600	87,000



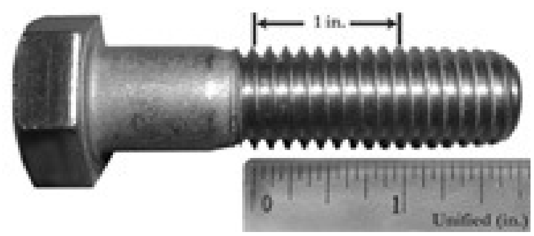
CHARACTERISTICS OF SCREWS

Screw Thread Fundamentals



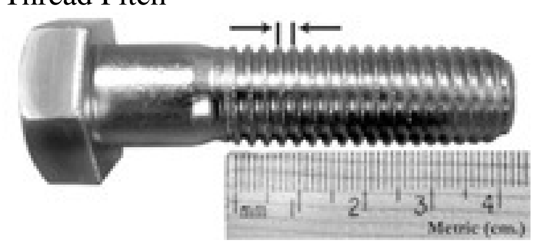
A screw thread is defined as a ridge of uniform section in the form of a helix on either the external or internal surface of a cylinder. Internal threads refer to those on nuts and tapped holes, while external threads are those on bolts, studs, or screws.

The thread form is the configuration of the thread in an axial plane; or more simply, it is the profile of the thread, composed of the crest, root, and flanks. At the top of the threads are the crests, at the bottom the roots, and joining them are the flanks. The triangle formed when the thread profile is extended to a point at both crests and roots, is the fundamental triangle. The height of the fundamental triangle is the distance, radially measured, between sharp crest and sharp root diameters.

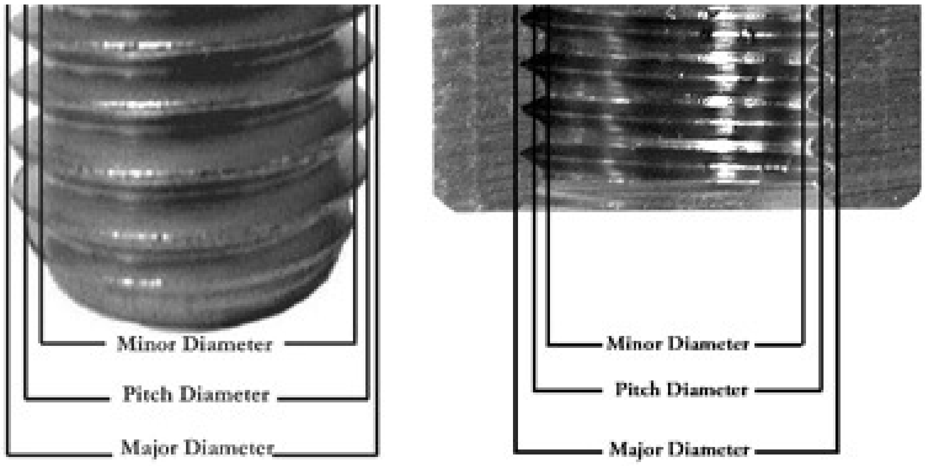


Threads Per Inch

Thread Pitch



The distance measured parallel to the thread axis, between corresponding points on adjacent threads, is the thread pitch. Unified screw threads are designated in threads per inch. This is the number of complete threads occurring in one inch of threaded length. Metric thread pitch is designated as the distance between threads (pitch) in millimeters.



External Internal

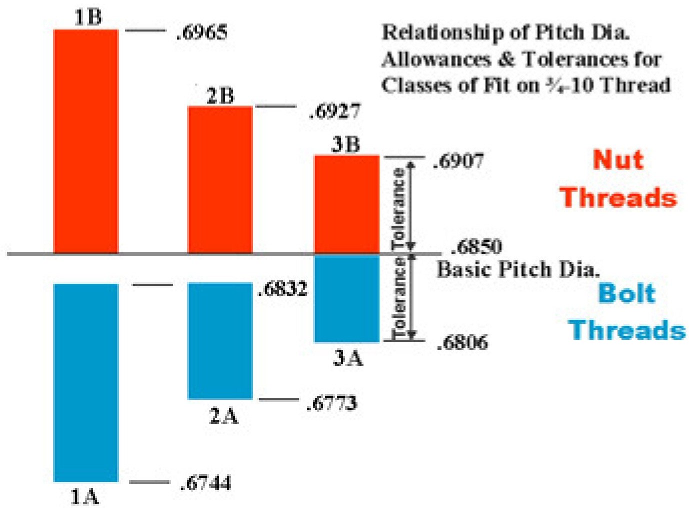
On an internal thread, the minor diameter occurs at the crests and the major diameter occurs at the roots. On an external thread, the major diameter is at the thread crests, and the minor diameter is at the thread roots.

The flank angle is the angle between a flank and the perpendicular thread axis. Flank angles are sometimes termed "half-angle" of the thread, but this is only true when neighboring flanks have identical angles; that is, the threads are symmetrical. Unified screw threads have a 30Âº flank angle and are symmetrical. This is why they are commonly referred to as 60Âº degree threads.

Pitch diameter is the diameter of a theoretical cylinder that passes through the threads in such a way that the distance between the thread crests and thread roots is equal. In an ideal product, these widths would each equal one-half of the thread pitch.

An intentional clearance is created between mating threads when the nut and bolt are manufactured. This clearance is known as the allowance. Having an allowance ensures that when the threads are manufactured there will be a positive space between them. For fasteners, the allowance is generally applied to the external thread. Tolerances are specified amounts by which dimensions are permitted to vary for convenience of manufacturing. The tolerance is the difference between the maximum and minimum permitted limits.

THREAD FIT



Thread fit is a combination of allowances and tolerances and a measure of tightness or looseness between them. A clearance fit is one that provides a free running assembly and an interference fit is one that has a positive interference thus requiring tools for the initial run-down of the nut.

For Unified inch screw threads there are six standard classes of fit: 1B, 2B, and 3B for internal threads; and 1A, 2A, and 3A for external threads. All are considered clearance fits. That is, they assemble without interference. The higher the class number, the tighter the fit. The 'A' designates an external thread, and 'B' designates an internal thread.

1. Classes 1A and 1B are considered an extremely loose tolerance thread fit. This class is suited for quick and easy assembly and disassembly. Outside of low-carbon threaded rod or machine screws, this thread fit is rarely specified.
2. Classes 2A and 2B offer optimum thread fit that balances fastener performance, manufacturing, economy, and convenience. Nearly 90% of all commercial and industrial fasteners use this class of thread fit.
3. Classes 3A and 3B are suited for close tolerance fasteners. These fasteners are intended for service where safety is a critical design consideration. This class of fit has restrictive tolerances and no allowance. Socket products generally have a 3A thread fit.

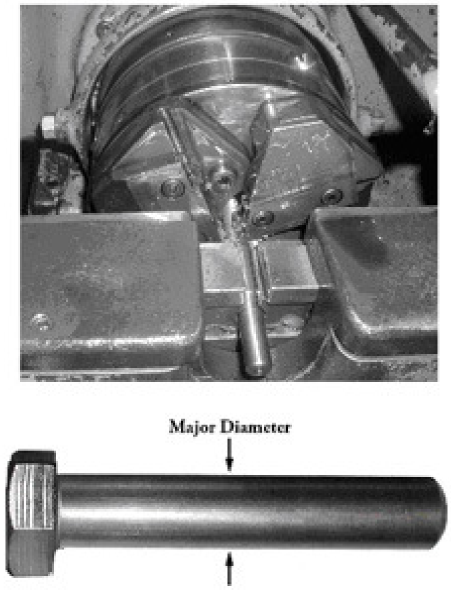
THREAD PRODUCTION

Threads can be produced by either cutting or rolling operations. The shank of a blank designed for cut threading will be full-size from the fillet under the head to the end of the bolt. Producing cut threads involves removing the material from a bolt blank with a cutting die or lathe in order to produce the thread. This interrupts the grain flow of the material.

Rolled threads are formed by rolling the reduced diameter (approximately equal to the pitch diameter) portion of the shank between two reciprocating serrated dies. The dies apply pressure, compressing the minor diameter (thread roots) and forcing that material up to form the major diameter (thread crests). Imagine squeezing a balloon with your hand; you compress with your fingers to form the valley, while allowing part of the balloon to expand between your fingers. This is the concept behind roll threading. Rolled threads have several advantages: more accurate and uniform thread dimension, smoother thread surface, and generally greater thread strength (particularly fatigue and shear strength).

Thread cutting requires the least amount of tooling costs. It is generally only used for large diameter or non-standard externally threaded fasteners. Thread cutting is still the most commonly used method for internal threads.

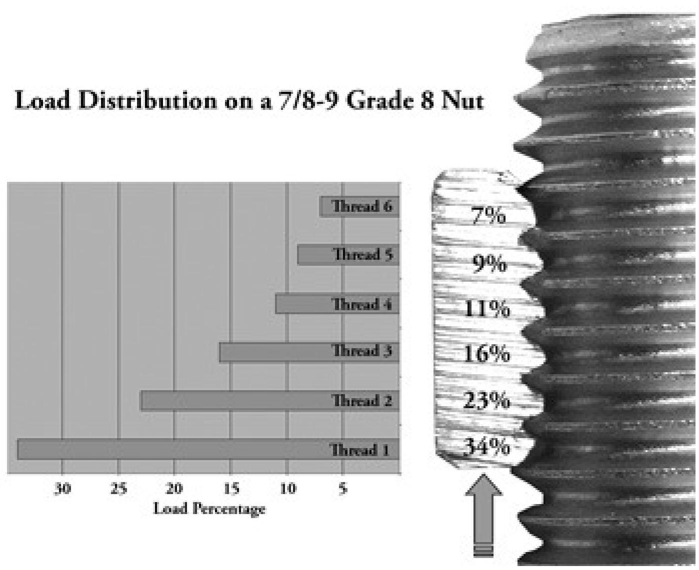
Cut Thread



Rolled Thread

THREAD STRENGTH
Two fundamentals must be considered when designing a threaded connection

1. Ensure that the threaded fasteners were manufactured to a current ASTM, ANSI, DIN, ISO or other recognized standard.
2. Ensure that the design promotes bolts to break in tension prior to the female and/or male threads stripping. A broken bolt is an obvious failure. However, when the threads strip prior to the bolt breaking, the failure may go unnoticed until after the fastener is put in service.



Generally the hardness and the actual material strength of a nut is less than the bolt. For example, if you look at the hardness of an SAE J995 Grade 8 nut (HRC 24-32 up to 5/8-in diameter), it is likely to be less than the SAE J429 Grade 8 bolt (HRC 33-39). This is designed to yield the nut threads to ensure the load is not carried solely by the first thread. As the thread yields, the load is further distributed to the next five threads. Even with the load distribution, the first engaged thread still takes the majority of the load. In a typical 7/8-9 Grade 8 nut, the first engaged thread carries 34% of the load. Using internally threaded materials with higher strengths and hardness can often result in fatigue and/or loosening.

The strength capacities of standard nuts are listed as the nut's proof stress. This should not be confused with the proof strength of the bolts. Proof stress is the ultimate load the nut can support without thread failure. For design purposes, the most important aspect of choosing the appropriate nut is to select a nut with a proof stress equal to or greater than the ultimate tensile strength of the bolt.

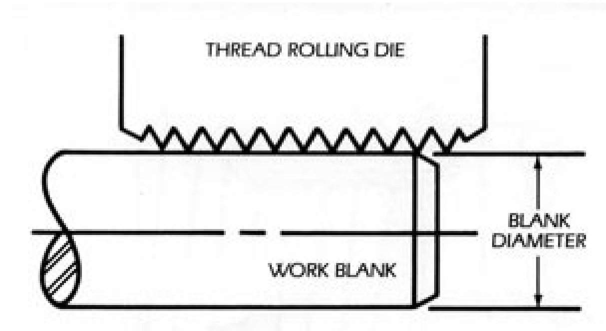
Caution: It appears that one could theoretically increase the thread strength by increasing the length of engagement. However, as illustrated in the Load Distribution chart above, the first thread will be taking the majority of the applied load. For carbon steel fasteners (including tapped holes) the length of engagement would be limited to approximately one nominal diameter (approximately 1-1/2 times the diameter for aluminum). After that, there is no appreciable increase in strength. Once the applied load has exceeded the first thread's capacity, it will fail and subsequently cause the remaining threads to fail in succession.

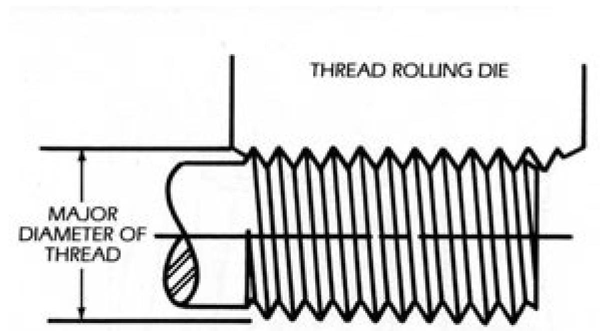
If the nut proof stress does not exceed the proof strength of the bolt, stripping failure is very likely.

Returning to the discussion of fundamentals in thread connection design, the nut or tapped hole should support more load than the bolt. Thus, the design criteria for threaded connections also leads to nut selection criteria which help the designer ensure functionality in the joint. The following are the basic rules:

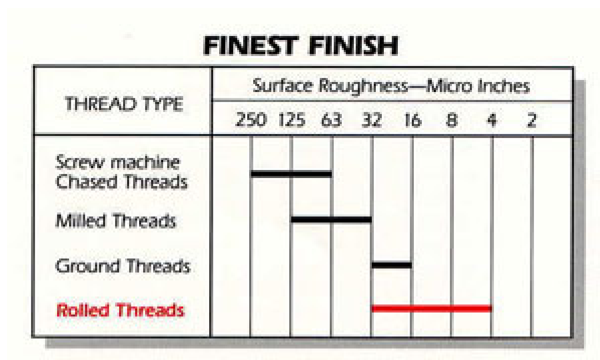
- Ensure that the nut adheres to a specification which is compatible with the specification of the bolt (ASTM A193 and ASTM A194, SAE J429 and SAE J995, etc.)
- Ensure that the selected nut has a proof stress greater than or equal to the tensile strength of the bolt.

PHYSICAL ADVANTAGES OF THREAD ROLLING

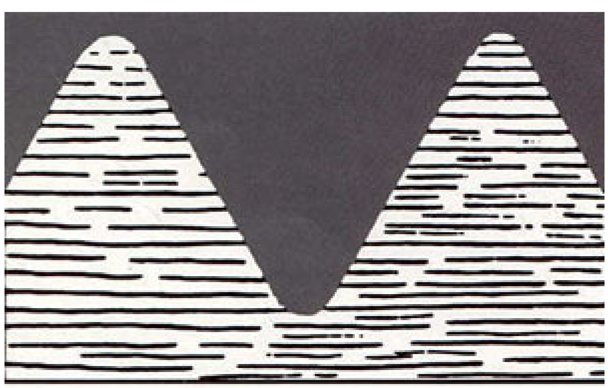




The threaded faces of hardened steel dies are pressed against a cylindrical blank to reform the surface into threads. The dies displace the material to form the roots of the thread and force the displaced material outward to form the crests.



As the table indicates, only a thread produced by the very expensive grinding technique, can even approach a rolled thread in the surface smoothness department. In any cold forging process, the finished product's surface very closely resembles the surface of the dies. Thread rolling dies are ground and polished to perfection. Reforming material with a highly polished die produces a smoother finish than removing material with a cutting tool.



CUT THREAD

ROLLED THREAD

These diagrams indicate a rolled thread's superior resistance to stripping. The rolled thread's grain structure is not severed in any way, but is, instead, reformed in unbroken lines that follow the thread's contours. Therefore, for a shear failure to take place, it must occur across, rather than with the grain.

REUSE OF FASTENERS

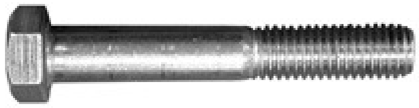
Mechanically, bolts may be reused provided the bolt never exceeded its yield point: a simple enough definition, but one that is more complicated than it may appear. This is because it is nearly impossible to verify if a bolt has ever been tensioned past the yield point.

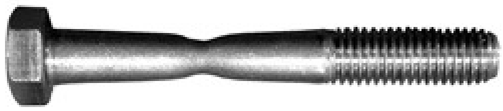
The proof load represents the usable strength range of the fastener. By definition, the proof load is the applied tensile load the fastener can support without permanent deformation. When a bolt is functioning in its proof range, it will return to its original shape upon removal of the load.

Thus, it would appear as long as the initial installation of the fastener did not stretch the material beyond the proof load and send it into the plastic range, reuse should be completely acceptable. This carries some truth; however, the complex issue of service conditions must also be accounted for.

As the fastened joint is put into use, it will encounter all types of various external loads including tension, shear, cyclic, prying, and other loads which may be a combination of these. These loads may be produced by outside factors, e.g. pressure changes in a pipeline, vibration from an engine, or the impact of a hydraulic ram. These loads either add to or subtract from the initial load of the fastener. In extreme cases these loads may even yield the fastener.

Other external factors, such as heat, will lower the yield value of the fastener. The yield strengths (as listed in most reference material) are determined at room temperature. ASTM A193 B7 has a yield strength of 75-105 ksi at 70°F (75 ksi for sizes over 4 inches in diameter and 105 ksi for material in diameters up to 2 1/2 inches), and drops to approximately 53-74 ksi at 800°F. So, if a user installs a B7 fastener of 2 1/2 inch diameter or smaller at room temperature, it is reasonable to expect each fastener to support a tensile load of 85 ksi. However, if enough heat is introduced to the joint, the temperature increase could cause the fastener to yield under the same 85 ksi stress.





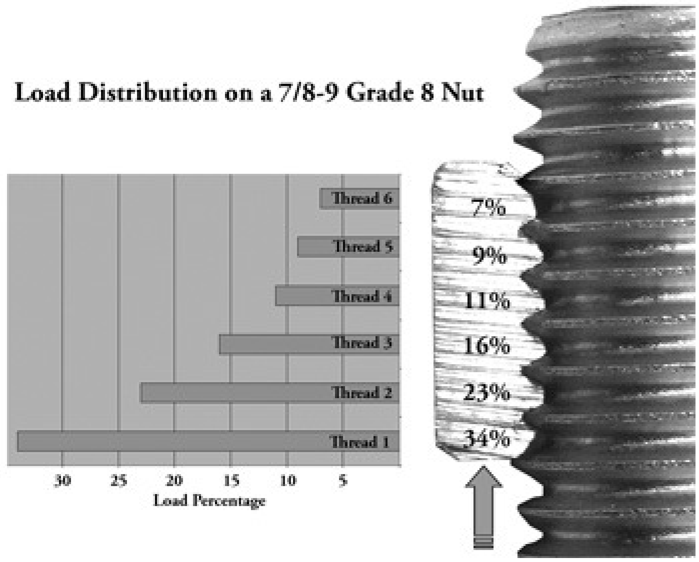
Another factor that can affect the reusability is the control of the initial installation. Was the fastener installed properly? This is one of the most difficult questions to answer. Extreme caution should always be used if the fastener was installed using an indirect method of tensioning. Even among those methods which directly indicate tension, many are still unable to indicate over-tightening of a fastener; thus, even with a direct method, it is very difficult to guarantee that a fastener has not yielded during installation or service.

Although in extreme cases such as the one illustrated here, you may be able to visibly detect yield in an externally threaded fastener. Typically, the amount of stretching may be as little as 0.001-in. In most cases there is no way to know whether or not the fastener has yielded, so, it is advisable to never reuse fasteners in critical applications.

Before reusing a fastener that shows signs of corrosion, some consideration to the application is warranted. If the environment is sour, caustic, acidic, basic, or generally corrosive, the fastener should be replaced if any corrosion is evident. If the environment is not corrosive in nature, then the amount of corrosion exhibited on the product should be noted. Plain and black oxide finished fasteners offer no corrosion protection and some surface oxidation (or rust) would be expected after time spent in service or even during shipping or storage. These do come with a light oil coating, but over time, this oil becomes less and less effective at preventing oxidation. These fasteners can be reused if the amount of rust doesn't prohibit the fastener from being assembled or disassembled from the joint. If the joint is critical in nature, i.e. holds a substantial load or would result in personal harm or equipment damage upon failure, it is recommended that you do not reuse the fastener. The cost of replacing a relatively cheap fastener with the cost of replacing a potentially expensive assembly should be considered when determining whether a fastener can be reused.

RE-USE OF FASTENERS AND TORQUE

In the event that a fastener is reused, attention must be given to the method of reinstalling the fastener. Upon reuse, a nut and bolt combination will require an increased torque value to reach the desired clamp load. This results from the deformation of the nut threads.



As the fastener elongates, it starts to apply a compressive load to the nut. The first engaged thread of the bolt experiences an enormous amount of tension. Some of this load is transferred to the adjacent nut thread causing less tension in the bolt at the second engaged thread. Then, this thread transfers part of this load to the third nut thread, and so on. The threads of the bolt will stretch. At the same time, the compressive forces acting on the bearing surface of the nut squeeze the bottom threads of the nut together. This is illustrated on the load distribution diagram. This type of load distribution is critical to the performance of the fastened assembly. If a larger proportion of the loading was concentrated on first engaged thread, the fastener would be more susceptible to fatigue failures, loosening or other modes of failure. However, due to this deformation causing an uneven load distribution, the first few internal threads may plastically deform (yield).

The first few threads of the nut will support the majority of the load. Research has shown in some cases involving UNC threaded nuts that the first thread will have to support nearly 35% of the load. The second thread will support about 25% of the load, and the third thread about 18%. In this case the first three threads support 78% of the load.

To allow this distribution, nut threads are designed to be softer than bolt thread and will conform to the contour of the bolt threads when tensioned. If a nut were reused, there would no longer be a "ideal" thread match. This will create more friction between the threads during installation, which will significantly alter the installation torque.

EXAMPLE: On a demonstration with a 1/2-13 zinc plated SAE J429 Grade 5 hex cap screw and zinc plated SAE J995 Grade 5 hex nut with an installation torque of 70 ft-lbs to obtain a clamp load of 9000 lbs (without any added lubrication). On the second installation, this torque had to be increased to 95 ft-lbs to obtain 9000 lbs. By the fourth installation, it required 145 ft-lbs to reach a clamp load of 9000 lbs. There are a number of clear indications that the fastener should not be reused, however typically the decision comes down to the economics of the fastener(s) vs. the cost of a failure of the fastened assembly.

TORQUING

Does it matter whether you tighten the bolt head or the nut?
Normally it will not matter whether the bolt head or the nut is torqued. This assumes that the bolt head and nut face are of the same diameter. If they are not then it does matter.

Say the nut was flanged and the bolt head was not. If the tightening torque was determined assuming that the nut was to be tightened then if the bolt head was subsequently tightened instead then the bolt could be overloaded. Typically 50% of the torque is used to overcome friction under the tightening surface. Hence a smaller friction radius will result in more torque going into the thread of the bolt and hence being over tightened.

If the reverse was true - the torque determined assuming that the bolt head was to be tightened then if the nut was subsequently tightened - the bolt would be under tightened.

There is also an effect due to nut dilation that can, on occasion, be important. Nut dilation is the effect of the external threads being pushed out due to the wedge action of the threads. This reduces the thread stripping area and is more prone to happen when the nut is tightened since the tightening action facilitates the effect. Hence if thread stripping is a potential problem, and for normal standard nuts and bolts it is not, then tightening the bolt can be beneficial.

Bolted shear joints can be designed as friction grip or direct shear. With friction grip joints you must ensure that the friction force developed by the bolts is sufficient to prevent slip between the plates comprising the joint. Friction grip joints are preferred if the load is dynamic since it prevents fretting.

With direct shear joints the shank of the bolts sustain the shear force directly giving rise to a shear stress in the bolt. The shear strength of a steel fastener is about 0.6 times the tensile strength. This ratio is largely independent of the tensile strength. The shear plane should go through the unthreaded shank of a bolt if not than the root area of the thread must be used in the calculation.

RUST NEVER SLEEPS
From a strength and preload standpoint the ideal steel fastener would have a plain black finish, (sometimes called a light oil finish). This finish produces a fairly consistent K-value and does not compromise the strength of the fastener. This finish would be unacceptable on a bike since it corrodes easily. The common solution is to apply a zinc or cadmium plating to prevent corrosion, and apply a conversion coating such as chromate to keep the finish looking nice. If a more decorative finish is desired, the fastener is usually polished and chrome plated. Plating causes problems with high-alloy steels due to hydrogen embrittlement, if appropriate measures are not taken after plating to "bake out" the hydrogen. This is especially true of chrome plating which tends to lock in the hydrogen. Plating does not adversely effect the mild steel used for 8.8 fasteners. The torque-tension relationship is greatly affected by plating due to its effect on the friction coefficient. Cadmium plating reduces the friction by 25% and zinc plating increases the friction up to 40%. This requires a corresponding 25% reduction or 40% increase in required torque for the same tension. Stainless steel fasteners have a friction coefficient about two times the corresponding plain steel fastener. This does not mean that stainless fasteners require double the specified torque since they usually cannot achieve the strength of a steel fastener.
Thread lubrication is another variable that affects the torque-tension relationship. Lubricant can change the torque to achieve a given tension by a factor of two (up or down!). Super clean fasteners or those lubricated with light lubricants like WD-40™ require a high torque to achieve

the desired tension. Fasteners lubricated with oil such as motor oil and the oil found on black fasteners require a medium torque. Fasteners lubricated with extreme pressure grease or anti-seize paste require the least torque. Loc-tite^{tm} has about the same lubrication action as light oil. The manufacturer states that this was by design so that the torque-tension relationship would be approximately the same as plain steel fasteners with normal manufacturing oil.

VIBRATION LOOSENING OF BOLTS AND THREADED FASTENERS

A significant advantage of a bolted joint over other joint types, such as welded and riveted joints, is that they are capable of being dismantled. This feature however, can cause problems if it unintentionally occurs as a result of operational conditions. Such unintentional loosening, frequently called vibrational loosening in much of the published literature, is an important phenomenon and is widely mis-understood by Engineers. It is important for the Designer to be aware of the bolt loosening mechanisms which can operate in order to design reliable joints. The information presented below is key information for the Designer on the theory of vibration loosening of threaded fasteners and how such loosening can be prevented.

Study of most Engineering magazines will reveal the multitude of proprietary locking mechanisms available for fasteners. For the Designer without the theoretical knowledge of why fasteners self loosen, this represents a bewildering choice. Presented below is key information, for the Designer, on why fasteners self loosen, and, how it can be prevented.

It is widely believed that vibration causes bolt loosening. By far the most frequent cause of loosening is side sliding of the nut or bolt head relative to the joint, resulting in relative motion occurring in the threads. If this does not occur, then the bolts will not loosen, even if the joint is subjected to severe vibration. By a detailed analysis of the joint it is possible to determine the clamp force required to be provided by the bolts to prevent joint slip.

Often fatigue failure is a result of the bolt self-loosening which reduces the clamp force acting on the joint. Joint slip then occurs which leads the the bolt being subjected to bending loads and subsequently failing by fatigue.

Pre-loaded bolts (or nuts) rotate loose, as soon as relative motion between the male and female threads takes place. This motion cancels the friction grip and originates an off torque which is proportional to the thread pitch and to the preload. The off torque rotates the screw loose, if the friction under the nut or bolt head bearing surface is overcome, by this torque.

There are three common causes of the relative motion occurring in the threads:
1. Bending of parts which results in forces being induced at the friction surface. If slip occurs, the head and threads will slip which can lead to loosening.
2. Differential thermal effects caused as a result of either differences in temperature or differences in clamped materials.
3. Applied forces on the joint can lead to shifting of the joint surfaces leading to bolt loosening.

Work completed during the 1960's in Germany indicated that transversely applied alternating forces generate the most severe conditions for self loosening. The result of these studies led to the design of a testing machine which allowed quantitative information to be obtained on the locking performance of self locking fasteners. Such machines, often called Junkers machines (a video of such a machine can be seen - see the bottom of this article) in the literature - after it's inventor, have been used over the last twenty years by the major automotive and aerospace manufacturers to assess the performance of proprietary self locking fasteners. As a result, a rationalisation of the variety of locking devices used by such major companies has occurred.

For example, conventional spring lock washers are no longer specified, because it has been shown that they actually aid self loosening rather than prevent it. There are a multitude of thread locking devices available. Through the efforts of the American National Standards Subcommittee B18:20 on locking fasteners, three basic locking fastener categories have been established. They are: free spinning, friction locking, and chemical locking.

The free spinning type are plain bolts with a circumferential row of teeth under the washer head. These are ramped, allowing the bolt to rotate in the clamping direction, but lock into the bearing surface when rotated in the loosening direction. The "Whizlock" is in this category.

Friction locking categories can be sub-divided into two groupings, metallic and non-metallic. The metallic friction locking fastener usually has a distorted thread which provides a prevailing torque; an example of this category is the "Philidas" nut. Non-metallic friction locking devices have plastic inserts which provides a thread locking function; an example being the "Nyloc" nut.

The chemical locking category are adhesives which fill the gaps between the male and female threads and bond them together; "Loctite" is an example. Such adhesives are now available in micro-encapsulated form and can be pre-applied to the thread.

To identify which category is the most suitable for an application, requires a careful consideration of the application. In brief, the chemical locking category provides the greatest resistance to vibration loosening, followed by the free spinning locking fastener. However each category has dis-advantages as well as advantages, the most suitable method being dependent upon the application.

In general terms, the key to preventing self loosening of fasteners is to ensure that:
1. There is sufficient clamp force present on the joint interface to prevent relative motion between the bolt head or nut and the joint.
2. The joint is designed to allow for the effects of embedding and stress relaxation.
3. Proven thread locking devices are specified. Specifically, thread locking compounds - such as "Loctite", flanged fasteners such as "Whizlok" or torque prevailing fasteners such as "Nyloc". In general, loose washers, of the plain or spring variety, are not generally advisable.

The self loosening of fasteners is just one aspect of bolted joint design the Designer must consider during the design process. As can be seen in the photo at the side, even if threads are completely locked together by adhesive, problems cannot be prevented if the bolt preload is insufficient to prevent joint movement.

Keeping fasteners tight, particularly the threaded sort, seems like a simple task, but the moving nature of the machinery they are used on is what makes it so troublesome. How nails and rivets work is fairly well known. But because the physics of the threaded fastener is not as well understood, it tends to cause the most problems.

CAUSES OF LOOSENING

Threaded fasteners are employed primarily to clamp objects together using tension. Rotary force or torque imposed on the fastener provides that tension. Problems occur when this clamp load deteriorates.

About 85 percent of the torque and effort of tightening a bolt is absorbed by the friction in the threads and under the head. Only 15 percent produces clamp load. Therefore, high torque may be absorbed by high friction and not produce tension. Torque is not the most precise method of controlling clamp load, although it is the most common. When bolt and nut manufacturing is closely controlled, the tension produced in a bolt for a given torque varies up and down by 15 percent.
Although it is always the first suspect in any case of lost clamp, vibration, as commonly perceived and observed, is not capable of bolt loosening by itself. If vibration is violent enough to cause shifting of the threads, then it will cause loosening – and in only 50 to 100 cycles. However vibration that violent is usually perceived as shock, shudder or impact. Towards the end of the loosening cycle, common vibration can and will rattle the fastener loose. This is why it often takes full blame for loosening.

The actual cause of loosening is side-sliding or shifting of the threads. The empty space between the threads of a nut and bolt leaves room for movement that leads to self-loosing and loss of clamping force. The friction in the threads and under the head of the bolt is reduced to zero when the clamped parts and threads slide sideways to the bolt axis. Each time this happens, the bolt can unwind by itself. The loosening process of a non-locking fastener starts with the first motion. It normally takes less than 100 side motions

THREADLOCKING

Various methods and devices have been employed over the years to reduce or prevent loss of clamp load in threaded fasteners. The earliest attempts involved the use of lock wires and split pins in conjunction with nuts and bolts with holes drilled in them. Although effective, these measures had some serious drawbacks. Each fastener had to be the correct length, and the holes had to be aligned on each individual bolt. Consider the difficulty and time required using this method to assemble numerous parts requiring thousands of threaded fasteners. As fastener manufacturing skills improved, more complex methods of threadlocking were developed. Two of the most common mechanical methods of threadlocking are the use of washers, and thread distortion. Although these methods can be affective for short-term threadlocking, anaerobic threadlockers can provide short-term, long-term and even permanent tightening when necessary.

LIQUID THREADLOCKERS

The first chemical threadlockers, developed by Loctite Corporation, eliminated any of the design faults and short comings of threaded fasteners. Chemical threadlockers are anaerobic liquids that cure to a tough, solid state when activated by a combination of contact with metal, and lack of air. The resulting cured material is a thermoset plastic that cannot be liquefied by heating, and resists most solvents. The purpose of threadlockers is to lock and sometimes seal threaded components without changing fastener characteristics or altering torque-tension relationships. In addition, the chemical fasteners offer a number of other advantages over mechanical tightening methods (i.e. lock washers).

• **Breakloose and Prevailing Torque –** Threadlockers find their way into tiny imperfections of threads. As they cure, these imperfections serve as molds for thousands of tiny keys that resists fastener movement in any dimension
• **Anti-corrosion** – Because threadlockers fill the voids between threads, they block the entry of moisture, preventing corrosion and subsequent seizure.
• **Strength Control –** Most threadlockers are graded by their various strengths and characteristics into distinct classification. The different formulations of Loctite threadlockers, for instance, are distinguished by the color of the threadlocking material: low-strength is purple, removable is blue, permanent is red, and the penetrating formula is green.

One size fits all – Threadlockers do not come in different sizes. The same bottle that locks in a tiny screw also can be used on a large bolt. Stocks of various size mechanical threadlockers are no longer necessary.

SELECTING THE RIGHT THREADLOCKER

There are several key factors to consider when choosing a threadlocking compound: shear strength, cure speed, gap-filling requirements and operating environment.
Shear Strength: If all threaded fasteners were designed never to be removed, then only one type of threadlocking compound would be necessary – the strongest available. However, not all threaded fasteners are meant to be permanent. Most assemblies that are held together with threaded fasteners will, with varying frequency, need to be dismantled for repairs, maintenance or adjustments. Consequently, threadlockers of various shear strengths are available.
Cure Speed: The cure speed of threadlockers can vary, depending on several factors, including temperature, base metal, surface treatments, clearance between parts, and surface cleanliness. The use of chemical primers can speed cure and result in higher ultimate strength.
Gap Filling Requirements: Most threaded fasteners are designed with some clearance between their mating surfaces larger clearances between mating surfaces require more product to fill them. Thixotropic liquid threadlockers will easily fill clearances in threaded fasteners, without migrating to other areas of the assembly. Where a higher shear strength product is required, and product migration is considered a potential problem, a higher viscosity compound is recommended.
Operating Environment: Both chemical resistance and operating temperature should be considered when selecting a liquid threadlockers.
The chemical resistance properties of threadlocking compounds vary between different grades. The most popular anaerobic products will generally resist water, natural or synthetic lubricating oils, fuels, organic solvents and refrigerants.
Like most organic materials, threadlockers lose strength at elevated temperatures. Most show significant strength retention at temperatures up to 150°C (300°F). Hot strength formulations can increase this working temperature to 230°C (450°F) for those applications where it is considered necessary.

REMOVABILITY
The most common myth about liquid threadlockers is that once it is cured, it cannot be removed. In fact, all threadlocked fasteners can be removed. Different grades of threadlocker can be used depending on the task. Fasteners secured with low and medium strength grades can be removed with common hand tools. Those secured with highstrength grades can be removed by applying heat for a specific time. Threadlockers are not just for specialized uses, either. They perform effectively on fasteners and threaded assemblies of any type and size, in any kind of equipment.

NEW FORM – SOLID THREADLOCKERS The newest development in locking and sealing technologies to further enhance the quality of maintenance programs in all industries, is the recent introduction of solid threadlockers. The same technology found in liquid thread lockers has now been formulated into a solid stick form. Maintenance crews now have a choice of using liquid or solid to keep their assembled fasteners from loosening. The solid sticks provide several benefits, which include portability and cleanliness – making them the perfect complement to their liquid counterparts. Examples include jobs where pre-treating bolts before hand can be a time saver. Other uses include overhead applications, where a liquid dripping would be an application issue, or in hard-to-reach areas the sticks can be the preferred method. Liquids are still required for certain applications such as treating fasteners in blind holes where, the traditional liquid remains the only effective means to ensure coverage. The introduction of these new 'solid form' products marks the beginning of a new era for maintenance professionals everywhere. These newly developed products are extremely convenient and simple to use. They can be stored in a pocket or thrown in a toolbox without making a mess. Even hands stay fairly clean during application. These new stick threadlockers are available in a medium strength formula, which can be removed with hand tools, as well as a high strength formula especially suited for heavyduty applications. Other maintenance solutions available in stick form include Pipe Sealant and Anti-Seize lubricants.