Purdue University Extension
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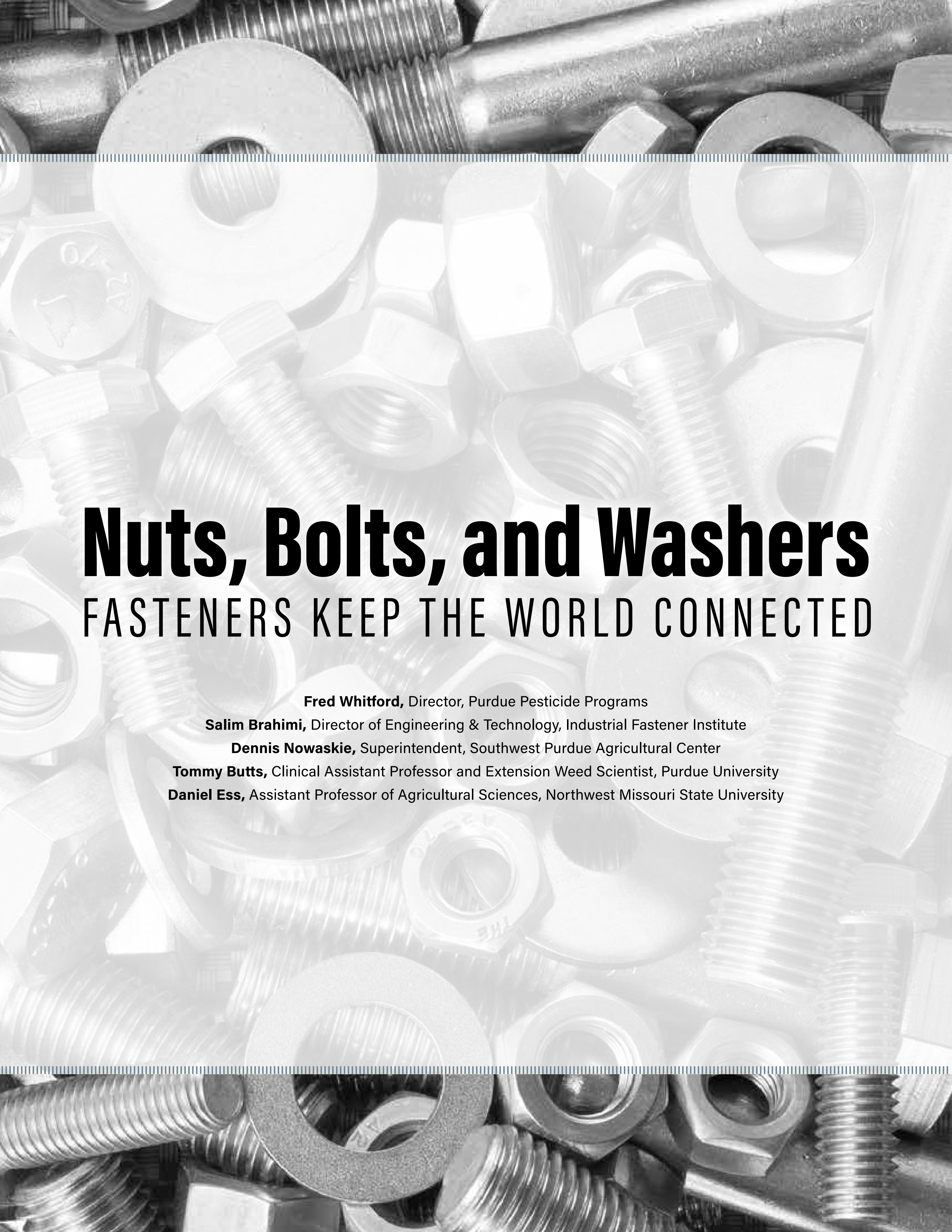
Nuts, Bolts, and Washers

FASTENERS KEEP THE WORLD CONNECTED



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Fred Whitford, Director, Purdue Pesticide Programs
Salim Brahimi, Director of Engineering & Technology, Industrial Fastener Institute
Dennis Nowaskie, Superintendent, Southwest Purdue Agricultural Center
Tommy Butts, Clinical Assistant Professor and Extension Weed Scientist, Purdue University
Daniel Ess, Assistant Professor of Agricultural Sciences, Northwest Missouri State University

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When you see the title of this publication—*Nuts, Bolts, and Washers: Fasteners Keep the World Connected*—you may ask yourself, "What is there to learn?" How hard can it be? Place a bolt into a hole in two separate parts, slip on a washer or two, screw the nut onto the bolt, and tighten it to fasten the objects together. It is true that securing a nut over a washer onto a bolt is easy, but selecting the proper hardware for the job may be more challenging than you think.

While they are easy to attach, nuts, bolts, and washers are engineered to meet specific uses. Selecting the wrong fasteners can lead to disastrous failures, such as bolts bending, stretching, or snapping; nuts losing their grip or failing entirely; or corrosion weakening the assembly.

YOU DON'T KNOW WHAT YOU DON'T KNOW

"A lot of people are lax about knowing 'nuts, bolts, and fasteners.' I have seen farm machinery, lawn and landscape equipment as well as other equipment fail because of using the wrong grade of bolt. Many people just grab a bolt and use it without knowing how to identify the bolt. Examples: Inch or metric? Coarse or fine thread? Grade 2, 5, or 8? For metric, Grade 5.8, 8.8, 9.8, or 10.9? Flat washers, lock washers, and nuts have hardness ratings too. Also, bolts can fail because of improper torque. How to check the thread pitch with a thread gauge."

—Comment from a farmer

A wide variety of materials are used to make bolts, nuts, and washers. Although the vast majority are made of steel, other materials include stainless steel, aluminum, titanium, silicon bronze, brass, carbon steel, alloy steel, and low-carbon steel. Many have coatings such as zinc plating, hot dip (zinc) galvanizing, and chromium plating. Each material and coating provides benefits, whether it be added strength, corrosion protection, greater strength, reduced weight, or aesthetics.

You may then ask whether the information on fasteners discussed in this publication is absolutely necessary. The answer is "maybe not" if your only interest is putting a bolt through a hole and attaching the nut with the hope and prayer that the choice you made will be strong enough to withstand the mechanical and physical forces placed on it by what is fastened together. On the other hand, the answer is an unequivocal "yes" if you are replacing fasteners on your farm and commercial equipment. The wrong choice of fastener components can lead to disastrous consequences when your equipment breaks down in the field or when one failed bolt leads to a chain reaction of additional parts failing because of the undue stress placed on them.

Collectively, bolts, nuts, and washers are called *fasteners* for a good reason—they mechanically clasp parts together so that they remain connected and locked in place for an extended period. However, selecting fasteners may require knowing something about their design: their size standard (metric or inch), length and diameter, the spacing between threads, the material used to make the fastener, the coating for corrosion protection, and the meaning of the markings on the bolt head.

If selecting the right fastener was as easy as we sometimes make it out to be, we would not see various common problems:

- bolts bending, shearing, and stretching
- nuts coming loose
- fasteners corroding
- bolt and nut threads failing to match one another
- pieces and parts loosening with moving equipment.

The reason behind many failures is a lack of understanding of the strengths and weaknesses of the nuts and bolts. Even washers play a critical role that is often overlooked.

Fastener manufacturers design bolted connections to satisfy a variety of design criteria. They then select *specific* fasteners that are fit for purpose to meet *specific* performance standards for *specific* parts being assembled on equipment, vehicles, or structures.

That selection process is largely based on the data derived from standards. More precisely, the dimensional, material and mechanical, and performance standards developed by the American Society of Mechanical Engineers (ASME), American Society of Testing and Materials (ASTM), Society of Automotive Engineers (SAE), International Organization for Standardization (ISO), and Industrial Fasteners Institute (IFI). These organizations, through collaboration with fastener experts in various technical committees, build consensus among all stakeholders—including fastener manufacturers, distributors, original equipment manufacturers, and end users—to develop standards for bolts, nuts, and washers; their testing; and guidelines for their correct use.

The need to connect things is so basic to manufacturing and building that when it comes to nuts and bolts, it is better to collaborate than to compete. In fact, standardized thread dimensions were the very first *industrial standards*, initially introduced in 1841 when Sir Joseph Whitworth presented his paper "A Uniform System of Screw Threads" to Great Britain's Institution of Civil Engineers.

Taking a few minutes to better understand fasteners is important given the many different designs in the marketplace.

Selecting a bolt made with the wrong material or coating can lead to rapid corrosion, preventing the fastener from effectively holding parts together.

In 1944 the so-called ABC countries (America, Britain, and Canada) met in Ottawa to begin a study that resulted in the Unified Screw Thread System. The need for this standard became apparent from the significant financial and time losses incurred during the two world wars, especially during World War II, due to a lack of interchangeability of screw threads between the allied nations. In 1949 the Unified Thread Standard (UTS) was adopted by Screw Thread Standardization committees of the United States, Canada, and the United Kingdom, combining the best features of existing standards. The fruits of that work are what we currently use around the world to describe threads for *inch* fasteners, notably, Unified Coarse (UNC), Unified Fine (UNF), Unified Extra Fine (UNEF), and Unified Special (UNS) threads.

Describing fasteners according to standards makes it easier to replace parts and repair equipment even when ordering from different manufacturers. When reviewing fastener catalogs, you can compare products because they use the same nomenclature and data to describe their bolts, nuts, and washers.

Since fasteners are made to specific dimensional and material standards—and tested using consistent procedures—equipment manufacturers rely on these standards to choose the bolts, nuts, and washers that best fit their assembly needs. Manufacturers consider tensile strength, hardness, shear strength, proof load, and corrosion resistance. Everyone in the supply chain, from the manufacturer of fasteners to the equipment manufacturer using the fasteners, understands that their reputation may literally hang on a nut and bolt!

This publication describes a step-by-step process for identification of a subset of mechanically threaded fasteners. Learning this terminology can guide you through choosing the right bolt, nut, and washer so that the products being reassembled remain coupled as they were initially designed to do by the equipment manufacturer.

Fasteners Working as a Cohesive Unit

Fastener is an umbrella term that encompasses hundreds, if not thousands, of different types of mechanical-threaded bolts and nuts. The working strength of each combination is often determined by how closely the physical characteristics of each part are matched when applied as a *cohesive assembly unit*. As parts of a cohesive unit, they are required to go together to fulfill their primary function, which is to clamp and hold parts together.

The weakest link in this three-part fastener assembly can undermine how well the whole unit remains intact. This is especially true when the fastener is under stress from physical, mechanical, chemical, or other factors.

The bolt bin above holds Grade 2, 5, and 8 bolts, but the corresponding nut bin had only Grade 2 nuts. Not matching grades of nuts and bolts when putting them together creates a weak link.

One of the key advantages of using *threaded* mechanical fasteners is the ability to disassemble a component to more easily perform repair work or interchange components. Think about how easy it is to change a tire by removing the wheel from a car.

The phrase *cohesive assembly unit* is purposefully used. When selecting and comparing which fasteners to use, you are making a lot of choices between product lines. A nut matching a bolt's strength, diameter, thread type, material, and coating means they will work as a cohesive unit and keep parts joined together for extended periods. Bad things like equipment breakdowns and failures can result when the fastener components are mismatched. Correctly matched nuts and bolts are designed for the bolt to break first when the assembly is stressed to its ultimate strength limit. This design choice is intended to provide predictability and to facilitate repair in case of failure. It is the basis for how standards establish the strength limits of matching bolt-nut-washer assemblies.

This is why trade magazine articles and fastener catalogs recommend that the individual components in a fastener should be correctly matched because that connection is only as strong as its weakest link.

What is the issue with using a Grade 2 nut with a Grade 5 bolt? The tensile strength is different; therefore, the nut's threads will not be as strong as the threads on the bolt. This can lead to the threads in the nut stripping during the tightening process and may also lead to loosening over time under stress.

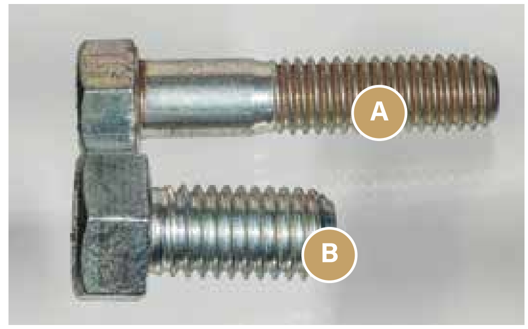
The Working Ends of a Bolt and Nut

Each part of a fastener has a specific role to play and provides benefits in keeping the joined parts together. This is why understanding each part is critical for making a solid, secure, and long-lasting connection.

Bolts: Providing Linear Strength

A bolt provides the linear (axial) strength through its threads. The size of a bolt thread is never tapered because the nut needs constant dimensions from start to finish to fully tighten against the bolt.

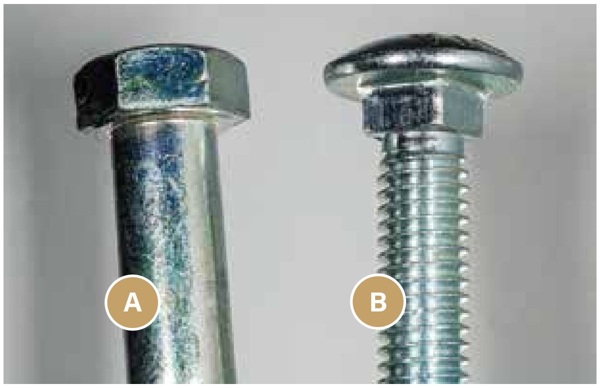
Threads allow you to control how much you can tighten the bolt-nut-washer assembly. The bolt is considered the “externally threaded” part of the assembly that when coupled with the “internally threaded” part clamps the unit together.



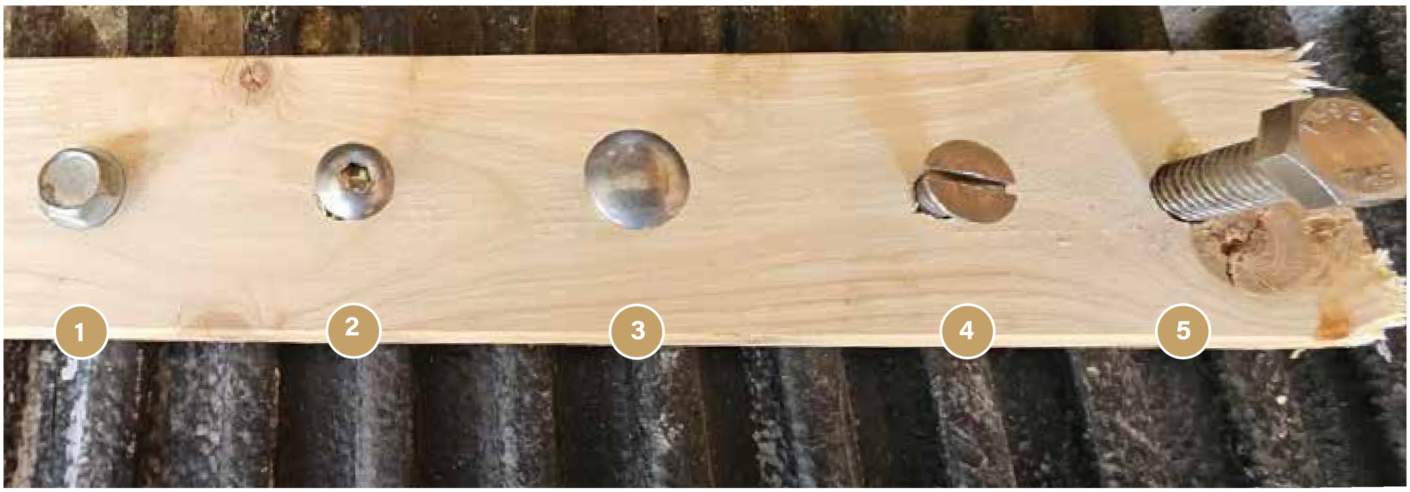
(A) The thread partially covers the length of the bolt.

(B) A bolt with threads that run the entire length is called a *full-thread bolt*. This can be an important decision to make as you do not want the threads to be in the shear plane of the clamped objects.

Imagine the thousands of bolts, nuts, and washers needed to keep this equipment in operating condition. Each fastener was selected by the manufacturer to meet specific demands placed on those fasteners.



The head of a bolt can take varying shapes: For example, the common hex bolt (A) has a hexagonal (six-sided) head, while a carriage bolt's head (B) is designed to minimize the protrusion of the head by fitting into a recessed hole.



These are some examples of different head styles and driving features (from left to right): (1) hex flange head bolt, (2) buttonhead screw with internal hex drive, (3) round carriage head bolt, (4) slotted countersunk head screw, and (5) hex head bolt. Each head has a specific use it is designed for. *Note:* A bolt is a fastener that is tightened using a nut, whereas a screw is a fastener that is tightened into a tapped hole or that forms its own mating threads.

The Nut: Providing the Locking Mechanism

When assembled with a bolt, the nut with its internal threads causes the bolt to stretch as the nut is turned. The stretching of the bolt, like a rubber band, creates a clamp force that secures the pieces being joined together.

Nut thread sizes are described the same as bolt thread sizes. However, if a ½″-13 nut had the same thread dimensions as a ½″-13 bolt, it would be impossible to assemble the two. Therefore, for the nut and bolt to properly fit together, the "true" size of the nut threads must be slightly larger than the *nominal* value. Nevertheless, both are called ½″, which makes matching easier.

Nuts come in countless designs and strengths. Manufacturers provide the details of a specific nut design in their catalogs. The unique "serrations" of a locking nut (B) do a better job of preventing self-loosening by vibration than a standard smooth nut (A).

Washers: Providing Additional Surface Area

A washer is typically manufactured from steel, but there are plenty of examples where plastic, copper, and rubber are also used. In the latter cases, they are often preassembled.

The nut and head of the bolt must be supported by a hard and flat surface to evenly distribute the load and to avoid becoming embedded if the component being joined is made of softer material. Washers are used for this purpose. And in some cases, a washer is required to keep the nut or bolt from damaging a surface. In structural applications or when the bolted connection requires a large clamping force, a *hardened washer* must be used.

Washers, like nuts and bolts, conform to standard specifications. (A) Metric flat washers. (B) Inch washers: split lock washers and a flat washer. Notice the differing amounts of metal that surround the opening of the washer.

The size of a washer is described by the size of the bolt and nut (e.g., ½ inch). However, to fit properly, the internal diameter (i.e., the hole size) of the washer must be slightly larger than the bolt diameter. The outside diameter of a washer can be smaller or larger, even for the same size (i.e., same internal diameter), depending on the purpose it serves in the assembly.

WHY DO WE USE NON-FLAT OR "SPLIT" LOCK WASHERS?

Non-flat washers, including split lock washers, are a group of washers with features to resist self-loosening of the bolt where there is vibration and frequent movement. They are intended to counteract the natural tendency of a nut or bolt to turn in the loosening direction when subject to vibration.

Non-flat washer families intended for this purpose are:

- **lock or split**
- **beveled**
- **toothed**

It should be noted that the most effective way to reduce the chances of self-loosening is to have a properly tightened or torqued joint. A non-flat washer, when used correctly, may help as a secondary feature to prevent self-loosening, or where the joint is not required to be tensioned, such as a panel door lock.

The Process of Tightening a Nut onto a Bolt

A nut tightens easily as it moves toward the surface of the parts being joined. More turning or tightening force (aka *torque*) is needed as the nut is further tightened against the parts connected together.

As described above, the advancement of the nut causes the bolt to slightly stretch as the nut pulls on the threads of the bolt when tightened or threaded on the bolt. As the bolt stretches, it creates the clamping force, also called *preload*, to hold the assembly in place. The more you turn the nut and stretch the bolt, the greater the preload. How much a bolted joint must be tightened depends on the component and the load it maintains while it is in use.

Tightening a nut on a bolt creates clamping force.

When the nut is loosened, the bolt gradually reverts to its original length, therefore reducing the preload until the assembly becomes loose. This is called *elastic tightening*. Such an assembly may be tightened and loosened many times, provided the threads on either the nut or bolt are not damaged. Think of the wheels on your car, where the lug nuts and studs can be reused many times. A bolt may also be stretched so far that the increase in length is permanent. This is called *overelastic tightening*, used to maximize clamping force, that is, to "get the most bang for the buck" from the bolt. In such a case, the bolt and nut may not be reused and must be replaced. Additionally, overtightening the nut too far beyond this point can cause the bolt to break. This is why knowing how bolts and nuts should be tightened is very important.

Fasteners Described as Inch or Metric

The first criterion in selecting a bolt is to determine if it is an inch or a metric fastener. It should be noted: The fastener industry settled years ago on the use of the term *inch* to simply and concisely describe fasteners made to US customary units (formerly known as *English* or *imperial units*). Differentiating between inch and metric fasteners is the first critical step because the nomenclature and units of measurement are described differently. Specifically, inch and metric thread nomenclature describe thread pitch differently. Last, you should NEVER mix-and-match metric and inch fasteners. Although a few sizes are close, they will never work properly together.

One way of distinguishing most metric fasteners from their inch counterparts is to look at the distinctive markings on the head of a bolt. With some exceptions, markings on inch bolts will have a series of radial dashes, while the metric will have two numbers separated by a point (e.g., 8.8, 10.9). Often, you will see the fastener manufacturer's trademark letters or a symbol that has been registered with the US Patent and Trademark Office. Some bolt heads are too small to mark with numbers so that designation will come from the fastener catalog.

Metric bolts contain numbers on the head.

Inch bolts may contain radial lines on the head. (A) No mark is indicative of a Grade 2 bolt. (B) A Grade 5 has three radial lines. (C) A Grade 8 has six radial lines.

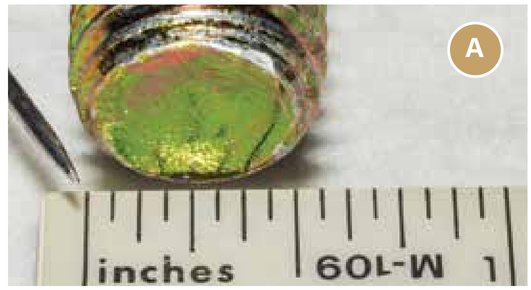
Describing Inch Fasteners

An understanding of how bolts are described, measured, and sold is an important part of the selection process.

How to Size Inch Bolts

The following nomenclature is used by fastener manufacturers to describe their inch bolts. You will need these measurements when ordering replacement parts.

Step 1. Measure the Size of the Bolt. To get the actual size or *nominal diameter*, take the measurement around the outside of the threads or at the end of the bolt opposite the head. When using a caliper, do not put the ends or bits into the root of the threads (i.e., grooves) as this will result in a diameter measurement that is inaccurate. Such a measurement gives an approximate value from which to determine the size, because the exact measurement of the major diameter of threads is slightly larger than the nominal diameter. Remember that the bolt's head is larger than the diameter of the shank, so it should not be used when measuring the diameter.



(A) Measuring the size of a bolt with a ruler.

(B) Using calipers to measure the size of a bolt. Placing the ends of the caliper into the thread root (i.e., grooves) will lead to incorrect measurements.

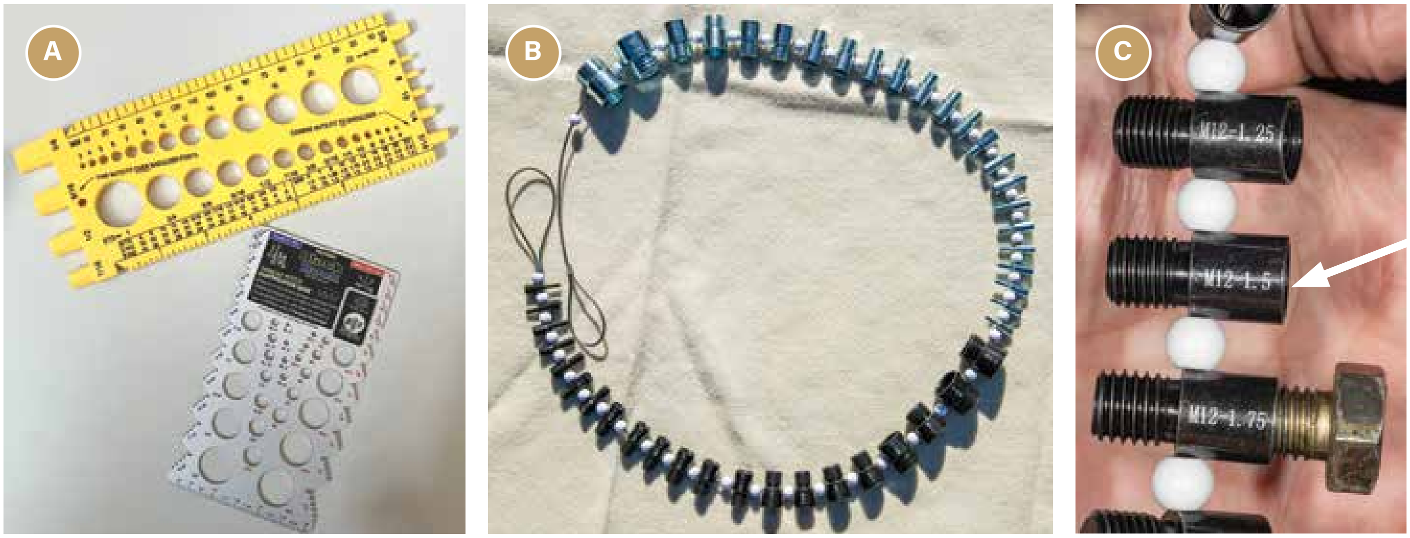
(C) The proper way of measuring the size of a bolt is by placing the ends on the outside of the thread, which is also known as the *major diameter.*

THREE FEATURES OF THE INCH BOLT'S DIMENSIONS

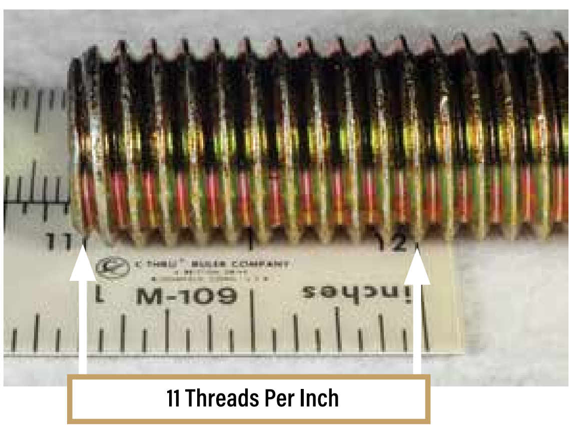
Bolt Size = Diameter — Number of Threads Per Inch × Length

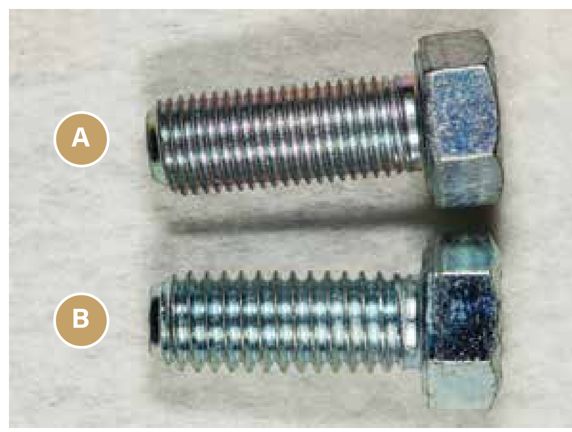
Example: 5⁄16 - 18 × 6½

A bolt with a 5⁄16-inch diameter with 18 threads per inch and an overall length of 6½ inches.



There are many inexpensive tools that provide ways to measure sizes for both inch and metric bolts: (A) A quick-fit guide can be used by matching the bolt on hand with the appropriate fitting on the guide. (B) This tool measures inch bolt sizes (silver) and metric sizes (black). (C) A close-up of the tool depicted in (B). The arrow points to a bolt that screws into a specific size of hole.

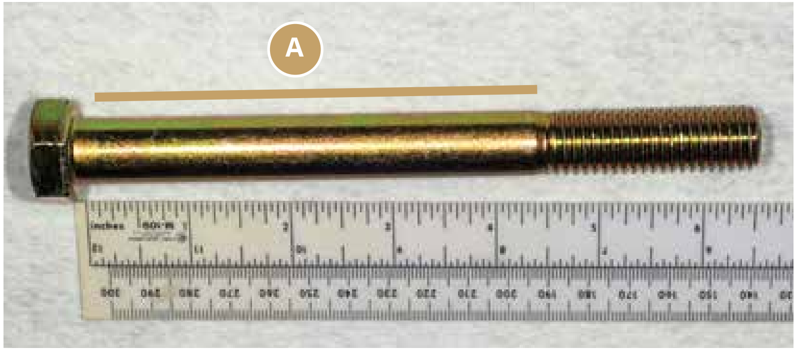




Two bolts with the same diameter but a different thread pitch: (A) a fine-threaded bolt and (B) a coarse-threaded bolt.

Step 2. Count the Number of Threads (aka Thread Pitch). Count the number of threads within a 1-inch span to get the thread pitch of an inch fastener. Alternately, you can use gauging tools, shown in the images at the top of the page, to determine the threads per inch (TPI).

Step 3. Determine If the Threads Are Coarse or Fine. A bolt can have the same size but a different thread pitch. Based on the thread pitch, bolts are divided into coarse- versus fine-threaded bolts: A bolt with fine threads has more threads per inch than a corresponding bolt with coarse threads. Coarse and fine threads are not interchangeable and cannot be mixed. Most shops will have a set of coarse-threaded fasteners and a set of fine-threaded fasteners, as required by different assemblies. Fine-threaded bolts are used when strength in tension, precision, stripping resistance, or vibration resistance is critical.



The overall length of the bolt and the length of the grip strength area, or shank (A), are both important.

Similar-size bolts of varying shank length.

Step 4. Measure the Overall Length. Length is measured from the underside of the head to the end of the bolt, as shown in above photograph. This bolt is 6½ inches long. The threads only cover the lower portion of the bolt.

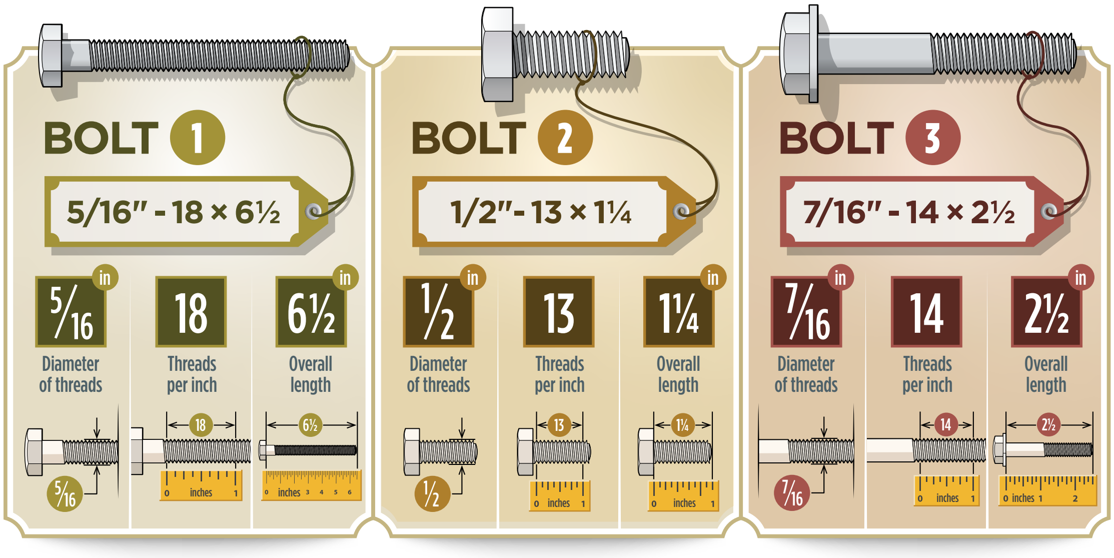
Step 5. Measure the Thread Length. The threads on a bolt can run the entire length from top to bottom or partly cover the body. This is an important consideration that impacts the integrity of the connection.

When connecting two items, the part between the head of the bolt and the nut is called the *grip length*. This is where the unthreaded section of the shank provides clamping stability to a connection under stress. You want as much of the unthreaded, solid portion of the bolt as possible to be in this area, while having enough space to accommodate the nut. For instance, you may request a ¾″-10 × 3-inch-long bolt with 2 inches of threads. That would leave 1 inch on the bolt that is unthreaded as the grip strength.

Step 6. Determine the Bolt Strength. The grade (aka *strength*) of a bolt is indicated by the presence or absence of radial lines on the head, with a greater grade indicating greater strength. Inch bolts with no marks on the head are a Grade 2. A Grade 5 has three radial marks while a Grade 8 has 6 marks. Thus, to determine the grade of a bolt, add 2 to the number of radial lines present. This grade designation system is used for steel bolts and nuts, making it possible to match a nut and bolt correctly in terms of strength. Grades 2, 5, and 8 constitute much of what is used in agriculture and the commercial pesticide application business.

A Grade 8 bolt is indicated by six radial lines. It is considered a high-strength bolt.

Three radial lines on the head of a bolt indicate a Grade 5 bolt. A Grade 5 bolt is often manufactured from carbon steel and is hardened for greater strength than a Grade 2 bolt.



3 FEATURES OF THE INCH BOLT'S DIMENSIONS

Size, length, and thread characteristics, it's all in the numbers

A Grade 2 bolt does not have any markings on its head. Its minimum tensile strength is either 60,000 or 74,000 pounds per square inch (psi) depending on size. It is made from low-to-medium-strength carbon steel. Grade 2 bolts are used where strength is not a high priority and are used for noncritical joints.

However, a Grade 2 bolt is often used when you want the bolt to break or shear before more serious damage is done to a particular piece of equipment. We call these *shear bolts*, and they are commonly used on the shank of a chisel plow or subsoiler so that the bolt shears before the entire shank is bent if the plow catches on something buried in the ground. They are also used in drivelines for limiting power transmission to safe levels.

Stainless steel bolts are identified not by the radial lines but by the grade of stainless used.

How to Grade Inch Bolts and Nuts

As was mentioned earlier, the tensile strength of bolts is identified by the number of radial lines on the head. The standards provide the minimum tensile strength for each grade. A bolt categorized as Grade 2 has a minimum tensile strength of 60,000 pounds per square inch (psi). A Grade 5 bolt is always heat-treated and has a minimum tensile strength of 120,000 psi. A Grade 8 is also heat-treated and has a minimum tensile strength of 150,000 psi. The heat treatment transforms the structure of the steel to make it stronger. Grades are used both for externally threaded bolts and for nuts. For example, a Grade 8 bolt must be matched with a Grade 8 nut. Different grades of inch nuts use different markings.

A Grade 2 inch nut has no marking.

Grade 2

A Grade 5 inch nut could be marked in three different ways:

- Two dashes spaced 120° apart
- Two dots 120° apart
- One hash mark at mid-height at the corner of each hex

Grade 5

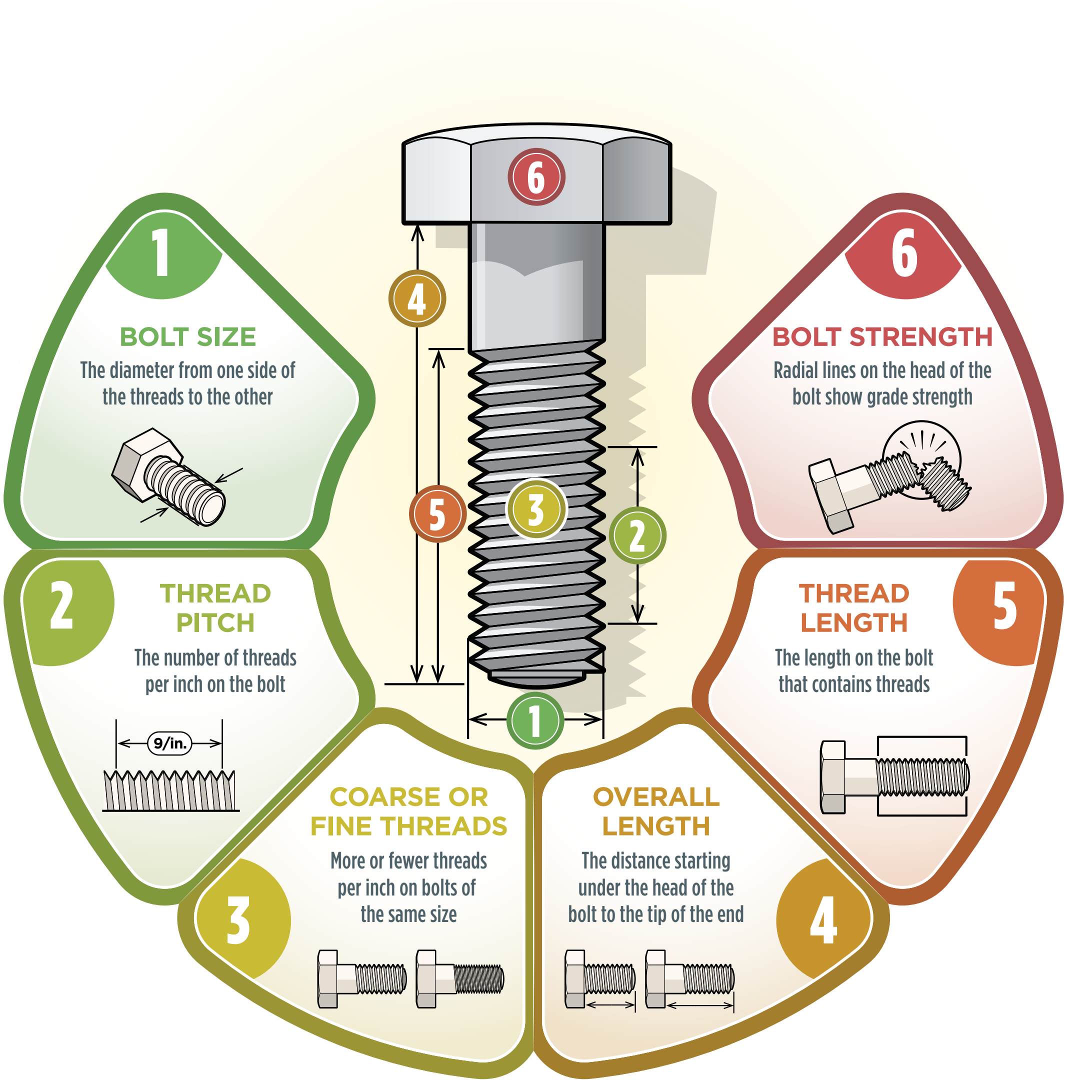
A Grade 8 inch nut could be marked in four different ways:

- Two dashes spaced 60° apart
- Two dots 60° apart
- Two hash marks at mid-height at the corner of each hex
- A dash and a dot spaced 60° apart

Grade 8

(A) A zinc-plated ⅜"-16 (coarse-threaded inch) locking nut with a nylon insert. The nylon insert helps minimize self-loosening caused by vibration.

(B) (Left) A box of hex flange nuts, 5⁄16"-18 (coarse-threaded inch) nuts. (Right) A box of hex nuts, ⅝"-11 (coarse-threaded inch).



6 STEPS IN SIZING INCH BOLTS

Determining the size of inch bolts is multidimensional

How to Grade Inch Washers

There are two types of flat washers dimensionally: Type A flat washers are intended for general application to minimize embedding and to aid tightening. Type B flat washers are intended for general application to distribute load over larger areas of lower-strength mating material.

With regard to strength, flat washers are classified simply as either plain (unhardened) or hardened. Plain washers are made from low-carbon steel. Hardened washers are made from high-carbon steel that has been heat-treated.

There are three main measurements that better define the size of a washer. These are the inside diameter, outside diameter, and thickness.

(A) An unhardened washer has no markings.

(B) A hardened washer will be stamped (ASTM) F436.

(C) This label on a box of zinc-plated Grade 2, non-heat-treated, ¼-inch flat washers contains very important information on size, grade, coating, and material.

(A) Measuring the inside diameter (size of the center hole): 0.4985 inches.

(B) Measuring the outside diameter: 1.37 inches.

(C) Measuring the washer's thickness: 0.12 inches.

Brief History of the Metric Standards

After World War II, there existed a need for international consistency in thread standards. Thus, the International Organization for Standardization (ISO) was founded in 1947, which took charge of developing optimized metric thread standards. Although the international organization considered inch-based standards, it abandoned the effort since the United States was already developing them independently. It took several years, but the final metric thread standard was released in 1964. These initiatives all had the objective of enhancing uniformity in the design of nuts, bolts, and washers.

In 1968 the United States passed a law that instructed the Secretary of Commerce to examine the benefits and disadvantages of going to the metric system. After a few years of analysis and deliberation, the US thread and fastener standards committees started creating a parallel but slightly simplified metric thread system in 1973, which they named the Optimum Metric Fastening System (OMFS). The OMFS died when, beginning in the 1990s, the automotive industry, wanting to build and sell cars globally, went metric using the ISO metric standards. This meant the American version of metric fastener standards largely gave way to the international ISO set of standards and that metric fasteners manufactured in the United States are manufactured to the ISO standard to this day.

Describing Metric Fasteners

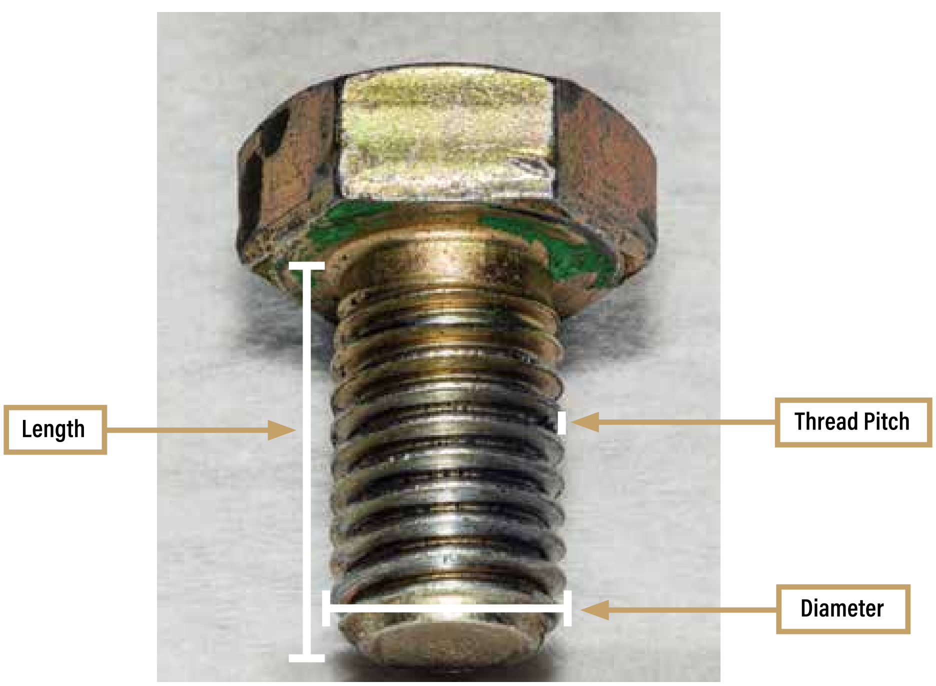
Metric fasteners have their nomenclature that differs from that for inch fasteners.Metric fasteners have their nomenclature that differs from that for inch fasteners.

How to Size Metric Bolts

Metric fasteners have a standardized method of describing bolts, nuts, and washers just like inch fasteners do. They are measured in millimeters (mm). For example, M12 × 1.5 × 20 describes a metric bolt (*M*) having a 12 mm diameter, a 1.5 mm thread pitch, and a 20 mm length.

Step 1. Measure the Size of the Bolt. Measure the distance from one side of the threads to the other. This quick measurement helps approximate the size of a fastener. For example, an M12 bolt will measure approximately 12 mm in diameter. Do not measure the head as this part has nothing to do with screwing the bolt into a nut or threaded hole. If using a caliper, be sure to measure the major diameter of the threads, taken from the crest (top) of the threads and not from the root of threads, as the latter would create misleading measurements.

Step 2. Measure the Thread Pitch. For metric bolts, thread pitch is the distance from one thread to the one adjoining it. With metric threads, this can be measured directly. This is very different from how we measure thread pitch with inch bolts, which uses the number of threads per inch to classify the bolt.



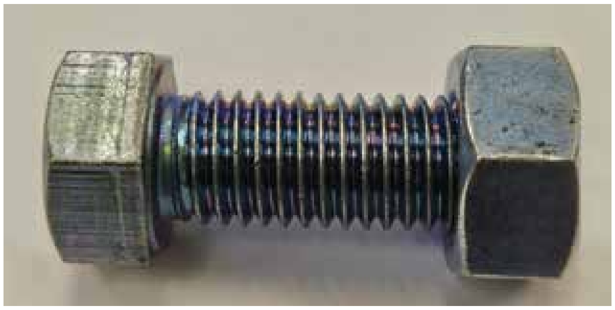
A **M12** bolt has a 12-millimeter diameter.

This M12 × **1.75** bolt has a thread pitch of 1.75 millimeters.

Step 3. Determine If the Threads Are Coarse or Fine. A metric bolt can have several different diameter-to-pitch combinations. Metric fasteners are categorized as standard, fine, and extra-fine. The designers selected optimal positions for fine and coarse pitches for each size fastener, which is what the thread standards use to this day.

As shown in the photograph to the right, a 12 mm bolt can have a thread pitch of 1.25 mm, 1.5 mm, or 1.75 mm.

One can deduce a relatively finer or coarser thread based on differences in the pitch. For instance, a M10 × 1.5 (coarse) would have fewer threads per centimeter than a M10 × 1.25 (fine). The number 1.25 specifies that the space from one thread to the next is smaller, indicating more total threads than for the 1.5 mm. The smaller the thread pitch, the more threads per centimeter and the finer the threads, which also correspond to increased bolt strength. The bolt in the figure to the right fits into the 1.75 pitch gauge range, making it a "coarse" thread.

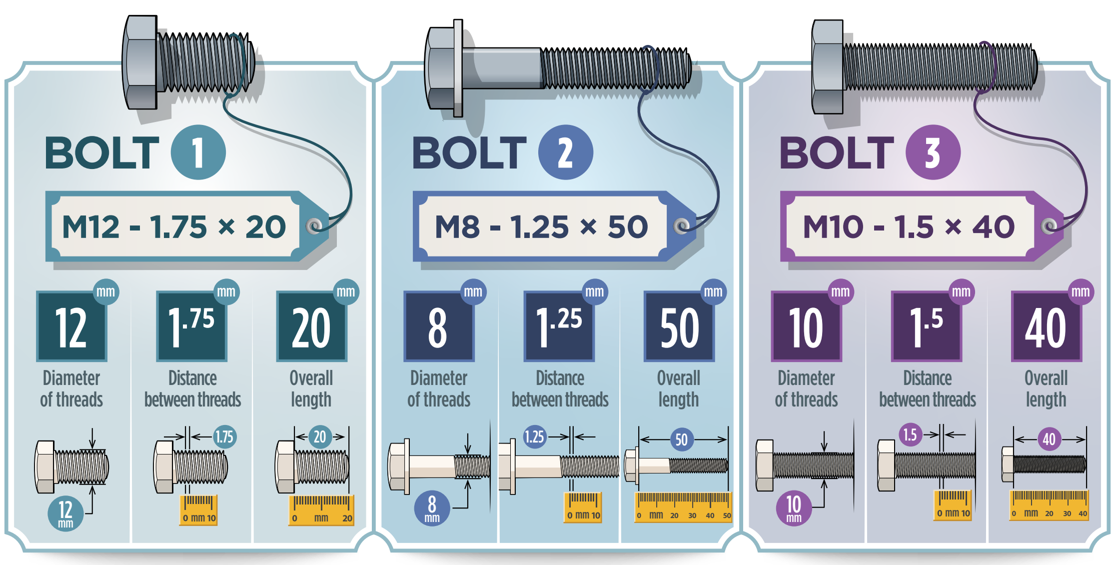


The thread pitches of the nut and bolt must match, or the combination will not tighten. In the photograph to the left, the thread pitch of nut and bolt is mismatched. This is as far as the nut will thread on the bolt. While the diameters match, the nut cannot rotate on the bolt due to differences in their thread pitch.

Step 4. Measure the Overall Length. The length is measured starting from under the head to the end of the bolt (the same as for inch bolts).

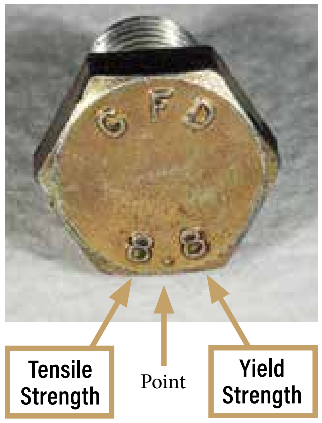
Step 5. Measure the Thread Length. The threads on a bolt can run the entire length from top to bottom or partly cover the body. This is an important consideration that impacts the integrity of the connection. You want as much of the unthreaded, solid portion of the bolt as possible to be in this area, while having enough space to accommodate the nut.

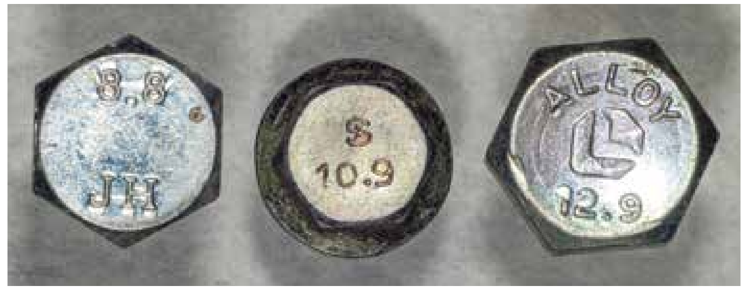
This M12 × 1.75 × **20** bolt has a length of 20 millimeters.



3 FEATURES OF THE METRIC BOLT'S DIMENSIONS

Like inch bolts, metric bolts are measured by thread diameter and shaft length, but threads are calculated as the distance between two individual ones





Three distinctive property classes are marked on these bolts: 8.8, 10.9, and 12.9. The first number gives the tensile strength, while the second number provides an estimate of the yield strength.

Step 6. Determine the Bolt Strength (Tensile and Yield Strength). Metric bolts are marked on the head with two numbers separated by a point. This is different from the marks or lines on inch bolts. These numbers are used to indicate the *property class*, the term used in the metric system to describe what we call the *grade* in the inch system. Typical metric property classes used in agriculture and other pesticide application businesses are 5.8, 8.8, 9.8, 10.9, and 12.9.

The numbers indicate the bolt's tensile and yield strengths. The first number to the left of the period gives the tensile strength (when a bolt breaks), measured in megapascals. This number ranges from 4 to 14. The megapascal (MPa) of the bolt can be obtained by multiplying the first number by 100. The unit MPa can then be converted to the more familiar pounds per square inch by multiplying the megapascal by approximately 145.

A metric bolt marked 8.8 has a converted nominal tensile strength of 116,000 psi (8 × 100 × 145). Officially, the psi is rounded to 120,000 since the measurements are used for reference only. The actual psi strength value exceeds the nominal value because manufacturers want to always ensure all the bolts exceed the minimum strength requirement.

The following table provides information on tensile strength, psi, and relative strength.

Property Class, Strength, and Application for Metric Bolts

Property Class	Mpa	psi	Relative Strength	Application
4.8[1]	400	58,000	Low strength Low-carbon steel	Noncritical and/or shear joints
5.8	500	72,500	Medium strength	Noncritical and/or shear joints
8.8	800	116,000	Medium-carbon steel	Suitable for most joint types requiring strength and clamping force
9.8	900	130,500	Medium strength Medium-carbon steel	Intended as an intermediate strength between 8.8 and 10.9
10.9	1,000	145,000	High strength Boron alloy steel	Suitable for high-strength joints requiring very high clamping force
12.9	1,200	174,000	High strength Alloy steel	Not recommended for most applications such as in combustion engines, due to high susceptibility to brittle fracture

[1] 4 × 100 = 400; 400 × 145 = 58,000 psi

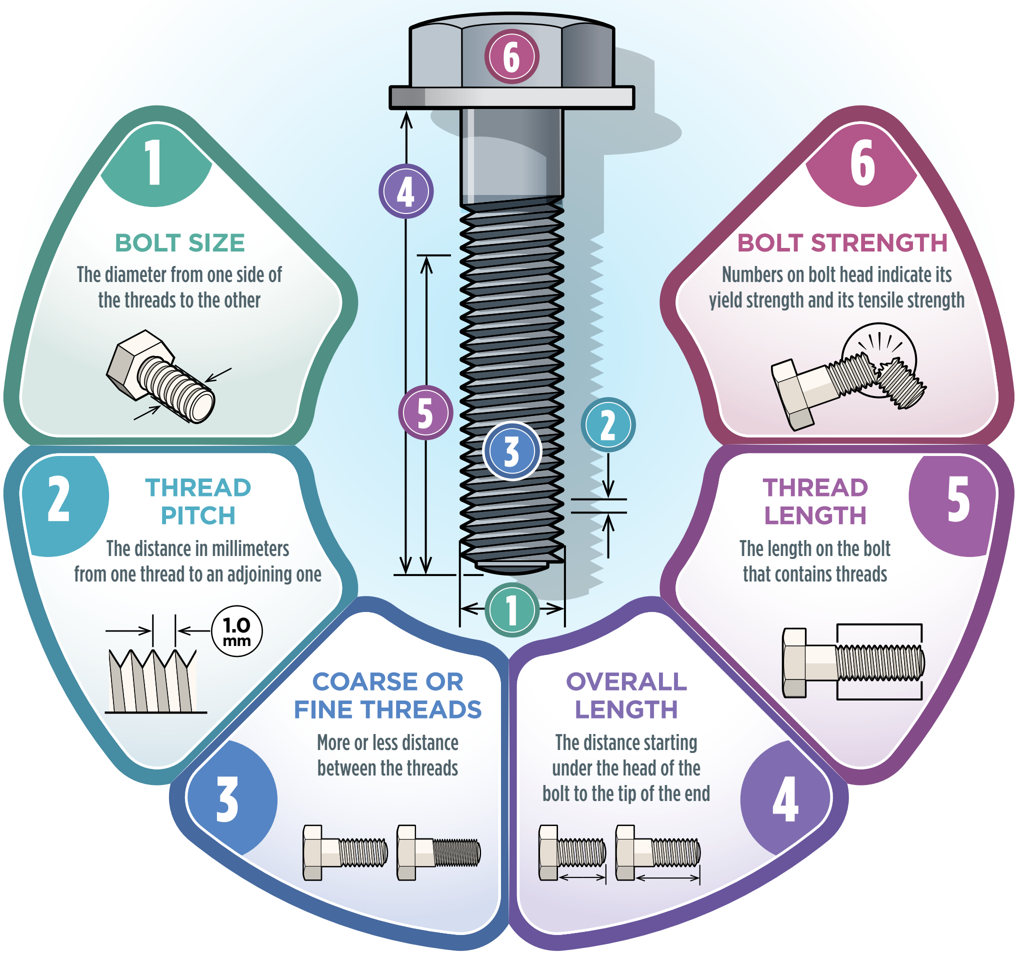
Comparing Grades Among Metric and Standard Bolts

Metric Property Class[1]	psi	Standard Grade	psi
Property Class 4.8/5.5	72,500	Grade 2	74,000
Property Class 8.8	120,000	Grade 5	120,000
Property Class 10.9	150,800	Grade 8	150,000
Property Class 12.9	176,000	A574 Socket Head Cap Screw	180,000

[1] *Property class* (PC) is terminology that has an equivalent meaning to *Grade* used in the inch standards.

The number after the period indicates the bolt's yield strength as a proportion of its tensile strength in megapascals. Yield strength is the point at which the bolt stretches permanently. By this standard notation method, yield strength is calculated as a percentage of the tensile strength. Using an 8.8 bolt as an example, the second number means the yield strength is 80% of the nominal tensile strength: 800 × 0.80 = 640 MPa (or in psi, 120,000 × 0.80 = 96,000).

Making these conversions from megapascals to psi allows for comparisons among metric and inch bolts (see table above).



6 STEPS IN SIZING METRIC BOLTS

Metric bolts have slight differences from inch bolts

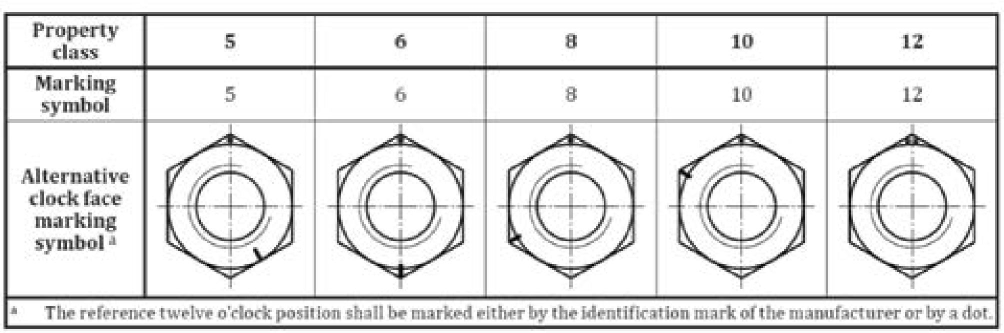
How to Grade Metric Nuts

Metric nuts are designated by their diameter and thread pitch. Unlike for bolts, there is no length to a nut. A nut may be described as an M10 × 1.5, which has the following meaning: *M* represents metric standard threads; 10 signifies the size or internal diameter in millimeters (mm); and 1.5 denotes the thread pitch in millimeters.

Metric nuts are identified by a single number to represent the property class (PC). Instead of 8.8 or 10.9, a nut is inscribed with an 8 or 10, respectively. Elements of a nut-bolt assembly should match. For example, a PC 8 nut with a PC 8.8 bolt, and a PC 10 nut with PC 10.9 bolt. By convention, a nut may be assembled with a lower PC bolt (a PC 8.8 bolt with a PC 10.9 nut) but never the other way around. In other words, nut rating should be as high or higher than the bolt rating, because as was mentioned earlier for inch bolts, by design, when an assembly is stressed to its limits, we want the bolt to break before the nut.

If the nut's surface is too small to place the single number, the manufacturers can follow a secondary method, which uses the face of a clock to identify property class. A dot is placed at 12 on a clock, and then a radial line is placed at the corresponding hour on the clock face (e.g., a line at the 8 o'clock position would indicate a PC 8 nut). The property class can thus be determined by the position of the radial line on the nut.

Nuts with a property class (Grade) designation of 8 (left) and 10 (right). Below is exactly what we want with the bolt breaking before the nut.



Property class	5	6	8	10	12
Marking symbol	5	6	8	10	12
Alternative clock face marking symbol [a]					

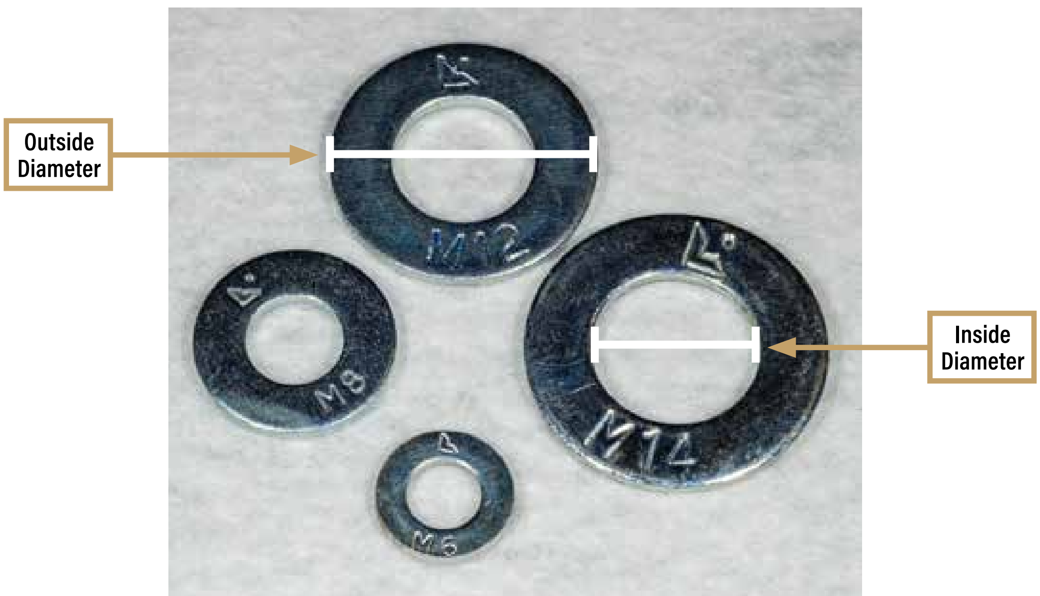
[a] The reference twelve o'clock position shall be marked either by the identification mark of the manufacturer or by a dot.

Markings for property classes of metric bolts. Source: ISO 898-2.

How to Grade Metric Washers

For a washer, the number following the *M* indicates the internal opening size (internal diameter) of the washer, which must match the size of the bolt. The outside diameter (OD) will not be marked on the washer, but a specific size can be ordered from fastener catalogs.

A hardened washer will have the marking HV (i.e., Hardness-Vickers scale) followed by a number, indicating its nominal minimum hardness (e.g., HV200, HV300, HV400). The higher the number, the harder the washer. A bolted joint that must be pretensioned must always have a hardened washer, because the washer provides a hard, flat surface for the bolt head and nut to be seated. If you use an unhardened washer in such a bolted joint, it will buckle and compromise the integrity of the joint.



Measurements for sizing metric washers.

What Is the Proper Torque to Use on a Given Nut-Bolt Assembly?

An often-overlooked aspect of fasteners is how much to tighten the bolt. For many applications, tightening the nut as tight as possible with a hand wrench works. For other applications, there are specific torque requirements that specify how much to tighten the fastener to minimize the likelihood of damage to the bolt, joint failure, or self-loosening. This is especially true when tightening nuts and bolts used in critical instances, for example, the internal parts of an engine or areas that are critical for the operation of a piece of equipment.

Tightening a bolt with a wrench for some applications lacks the necessary precision. In these cases, a torque wrench is needed.

Equipment owner's manuals should be referenced as they will often specify the required torque for various connection points. These values should be targeted precisely as undertorqued connection points may result in bolts coming loose, equipment being damaged, and a safety risk for users. Overtorqued connection points can result in additional stress placed on the bolt, which may lead to it breaking. Always check the equipment manufacturer's owner's manual to see when a torque wrench is needed for a more precise clamping of nut and bolt.

So, "What is the proper torque to use?" is the question fastener suppliers are frequently asked by customers and end users. Every bolted joint is unique, and the optimum tightening torque must be determined for each application by careful experimentation.

A properly tightened bolt is one that is stretched such that it acts like a very rigid rubber band pulling mating surfaces together. The rotation of a bolt (torque) at some point causes it to stretch (tension). Several factors affect how much tension occurs when a given amount of tightening torque is applied. The first factor is the bolt's diameter. It takes more force to tighten a ¾″-10 bolt than to tighten a ⅜″-16 bolt because the former is larger in diameter. The second factor is the bolt's grade. It takes more force to stretch a Grade 8 bolt than it does to stretch a Grade 5 bolt because of the greater material strength.

A bolt that broke because of excessive tightening.

(A) A torque wrench is required to achieve the exact torque specified by the equipment manufacturer.

(B) A close-up of a digital display on a torque wrench shows 100 foot-pounds.

(C) The torque required on the lugs of a sprayer is listed on the wheel itself.

The third factor is the coefficient of friction: Harder, smoother, and/or more lubricated bolting surfaces, such as threads and bearing surfaces, require less rotational force (torque) to stretch (tension) a bolt than do softer, rougher, and stickier surfaces.

The only way to properly determine the optimum tightening torque for a given application is to test it. This should be done with a tension-indicating device of some type on the bolt in the application. The bolt is tightened until the desired *P* (load) is indicated by the tension-indicating device. The tightening torque required to achieve the desired tension is the actual tightening torque that should be used for that given application.

It is extremely important to realize that this tightening value is valid only so long as aspects of the application remain the same. End users often think their bolts are no good because they have started breaking while being installed. Proper investigation often reveals that the user lubricated the bolt threads to make it easier during assembly but maintained the same torque as when they were not lubricated.

The Importance of Organization of Inch and Metric Fasteners

Some individuals meticulously organize and store fasteners in their work areas. Some of the benefits associated with a well-organized shop include:

- Saving time
- Quickly accessing the correct size when fasteners are segregated into labeled bins
- Easily identifying when a bin's content needs reordering
- Keeping inch and metric sizes segregated to help prevent cross-contamination

Collecting bolts for future reuse by randomly mixing them is never a good idea, because it can lead to using the wrong fastener or a damaged fastener. Disorganized storage or keeping fasteners that have been compromised will drastically increase the likelihood of equipment or structure failures.

Conclusion

We often take for granted that fitting a nut over a washer onto a bolt is relatively simple, which of course it is. We asked early on whether the information presented in this publication on fasteners was necessary. It is safe to say yes, if you expect the fasteners you are assembling for equipment to hold up under strenuous field use.

Getting the right bolt, nut, and washer combination to match and work together as a unit can be challenging. However, understanding basic terminology and nomenclature overcomes most challenges in getting the right fastener. Putting like with like goes a long way in ensuring that fasteners being repaired and replaced will meet the rigors of agricultural and industrial jobs. On the flip side, there is a wealth of knowledge involved in selecting which fasteners should be used and the proper torque to tighten them together.

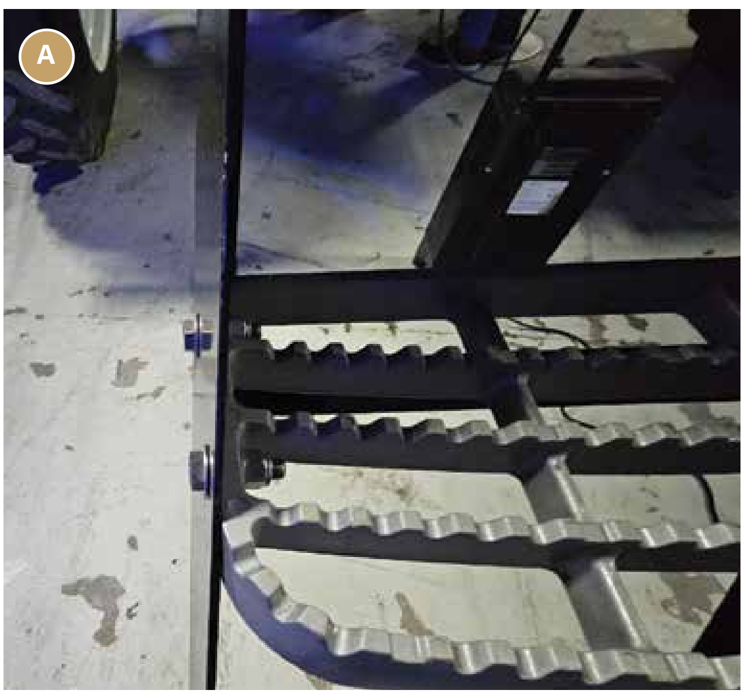
We oftentimes hear people say that the proper torque for a bolt is as tight as you can get it just before it twists off. However, overtorquing a bolt is almost as bad as not tightening it enough. The next time you are tightening a bolt, it might be worth your time and effort to check the proper torque if it is a fastener that is used to secure two critical pieces of equipment together.

To say that "fasteners hold the world together" is not an exaggeration. Threaded fasteners are varied and as different as the applications for which bolts, screws, and nuts are used. Often, the fasteners that hold the product and its components together are an afterthought. That's where problems often originate. Any user of fasteners must be well versed in many topics, beginning with an understanding of fastener standards.

So, the next time you board a plane, would it not be comforting to know that a person constructing the wings on that airplane used the correct fasteners for the application and tightened them to the proper torque rather than just tightening them until they thought they were tight enough? Food for thought: Right-tight fasteners keep the world from falling apart!

Think of the complexity of equipment and the hundreds if not thousands of bolts, nuts, and washers that are used to keep it running and intact. Each of those fasteners is chosen with a purpose based on the operation it is being asked to do.

Each part of a fastener is manufactured to industry standards. Getting the three components to match each other is critical in keeping equipment operational. Knowing what the numbers on a fastener tell you helps to keep parts working together.

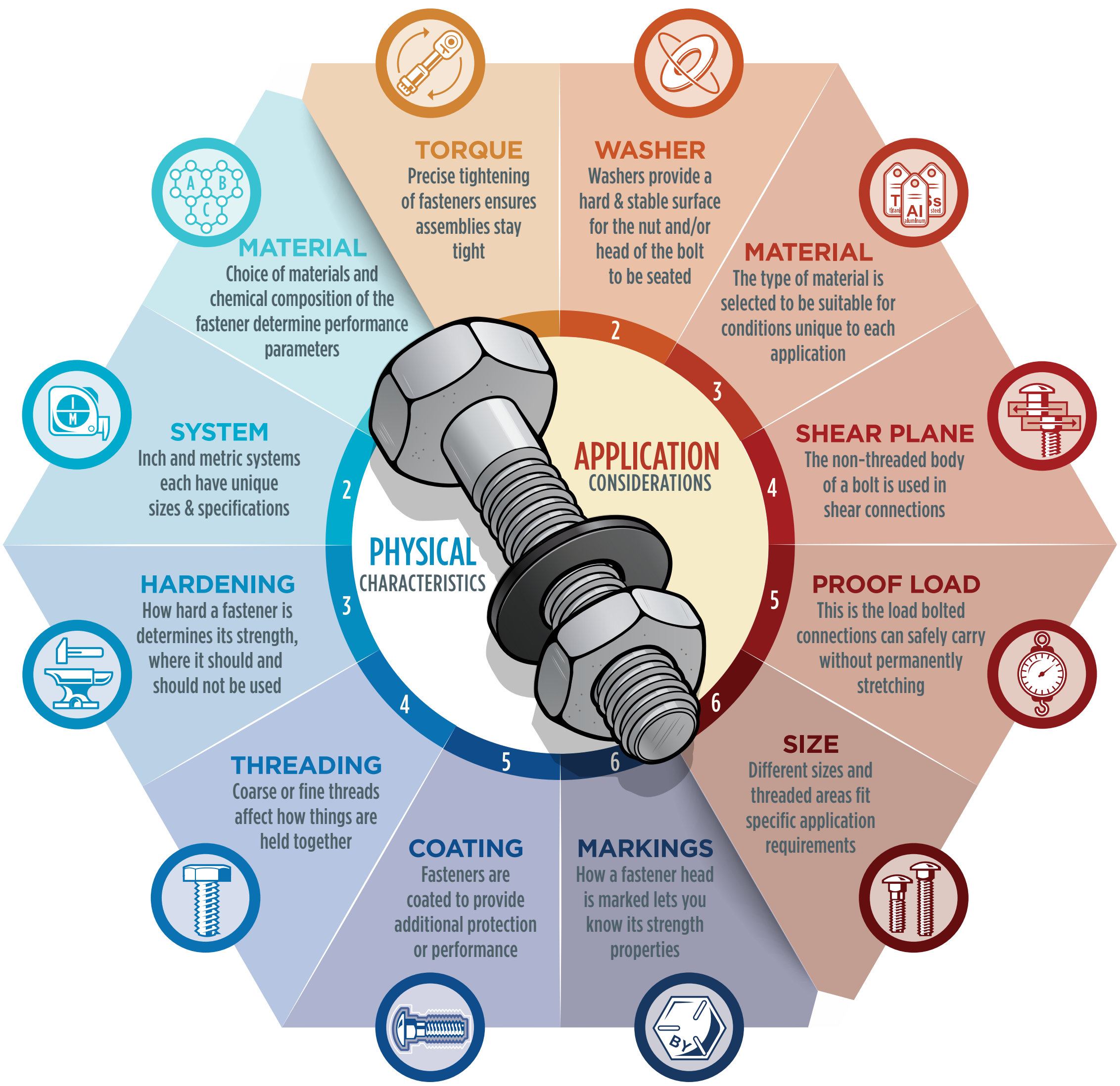


(A) Bolts holding a series of steps for a piece of equipment together might not seem like much, but what if a bolt broke when a person stepped onto the step, because it was not the correct bolt or improperly torqued?

(B) Keeping an implement attached with bolts is serious, considering what would happen if one of the bolts broke. Attention to detail is critical when securing items together with a fastener.

THE TIP OF THE ICEBERG

This basic information should enable you to expand your knowledge by accessing websites where fastener manufacturers provide additional details on bolts, nuts, and washers. An excellent resource is the Fastener Training Institute at www.fastenertraining.org.



ALL FASTENERS ARE NOT CREATED EQUAL

Know what you need to put together a cohesive unit to do the job safely and effectively!

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